Natural England Research Report NERR054

National biodiversity climate change vulnerability model

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Summary

Introduction

Climate change will exacerbate existing pressures on biodiversity and bring new challenges of its own. Adaptation to climate change is therefore a priority for conservation and environmental management. It is, however, an issue where specialist knowledge and theoretical principles need to be made accessible to a much wider group of people, if progress is to be made on the ground.

Natural England has developed a model that allows non-specialists to assess the vulnerability of areas of priority habitat to climate change based on widely accepted principles of climate change adaptation for biodiversity. The assessment provides a high level indication of the relative vulnerability of priority habitats to climate change in different places. It identifies why areas are vulnerable and which possible interventions can have the biggest impact in increasing resilience in a changing climate. This will inform prioritisation of adaptation actions and assist in the development of adaptation strategies for biodiversity both within Natural England and with our partners – some of whom helped us trial the model approach and outputs.

Aims

The National Biodiversity Climate Change Vulnerability Model (NBCCVM) aims to provide:

- a spatially explicit assessment of the relative vulnerability of priority habitats, based on established climate change adaptation principles;
- a suite of map-based GIS outputs at a variety of scales, which can be used (in conjunction with other relevant spatial data) to target action to build biodiversity resilience; and
- a flexible, GIS based, decision support tool that allows the user to incorporate locally specific datasets and select how adaptation principles are combined to reflect local circumstances and priorities.

The NBCCVM is a practical way to identify areas most at risk from climate change, and it will provide a focus for discussion with partners helping to develop shared priorities and inform decisions on where to concentrate limited resources.

Methodology

The NBCCVM methodology uses a GIS-based 200 x 200m grid to assess areas of priority habitat for their:

- Intrinsic **Sensitivity** to Climate Change; the model assigns high, medium or low sensitivity to direct climate change impacts – reflecting the habitat itself on the basis of expert judgement and scientific literature.
- **Adaptive capacity**; a range of different local factors can increase or decrease the ability of the habitat to adapt to climate change – to reflect this the model includes measures of fragmentation, topographic variation and management and condition.
- **Conservation Value**; this assigns a relative value to (i) priority habitat only, (ii) priority habitat within a national designation, or (iii) priority habitat within an international designation – with the latter valued highest.

These elements are then added together to produce an overall assessment of vulnerability. Key outputs are maps showing the results for individual and combined metrics and the range of relative vulnerability across the country, giving a visual representation of the areas vulnerable to climate change.

To enable us to ‘run the model’ in an interactive way we created a software tool, the National Biodiversity Climate Change Vulnerability Assessment Tool (NBCCV Assessment Tool). The tool enables us to re-run assessments of vulnerability; easily using updated or local data, changing the weightings used and combining metrics in different ways. It can also be used to test the impact of habitat creation and management scenarios on vulnerability.

National scale GIS outputs, created from the assessments, have been developed to help prioritise adaptation action and assist Natural England and our partners target measures to build biodiversity resilience. These measures include three of the attributes of ecological networks identified in the ‘Making Space for Nature’ review as promoting coherence and resilience: **better** habitat management; **bigger** patches of habitat; and **joined** up networks of habitat.

To test the usefulness of the NBCCVM approach and outputs for our partners we conducted a series of trials. In these trials preliminary datasets and draft documentation were provided to partners and feedback sought.

Applications of the model

This is the first time a practitioner focussed GIS model has been developed at a national level. It will inform future projects, adaptation action and partnership working and forms part of our work towards understanding how our natural environment will change and adapt in the future.

The potential users of the national biodiversity climate change vulnerability model are varied, and include Natural England’s own staff working at a range of levels from local to national.

There are also a range of external partners who expect to use the products. At a national level partners include other organisations that operate across England, including the Environment Agency and the Forestry Commission. There are also a range of partners and partnership groups operating at a local or landscape scale, for example: Nature Improvement Areas (NIAs); Local Authorities; Wildlife Trusts; and other landscape scale projects.

The vulnerability assessment can help identify spatial priorities and, therefore, help to focus resources, and inform spatial planning decisions to help adaptation of the natural environment to climate change. Within Natural England, we expect it to contribute to our work on Biodiversity 2020 targets, our partnership working with National Parks, Areas of Outstanding Natural Beauty, Nature Improvement Areas, and other landscape scale conservation projects. We also anticipate that it will be useful in targeting agri-environment measures and developing management plans for National Nature Reserves.

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1 Introduction

1.1 A healthy natural environment is important not only for biodiversity but for society as a whole, as our health, wellbeing and our economy are underpinned by it. Over many years the natural environment has been under pressure from a number of threats, such as changes in land use and management, which lead to habitat degradation and habitat destruction. We are now facing the impacts of climate change which brings a variety of direct and indirect consequences and will exacerbate those existing pressures. The natural environment is recognised as a priority area for adaptation in the UK Climate Change Risk Assessment (HM Government, 2012) and the National Adaptation Programme (HM Government, 2013).

1.2 Species and habitats are strongly influenced by factors such as temperature and rainfall and the interactions between them (Morecroft and Speakman, 2013). As our climate changes, so too will the ecological communities that are such an important part of our landscapes. In order to deliver successful conservation in a changing climate, it is important to assess the vulnerability of different species, habitats and landscapes to climate change, and to understand the causes of this vulnerability.

1.3 We need to assess the relative vulnerability of habitats and ecosystems across large areas ('landscape scale'), to identify where conservation action should be targeted. The results of such vulnerability assessments will help us prioritise where the use of scarce conservation resources should be directed.

1.4 We have developed a 'model' that provides the basis for an analysis of current datasets to assess the vulnerability of priority habitat to climate change. This model is based on established principles of adaptation for biodiversity (Hopkins *et al*., 2007; Smithers *et al*., 2008). Through the model we are now able to spatially represent the relative vulnerability of priority habitats to enable better prioritisation of adaptation actions at a range of scales.

1.5 There are three elements to our approach to assessing the vulnerability of priority habitats:

- The **National Biodiversity Climate Change Vulnerability Model (NBCCVM)** – we first developed our approach to assessing the vulnerability of priority habitats. This is the collection of principles and scoring systems on which we will base the assessment of vulnerability, otherwise known as the National Biodiversity Climate Change Vulnerability Model (NBCCVM).
- **National Biodiversity Climate Change Vulnerability Assessment Tool (NBCCV Assessment Tool)** – to enable us to carry out this approach, or 'run the model' we created a software tool, the NBCCV Assessment Tool. The tool enables us to re-run assessments of vulnerability easily using updated or local data, changing the weightings used and combining metrics in different ways. It can also be used to test the impact of habitat creation and management scenarios on vulnerability.
- **National Biodiversity Climate Change Vulnerability Assessments (NBCCVAs)** – this term is used to describe the assessments, or runs, carried out by the tool and based on the model.

1.6 The aim was to provide data on habitat vulnerability for use by Natural England in planning for nature conservation and enhancement. We also aimed to provide a straight forward approach that could be easily understood and used by a range of our partners. The data will form one of the main tools offered by Natural England to our partners on climate change adaptation planning.

1.7 The model and the NBCCVM Assessment Tool allow us to provide a high level assessment of the relative vulnerability of priority habitats to climate change in different places. It identifies why

areas are vulnerable and allows us to identify which possible interventions and solutions can have the biggest impact in increasing resilience to the changing climate. This will inform prioritisation of adaptation action and assist in the development of adaptation strategies for biodiversity both within Natural England and with our partners, such as Nature Improvement Areas (NIAs) and Local Authorities, some of whom helped us trial the model approach and outputs.

1.8 The priorities highlighted within the 'Making Space for Nature' report (Lawton *et al*., 2010) provide design principles for ecological networks that will help us to address climate change vulnerability and help deliver adaptation action. GIS outputs from the NBCCV Assessment can help prioritise action on 3 of the 4 priorities from this report:

1) Better management – use of the NBCCV Assessment can help prioritise action on managing habitats to reduce current sources of harm and increase resilience to climate change.
2) Bigger areas of habitat – the NBCCV Assessment can help highlight priorities for increasing habitat patch size.
3) Joined up networks – the NBCCV Assessment can help to identify priorities for joining up fragmented habitats.

1.9 An earlier methodology for a national scale vulnerability model was published by Natural England in 2011 (Catchpole 2011). This project is informed by the work on this earlier model, and is largely based on the same principles, but takes a different approach. Some of the main differences of this are that: it provides an assessment of all priority habitats based on five distinct elements; habitats are assessed individually; the NBCCV Assessment Tool means new assessments can easily be produced to respond to changes in data and priorities; and it is at a finer scale (200m squares, rather than 1km squares), therefore it can be used to produce outputs that help prioritise broad actions on adaptation at a strategic and local scale.

1.10 This report describes the development of the model, the methodology used, the outputs available and their trialling with partners, and a description of the audience and potential uses of the data.

Aims and objectives

1.11 The National Biodiversity Climate Change Vulnerability Model (NBCCVM) aims to provide:

- a spatially explicit assessment of the relative vulnerability of priority habitats based on established climate change adaptation principles;
- a suite of map-based GIS outputs at a variety of scales which can be used (in conjunction with other relevant spatial data) to target action to build biodiversity resilience; and
- a flexible, GIS based, decision support tool that allows the user to incorporate locally specific datasets and select how adaptation principles are combined to reflect local circumstances and priorities.

Approach

1.12 This section describes the approach we have taken in developing the NBCCVM. The approach and parameters used were defined by Natural England specialists and the GIS analysis was implemented by the GeoData Institute.

Framework

1.13 Climate change vulnerability is 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity' (IPCC 2007). When applying this concept in policy and practice the three elements – sensitivity, exposure and adaptive capacity – provide a logical framework for considering the components of vulnerability (Willows &

Connell 2003) – see example below and Figure 1 Natural England, 2008. We have used this framework to identify data and parameters to express these components of vulnerability in the development of the NBCCVM.

Climate sensitivity, adaptive capacity and vulnerability (from Willows & Connell 2003)

Sensitivity – The degree to which a system, receptor or exposure unit would be affected, either adversely or beneficially, by a particular change in climate or climate-related variable. (for example, a change in agricultural crop yield in response to a change in the mean, range or variability of temperature). Different systems may differ in their Sensitivity to Climate Change, resulting in different levels of impact.

Adaptive capacity – The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, ie. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions.

Vulnerability – Vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity.

(Based on IPCC, 2001, p. 238).

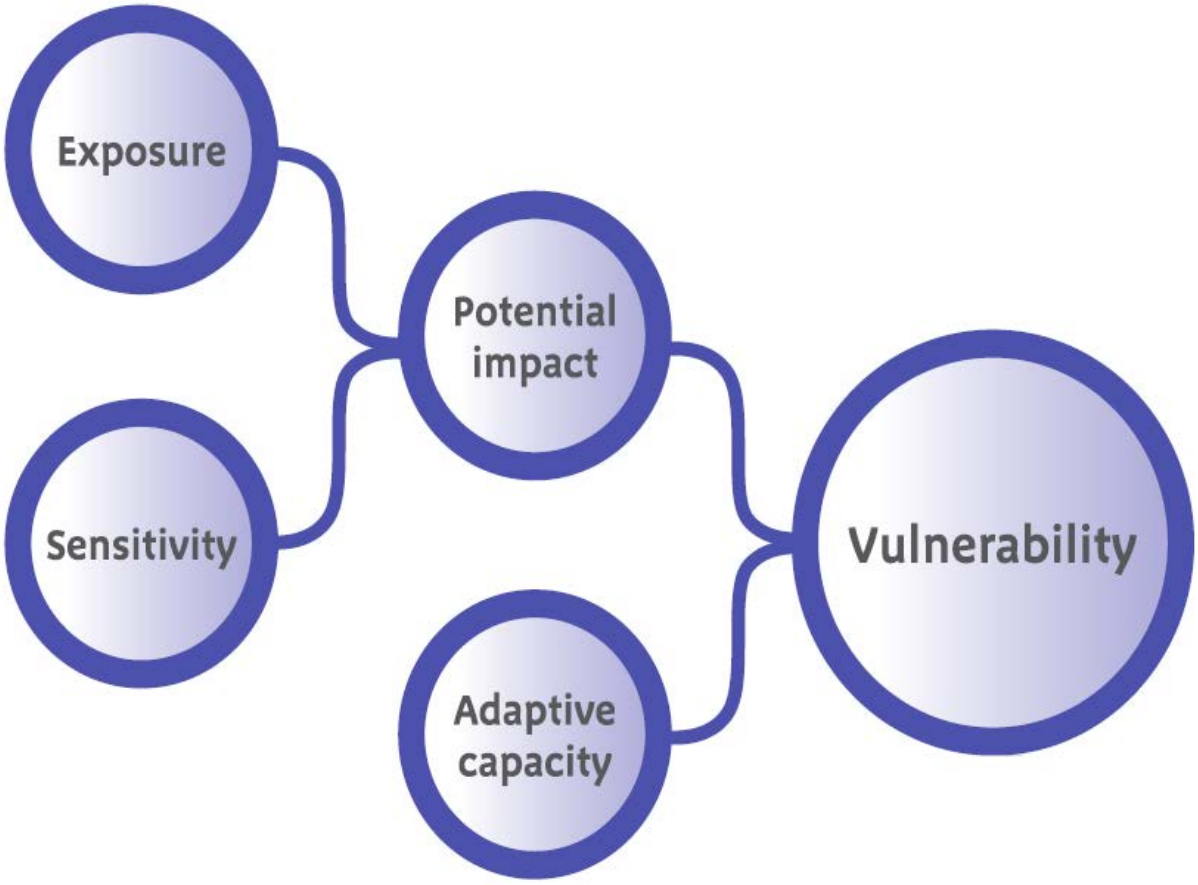


Figure 1 Framework for the assessment of the vulnerability of the natural environment to climate change (Natural England 2008)

1.14 Assessing the vulnerability of the natural environment in practice is not always straightforward. This is not just because of uncertainties about the scale and timing of climatic changes, but because there are still gaps in our knowledge about species and ecosystem processes. We do not yet have a complete understanding of the specific factors that lead to a high or low 'sensitivity' or 'adaptive capacity', or what makes an ecosystem 'resilient'. However, there has been considerable development of the science in this area and enough of the basic principles are agreed to start developing practical approaches to build resilience (Morecroft *et al*., 2012).

Climate change projections

1.15 The UK has produced detailed, probabilistic climate change projections, based on cutting-edge science, that provide scenarios for our climatic future. These are the UK Climate Projections 2009, also known as UKCP09. We are already committed to climate change due to past and current greenhouse gas emissions and these projections provide us with an idea of what our future climate might look like. In the NBCCVM we have used the overarching message from the UKCP09 projections, that our climate will be hotter and drier in the summer and warmer and wetter in winter to guide the assessment of habitat sensitivity. The model is, however, based on vulnerability not modelled impacts – it does not assume any particular climate change scenario. This is because information on individual habitat Sensitivity to Climate Change is limited, and the ecological complexities and cumulative or interactive effects make it very difficult to identify thresholds over which a given change in any climate variable will have an impact on a particular habitat. The approach to sensitivity adopted in the assessment is, therefore, to attribute a summarised risk to each priority habitat from the direct impact of climate change. Furthermore, the NBCCVM does not take into consideration regional differences in climate change projections, nor does it seek to examine the scenarios of climate change over time at this stage – see section 2 for more detail on the approach used to include habitat Sensitivity to Climate Change. This approach is consistent with the emphasis on 'no regrets' or 'low regrets' measures that are usually advocated for climate change adaptation, and are likely to be beneficial under a wide range of scenarios.

Biodiversity climate change adaptation principles

1.16 The approach we have used to assess habitat vulnerability is underpinned by the UK Biodiversity Partnership adaptation principles in the document 'Conserving biodiversity in a changing climate: guidance on building capacity to adapt' (Hopkins *et al*., 2007). These principles have informed more recent approaches to adaptation under the England Biodiversity Strategy (Smithers *et al*., 2008) and the National Adaptation Programme (H M Government, 2013). They provide high level principles for adaptation to increase the resilience of biodiversity to climate change, and the rationale for inclusion of the parameters used in the NBCCVM.

UK Biodiversity Partnership adaptation principles (Hopkins *et al*., 2007)

1) Conserve existing biodiversity:
   - Conserve Protected Areas and other high quality habitats.
   - Conserve range and ecological variability of habitats and species.
2) Reduce sources of harm not linked to climate.
3) Develop ecologically resilient and varied landscapes:
   - Conserve and enhance local variation within sites and habitats.
   - Make space for the natural development of rivers and coasts.
4) Establish ecological networks through habitat protection, restoration and creation.
5) Make sound decisions based on analysis:
   - Thoroughly analyse causes of change.
   - Respond to changing conservation priorities.
6) Integrate adaptation and mitigation measures into conservation management, planning and practice.

Model parameters

1.17 A set of five parameters, or “metrics”, were developed to represent these adaptation principles within the model. These metrics (summarised below) form the components of the analysis of vulnerability.

A summary of the five component metrics

1) **Sensitivity to Change:** this element of the model assigns high, medium or low sensitivity to direct climate change impact for each priority habitat on the basis of expert judgement and scientific literature (for example, Mitchell *et al*., 2007);
2) **Habitat Fragmentation:** including measures of aggregation of same habitat and the permeability of the surrounding landscape matrix to provide a measure of structural fragmentation;
3) **Topographic Heterogeneity:** reflects variation in height and aspect across habitats and the landscape matrix;
4) **Management and Condition:** management applications and condition indicators that address current sources of harm are identified for each habitat; and
5) **Conservation Value:** this is based on designation status, and assigns a relative value to priority habitat only, priority habitat within a national designation or priority habitat within an international designation, with the latter valued highest. This is not a component of vulnerability per se, but is an important element of any prioritisation in which the model is likely to be used.

GIS analysis

1.18 The input datasets required for the analysis were generalised to a 200m x 200m GIS grid for England. The metrics were then calculated and combined to produce an overall climate change vulnerability score for each 200m grid square.

GIS tool

1.19 The processing steps in the analysis were built into a GIS application tool, the NBCCV Assessment Tool, allowing the analysis to be easily repeated for specific localities or when new data becomes available. The operation of the tool is detailed within the tool’s integrated help files.

Pilot project

1.20 The approach we have used was originally piloted in South East England (described in GeoData Institute 2010 and Taylor and Knight 2011), and considered habitats appropriate to that region. The habitats considered in this project were broadened to include all national priority habitats for which a spatial inventory existed.

Key characteristics

1.21 The following highlights some of the key characteristic of the vulnerability model.

NBCCVM at a glance, a summary of key characteristics

The National Biodiversity Climate Change Vulnerability Model:

- Is based on the Intergovernmental Panel on Climate Change and United Kingdom Climate Impacts Programme definitions of vulnerability and framework for assessment.
- Is underpinned by the UK Biodiversity Partnership principles in the document 'Conserving biodiversity in a changing climate: guidance on building capacity to adapt' (Hopkins *et al*., 2007).

- Assesses vulnerability of Priority Habitats in situ as they are currently distributed, providing a snapshot of the current situation based on the existing distribution and condition of priority habitats (although data can be easily updated).
- Is based on vulnerability to climate change defined in terms of a broad 'direction of travel' rather than using projections from specific climate change scenarios.
- Provides a spatial representation of relative vulnerability of priority habitats.
- Provides additional evidence on which to base action to increase resilience alongside other data, such as habitat opportunity mapping.
- Provides a broad approach for targeting action within which local detail should define specific action based on local ecology and opportunities and constraints, etc.
- Does not include species responses to climate change or model specific climate scenarios. However, it has been designed so that such data can be readily combined and integrated.

2 Methodology

2.1 The NBCCVM method has been developed using expert knowledge, experience and opinion gathered from Natural England specialists, and has been evaluated by partners and stakeholder groups at various stages of its development.

2.2 Following the framework provided by UKCIP (Willows and Connell, 2003), the assessment was configured into five stages, in which each component of vulnerability is modelled separately before being combined into an overall assessment. The process can be summarised as follows and in Figure 2:

1) **Identify biodiversity assets:** in this case priority habitats.
2) **Sensitivity:** assess the sensitivity of the assets identified in stage 1 to climatic change.
3) **Adaptive Capacity:** assess the capacity of assets to adapt to climate change and consider the influence that additional sources of harm, not attributable to climate change, may have on their adaptive capacity.
4) **Vulnerability:** combine the assessments made in stages 1 to 3 to derive an overall assessment of relative vulnerability to climate change.
5) **Conservation Value:** the Conservation Value of the assets under the current designated site mechanisms can be used to help prioritise actions.

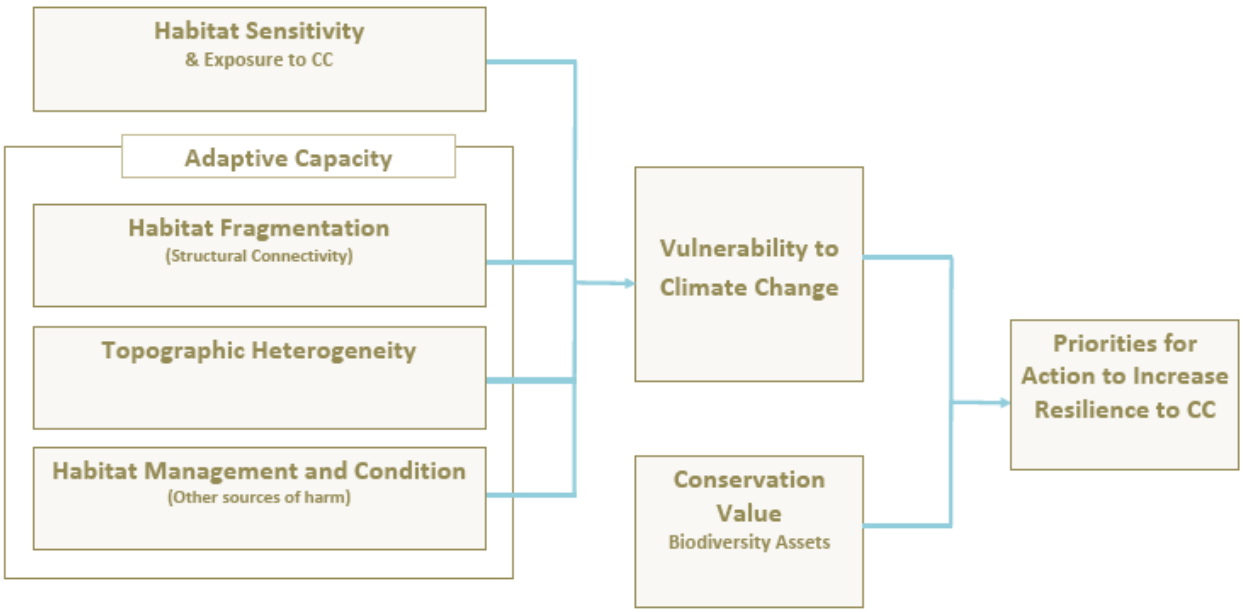


Figure 2 Flow diagram illustrating the components and process of the NBCCVM

Input data

Habitat data

2.3 Priority habitats were chosen to represent England's biodiversity assets in the NBCCVM. These have been identified nationally as habitats of principal importance for the conservation of biodiversity (Section 74(3) of the Countryside and Rights of Way Act 2000) (JNCC, 2007). The

model assumes that maintaining healthy, resilient and well connected habitats will be fundamental to maintaining biodiversity in a changing climate.

The Land Cover Matrix

2.4 The Land Cover Matrix is used in the model to represent the nature of land cover in the landscape surrounding the priority habitat which is the focus of the assessment. For the NBCCVM Assessment a generic set of land cover classes was used in the Land Cover Matrix to represent 'permeable' semi-natural land. These land cover classes were derived from the Land Cover Map (LCM) for the UK (CEH, 2011) and the priority habitat datasets. However, it is possible, using the NBCCV Assessment Tool, to tailor the land cover classes incorporated for individual priority habitats. In this way it is possible to create a matrix to reflect the dispersal characteristics of particular species, or groups of species, in order to reflect the relative permeability of the landscape.

Terrain data

2.5 Terrain data in the form of a digital elevation model (NextMap Bare Earth Digital Elevation Model 5m resolution, vertical precision 1cm, download date January 2013) was used in the model to allow the analysis of both height and aspect variance within habitats and the surrounding landscape. These are used to assess Topographic Heterogeneity. Heterogeneity is included as it supports microclimatic variation, which may allow persistence of species.

Management and Condition data

2.6 Selected datasets indicating current Management and Condition of habitats are used to assess the degree to which their adaptive capacity may be affected by sources of harm other than climate change. Habitats in good condition would be expected to be more resilient to climate change than those that are in poor condition.

Conservation Value data

2.7 National and international nature conservation designations (SSSI, SAC, SPA, Ramsar) are used to reflect the relative Conservation Value of habitats. While all priority habitats are important biodiversity assets, their regional, national and international significance will vary with both habitat type and quality. For the purposes of the assessment it has been assumed that these differences in significance are well represented by these designations.

2.8 For a detailed description of the input datasets used see Appendix 1.

The GIS model

2.9 A GIS data model based on a 200m resolution raster grid was developed to provide the framework for the spatial analysis required (based on the metrics introduced above) in the climate change vulnerability assessment.

2.10 Each priority habitat dataset was generalised to produce a set of binary presence/absence grids (habitat presence grids). This was achieved in three stages:

1) The area of overlap between the input polygons and the 200m x 200m cells of the model grid was calculated for each cell.
2) The distribution of area overlap values was analysed for each habitat and used to set a lower cut off threshold (see Appendix 2).
3) Each cell where the area overlap exceeded the threshold was given a value of 1 to indicate presence of that habitat, while all other cells received a value of 0 to indicate its absence.

2.11 The same process was used to generate similar presence/absence grids for the other input vector datasets used in the NBCCVM analysis.

2.12 This grid-based approach allowed us to calculate the model metrics independently of any given geography and then combine and aggregate them at a variety of scales to produce outputs ranging from national level strategic overviews to detailed spatial data to support decision making at the local or landscape scale.

2.13 Where more detailed local outputs are required, the NBCCV Assessment Tool developed to undertake the spatial analysis required allows input data to be generalised and analysed using grids at finer resolution, for example, 50m^2 and 100m^2.

The model metrics

2.14 As described in paragraph 1.17, the metrics used in the model represent biodiversity adaptation principles and follow the stages set out in Figure 2 above. Also see below, for a list of the metric and sub-metrics. The rationale, calculations and scoring for these metrics are set out below.

The metrics and sub-metrics used in the NBCCVM

1) Sensitivity to Climate Change
2) Habitat Fragmentation - including 2 sub-metrics:
   a) Habitat Aggregation
   b) Land Cover Matrix
3) Topographic Heterogeneity - including 4 sub-metrics:
   a) Habitat Height Variance
   b) Land Cover Height Variance
   c) Habitat Aspect Variance
   d) Land Cover Aspect Variance
4) Management and Condition
5) Conservation Value

Sensitivity to Climate Change

Rationale

High: At risk from particular threats such as sea level rise, particularly high sensitivity to hydrological changes on top of a wide range of changes from all climate change variables. Significant loss of extent/increase in unfavourable condition by 2050 (scores high sensitivity in the model).

Med: Largely includes habitats at risk from hydrological changes alongside a wide range of changes from all climate change variables. Some loss of extent or increase in unfavourable condition by 2050, climate change affects part of range or sub-types (scores medium sensitivity in the model).

Low: At risk from the broad range of changes from all climate change variables (scores low sensitivity in the model).

Figure 3 An overview of the sensitivity of habitats showing that a higher sensitivity metric classification contributes to a greater level of vulnerability in the assessment

2.15 Information on individual habitat Sensitivity to Climate Change is limited. Complexities in ecology, habitats and ecosystems and cumulative or interactive effects make it very difficult to identify thresholds over which a given change in any climate variable will have an impact on a particular habitat. The approach to sensitivity adopted in the assessment is, therefore, to attribute a summarised risk to each priority habitat of direct impact from climate change.

2.16 UKCP09 ‘Key Findings’ for each region are presented as a central estimate within a range of uncertainty or probability. The regional variation in UKCP09 projections for specific climatic variables is relatively small across England and the error margin for any given region is much greater than the regional differences for the central estimate.

2.17 Given this, and the absence of ecological evidence for specific climatic thresholds over which a habitat will be impacted by climatic change, it was decided that it was not possible to consider regional variation in exposure to climate change within the model.

2.18 Each priority habitat was assigned with a classification denoting its relative sensitivity to direct climate change impacts, based on an increase in temperature of the order of 2-4 °C and the possibility of both more droughts and more high rainfall events. This reflects the fact that UKCP09 (and earlier) projections indicate a trend towards drier summers and wetter winters and the expected trend towards a more dynamic hydrological cycle in a warmer climate. It should be emphasised that this is a tool to identify vulnerability to climate change, rather than to predict impacts under particular scenarios.

2.19 The England Biodiversity Strategy (EBS) document ‘Towards Adaptation to Climate Change’ (Mitchell *et al*., 2007) includes an assessment which classifies habitats as high, medium or low risk of direct impact from climate change by 2025 at a national scale. Our sensitivity score for habitats is based on this classification, however we adapted the assessment in two ways. Firstly, we assessed the risk over a longer timescale, using the 2050 medium emissions scenario at the central estimate (50% probability) from UKCP09 (Mitchell *et al*., used UKCP02) to frame our thinking on habitat sensitivity and provide the direction of travel for changes in climate. Secondly, a number of changes were made to the list of habitats included in the assessment. These changes included priority habitats that were not in the original report where a national scale habitat inventory exists, splitting flood plain grazing marsh and coastal grazing marsh to provide separate sensitivity classifications and combining all woodland habitat types in to one habitat type due to dataset availability.

2.20 Modifications made to classifications in the EBS report were informed by Natural England habitat and climate change specialists and any further evidence that has become available since its publication. See Figure 3 above for an overview of how we approached classifying the vulnerability of habitats based on their Climate Change Sensitivities. The sensitivity values used within the model are listed in Table 1.

2.21 It is important to note that using relative sensitivity does not mean that habitats classified as low sensitivity are not sensitive to climate change, just that they are relatively less sensitive than other habitats.

Table 1 The Climate Change Sensitivity classifications for each habitat

Habitat	NBCCVM classification	England Biodiversity Strategy classification (Mitchell *et al.,* 2007)
Coastal Grazing Marsh	H	H (combined floodplain and coastal)
Coastal Saltmarsh	H	H
Lowland Raised Bog	H	Not in Mitchell *et al*., classification
Maritime Cliff and Slope	H	H
Montane	H	H
Saline Lagoons	H	H
Standing Water	H	H
Upland Hay Meadows	H	Not in Mitchell *et al*., classification
Floodplain Grazing Marsh	M	H (combined floodplain and coastal)
Purple Moor Grass and Rush Pasture	M	M
Coastal Vegetated Shingle	M	M
Lowland Meadows (wet)	M	M
Reedbeds	M	Not in Mitchell *et al*., classification
Blanket Bog	M	Not in Mitchell *et al*., classification
Coastal Sand Dunes	M	M
Lowland Fen	M	Not in Mitchell *et al*., classification
Upland Fens and Flushes	M	Not in Mitchell *et al*., classification
Lowland Heathland	M	M
Rivers	M	M
Upland Heathland	M	M
Intertidal Mudflats	M	L
Limestone Pavements	L	Not in Mitchell *et al*., classification
Lowland Meadows (Dry)	L	L
Deciduous Woodland	L	Not in Mitchell *et al*., classification (they used separate classes for different woodland types)
Lowland Calcareous Grassland	L	L
Lowland Dry Acid Grassland	L	L
Upland Calcareous Grassland	L	Not in Mitchell *et al*., classification

Scoring

2.22 For the sensitivity metric each cell containing priority habitat was assigned a score according to its sensitivity class as follows.

Table 2 Scoring for the sensitivity metric

Sensitivity metric score	Sensitivity metric classification	Vulnerability component score	Vulnerability classification
3	High	3	High
2	Med	2	Med
1	Low	1	Low

Habitat Fragmentation

Rationale

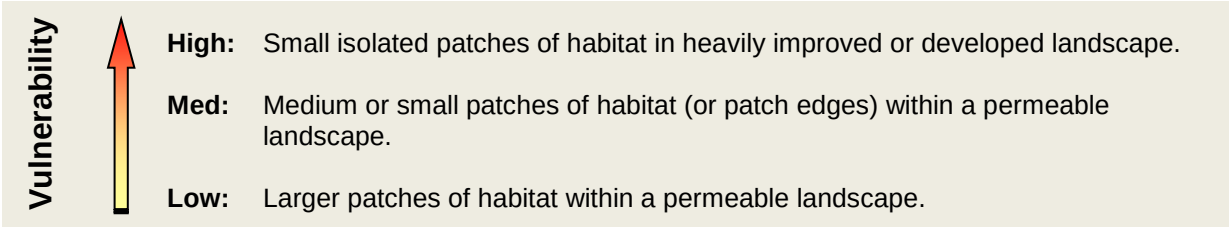


Figure 4 An overview of the Habitat Fragmentation metric, showing the general principle that as the fragmentation of habitats increases, vulnerability to climate change increases

2.23 The rationale for the inclusion of the Habitat Fragmentation metric is that larger habitat patches support larger populations which are less susceptible to extinction during extreme climatic events such as droughts and floods. They can also accommodate a wider range of soil types and topographical variations in microclimate. More and better connected patches, set in a more permeable landscape may also promote species dispersal into new areas and allow re-colonisation following local extinctions. Thus both the size of individual habitat patches and the permeability of the landscape surrounding these patches are important for persistence of biodiversity.

2.24 The Habitat Fragmentation metric consists of two component sub metrics: the Habitat Aggregation sub-metric and the Land Cover Matrix sub-metric.

2.25 The Habitat Aggregation sub-metric is a measure of the distribution of individual habitats. Bigger aggregations are more resilient as they can have larger populations, greater landscape diversity and reduced edge effects (Rosenzweig 1995; Whittaker & Fernández-Palacios 2007, Reis *et al*., 2004, Lawton *et al*., 2011).

2.26 The Land Cover Matrix sub-metric is a measure of the distribution of all semi-natural land cover types. This is a proxy for the 'permeability' or 'hostility' of the landscape surrounding the priority habitat. The Land Cover Matrix used within the assessment is a grouping of priority habitats and semi-natural land cover types that can be identified as providing some level of landscape permeability through which species can move in response to changes in climate or land use. We include non priority habitat in the Land Cover Matrix because the wider landscape outside priority habitat areas is also important for biodiversity.

2.27 For the NBCCVM assessment a generic set of land cover classes was used for all habitats in the Land Cover Matrix (see Appendix 1). However, it is possible, using the NBCCV Assessment Tool, to tailor the land cover classes used in the Land Cover Matrix for individual priority habitats. For example, for a grassland habitat, a group of habitats and/or land cover types considered to be permeable for grassland species could be identified and used as the Land Cover Matrix for this

habitat. Each priority habitat assessed within the model can therefore have a specifically created land cover grouping for use within this sub-metric.

Calculation and scoring

2.28 The method used to calculate the **Habitat Aggregation sub-metric** is illustrated in Figure 5 below. For any cell containing a given habitat, the more cells there are in the surrounding 1km square which contain the same habitat, and the closer they are aggregated around the central cell, the higher the score for that cell.

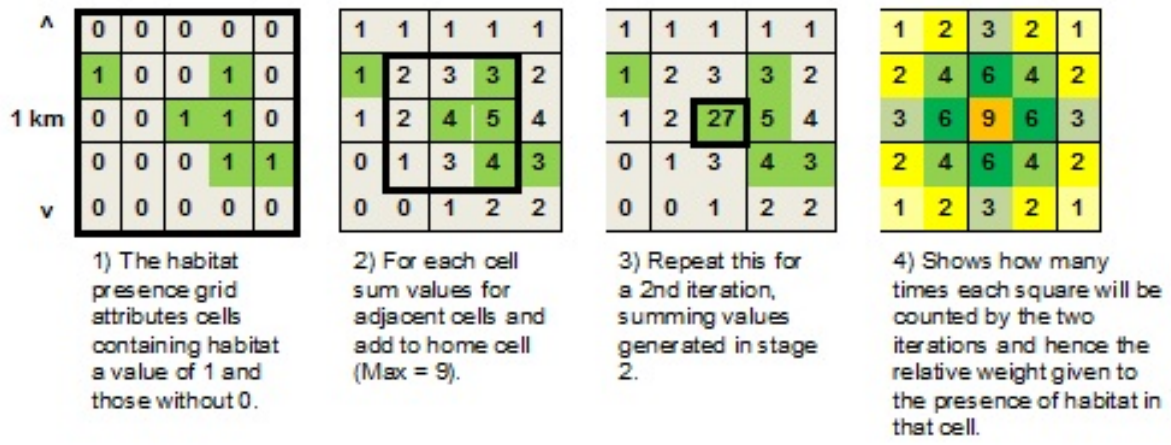


Figure 5 Method for calculating the Fragmentation metric and sub-metrics. In this example the central cell has three adjacent cells containing the same habitat and two further cells in the wider 1km square. This distribution yields a Habitat Aggregation score of 27 for the central cell.

2.29 This method generates a range of possible scores for this sub-metric of min = 9 to max = 81. This is then scaled to give a Habitat Aggregation score ranging from min = 0, to max = 1.

2.30 The calculation of the **Land Cover Matrix sub-metric** follows a similar approach to that of Habitat Aggregation sub-metric but looks at the distribution of all semi-natural land cover in the 1km square surrounding the cell.

2.31 This generates a range of possible scores for this sub-metric of min = 9 to max = 81. This is then scaled to give a Land Cover Matrix score ranging from min = 0, to max = 1.

2.32 The scores from the **Habitat Aggregation sub-metric** and **Land Cover Matrix sub-metric** are combined, inverted and rescaled to give a score for the **Habitat Fragmentation metric** that will have a value in the continuous range 0 to 3. When this metric is combined with other metrics to calculate Overall Vulnerability the continuous values are categorised in to Vulnerability Component Score as shown in Table 3 below.

Table 3 Scoring for the Fragmentation metric

Fragmentation score range	Fragmentation classification	Vulnerability component score	Vulnerability classification
2 - 3	High	3	High
1 - 2	Med	2	Med
0 - 1	Low	1	Low

Weighting of the sub-metrics

Fragmentation weighting approach

2.33 The NBCCV Assessment Tool allows the user to decide which habitats or land cover classes are used within the calculations of the Habitat Aggregation and Land Cover Matrix sub-metrics. The input data chosen will affect how these sub-metrics relate to one another and combine to give the overall Habitat Fragmentation metric score. It is therefore important to consider carefully how you wish to assess habitat fragmentation and how the two sub-metrics may best be set up and weighted relative to one another in order to achieve this.

2.34 In the national assessment we included a broad set of priority habitats and semi-natural land cover classes in the Land Cover Matrix sub-metric to represent broad landscape permeability, this included the habitat that is being assessed (the target habitat). The aggregation sub-metric included only the target habitat (using the NBCCV Assessment Tool, closely related habitats can be included in a habitat grouping to be assessed under the Habitat Aggregation metric as a single habitat).

2.35 We then set the following criteria where the aggregation sub-metric is the primary factor determining the fragmentation metric score with the Land Cover Matrix acting to modify mid range aggregation scores. Table 4 below shows the criteria for how the Habitat Aggregation and Land Cover Matrix sub-metrics combine to give the overall Fragmentation metric score.

Table 4 The criteria for the combination of the Fragmentation sub-metrics

Aggregation sub-metric	Land Cover Matrix sub-metric	Fragmentation metric score
High (greater than 75%)	Any	Low
Med/High (between 75% & 50%)	High	Low
Med/High (between 75% & 50%)	Low	Med
Med/Low (between 50% & 25%)	High	Med
Med/Low (between 50% & 25%)	Low	High
Low (less than 25%)	Any	High

2.36 We then adopted a weighting scheme which would combine the two sub-metrics to give results for the Habitat Fragmentation metric which meet these criteria.

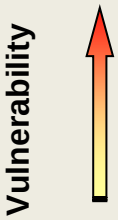
2.37 The resulting weighting used for the national assessment was:

Aggregation sub-metric x 6 and **Landcover Matrix sub-metric x 1**

2.38 It is important to think about the criteria you want the metric to reflect first then find the correct weighting to achieve this.

Topographic Heterogeneity

Rationale



High: Little variation in either height or aspect in the habitat or surrounding landscape.

Med: Some variation in height and/or aspect in the habitat and/or surrounding landscape.

Low: Wide variation in both height and aspect over the habitat and surrounding landscape.

Figure 6 An overview of the Topographic Heterogeneity metric, showing the general principle that as the variation in topography of habitats decreases, vulnerability to climate change increases

2.39 Heterogeneity in height and aspect provides topographical variations in microclimate which increase the probability of species being able to persist in localised pockets of suitable conditions or move to take advantage of a preferred climatic situation. A higher variation in both height and aspect in an area suggests lower vulnerability (Figure 6).

Calculation and scoring

2.40 Four separate metrics were developed to describe the Topographic Heterogeneity within habitats and their surrounding landscape using a bare-earth elevation raster dataset for England with a cell size of 5m and a vertical precision of 1cm. Scores were generated for each cell reflecting the height and aspect variance within the surrounding 1km square for 1) all cells containing the same habitat (Habitat Aggregation); and 2) for all cells containing semi-natural land cover (Land Cover Matrix), in a similar way to the Habitat Fragmentation metric. The following describes the 4 Topographic Heterogeneity sub-metrics:

a) **Habitat Aggregation Height Variance:** For each 200m grid square containing priority habitat, the variance in height is calculated across all squares containing the same type of priority habitat in the surrounding 1 km square.
b) **Land Cover Matrix Height Variance:** For each 200m grid square containing priority habitat, the variance in height is calculated across all squares containing any priority habitat or other semi natural land cover types in the surrounding 1 km square.
c) **Habitat Aggregation Aspect Variance:** For each 200m grid square containing priority habitat, directional variance of the range of aspects was calculated across all squares containing the same type of priority habitat in the surrounding 1 km square.
d) **Land Cover Matrix Aspect Variance:** For each 200m grid square containing priority habitat, directional variance of the range of aspects was calculated across all squares containing any priority habitat or other semi natural land cover types in the surrounding 1 km square.

2.41 The formula used for directional variance was: Circular Variance = $1 - \sqrt{(\overline{\cos\ t})^2 + (\overline{\sin\ t})^2}$.

2.42 The circular variance has a potential range of 0 to 1, and so before combining the height and aspect variances, the height variances were normalised. This was achieved by linear stretch such that 0 maps to the lowest value and 1 maps to the 95th percentile value, with the 5% of values greater than this all being set to 1.

2.43 The Topographic Heterogeneity metric is calculated by summing the 4 component metrics and rescaling so that a score for the Topography Heterogeneity metric that will have a value in the continuous range 0 to 3. When this metric is combined with other metrics to calculate Overall Vulnerability the continuous values are categorised in to Vulnerability Component Score as shown in Table 5 below.

Table 5 Scoring for the Topographic Heterogeneity metric

Topographic Heterogeneity score range	Topographic Heterogeneity classification	Vulnerability component score	Vulnerability classification
0 – 1	Low	3	High
1 – 2	Med	2	Med
2 – 3	High	1	Low

Management and Condition

Rationale

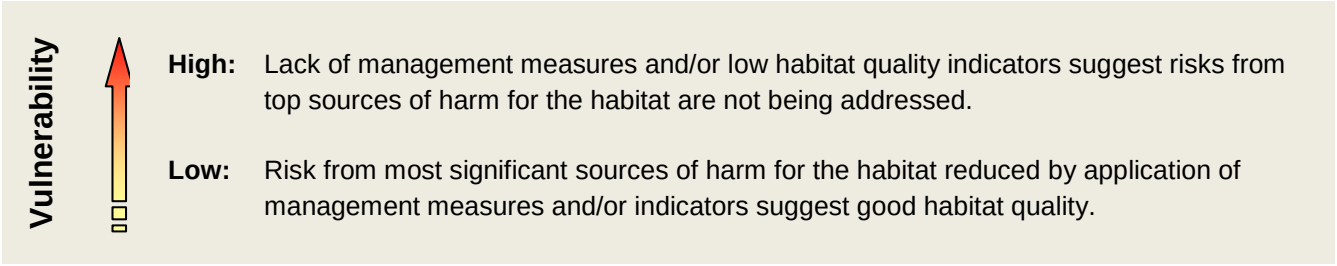


Figure 7 An overview of the Management and Condition metric, showing the general principle that as the condition of habitats decreases, vulnerability to climate change increases

2.44 This aspect of the adaptive capacity score assesses measures currently in place to alleviate negative impacts that are not linked to climate change. The UK Biodiversity Partnership and England Biodiversity Strategy biodiversity climate change adaptation principles (Hopkins *et al*., 2007, Smithers *et al*., 2008) both recommend reducing current sources of harm to habitats that are not linked to climate change. The assumption is that where the most significant impacts are wholly or partially mitigated, the habitat's resilience to climate change is enhanced.

2.45 We identified the most significant sources of harm for each priority habitat. This was done through an assessment of 'Adverse Condition Reasons' from SSSI condition reports, wider literature and consultation with Natural England habitat specialists (Appendix 3).

2.46 A set of management indicators were then identified which address the identified sources of harm for each habitat. Habitats within a SSSI in favourable or unfavourable recovering condition, under a Higher Level Stewardship (HLS) agri-environment option that is deemed beneficial for biodiversity or Woodland Grant Scheme (WGS) were assumed to mitigate the sources of harm identified in that location. For freshwater habitats two additional factors were considered: current ecological status from Water Framework Directive data and current water availability status from Catchment Abstraction Management Strategies (CAMS). This recognises that some causes of water based stresses cannot be fully dealt with at a site level and a catchment wide indicator of management or quality is required.

Calculation and Scoring

2.47 Resilience was considered to be enhanced only where management was in place to mitigate all significant sources of harm identified for the habitat concerned. Where this condition was met for habitat(s) within a cell the Management and Condition metric was scored as 1. Where this was not the case it was scored as 0. See Table 6 for habitat condition measures or indicators required for each habitat.

Table 6 The habitat condition measures or indicators for each habitat

Habitats	Mitigation of sources of harm At least one of the conditions which = Y must be met			Evidence of good condition All conditions which = Y must be met	
	HLS options	WGS	Designated sites (SSSIs favourable or recovering)	Good water quality	Good water supply
Rivers	Y	_	Y	Y	Y
Standing water	Y	_	Y	Y	Y
Deciduous woodland	Y	Y	Y	_	_
Lowland calcareous grassland	Y	_	Y	_	_
Upland calcareous grassland	Y	_	Y	_	_
Lowland dry acid grassland	Y	_	Y	_	_
Dry lowland meadows	Y	_	Y	_	_
Upland hay meadows	Y	_	Y	_	_
Floodplain grazing marsh	Y	_	Y	_	Y
Wet lowland meadows	Y	_	Y	_	Y
Lowland heathland	Y	_	Y	_	_
Upland heathland	Y	_	Y	_	_
Montane	Y	_	Y	_	_
Lowland fen	Y	_	Y	_	Y
Upland fens and flushes	Y	_	Y	_	Y
Purple moor grass and rush pasture	Y	_	Y	_	Y
Lowland raised bog	Y	_	Y	_	Y
Blanket bog	Y	_	Y	_	_
Reedbeds	Y	_	Y	_	Y
Limestone pavements	Y	_	Y	_	_
Coastal grazing marsh	Y	_	Y	Y	_
Coastal saltmarsh	Y	_	Y	Y	_
Coastal sand dunes	Y	_	Y	_	_
Coastal vegetated shingle	Y	_	Y	_	_
Intertidal mudflats	_	_	Y	Y	_
Maritime cliff and slopes	Y	_	Y	_	_
Saline lagoons	_	_	Y	Y	_

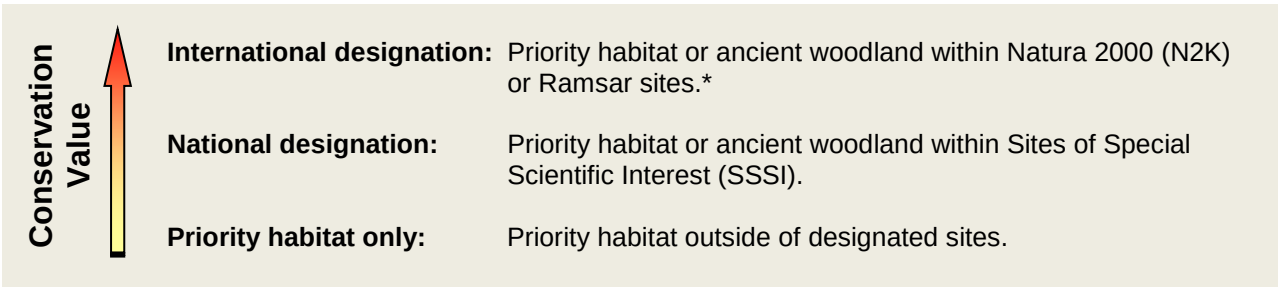
2.48 These values were reclassified and inverted prior to inclusion in the vulnerability calculation as follows.

Table 7 Scoring for the Management and Condition metric

Management/ Condition score	Management/ Condition classification	Vulnerability component score	Vulnerability classification
0	Threats unmitigated	3	High
1	Threats mitigated	1	Low

Conservation Value

Rationale



*Natura 2000 (N2K) sites are Special Areas of Conservation (SACs) which are designated under the EC Habitats Directive and Special Protection Areas (SPAs) which are designated under the EC Birds Directive. Ramsar sites are wetlands on international importance designated under the Ramsar Convention.

Figure 8 An overview of the use of Conservation Value within the model, showing that when included the higher the Conservation Value potentially the greater the priority for action given their importance to the habitat network, their legal status and their important characteristics

2.49 The Conservation Value of a habitat does not affect its vulnerability. But it is an important consideration in prioritisation and targeting of action to build resilience to climate change

2.50 Climate change will lead to some species moving from sites they currently occupy, leading to changes in habitats and species composition. However, due to characteristics such as low soil fertility and varied hydrology, soils, geology and landform, the sites that are currently good for wildlife are likely to continue to be good in the future (Grime *et al.*, 1973, Lawton *et al*., 2010). There is also evidence that as species move through the landscape they preferentially occupy designated sites (Thomas *et al*., 2012).

2.51 The UK Biodiversity Partnership principles and the England Biodiversity Strategy biodiversity climate change adaptation principles (Hopkins *et al*., 2007, Smithers *et al*., 2008) both advise the conservation of existing biodiversity including protected areas and high quality habitat and the range and variability of habitats and species. Protected areas and other high quality habitats which currently support the full range of England's biodiversity (Lawton *et al.*, 2010), will therefore form the basis of future biodiversity. This does not mean preserving current biodiversity exactly as it is, but does support increasing resilience and accommodating change at sites that are currently valuable for conservation.

2.52 Priority habitats were chosen to represent England's biodiversity assets in the model. These have been identified nationally as habitats of principal importance for the conservation of biodiversity (Section 74(3) of the Countryside and Rights of Way Act 2000).

2.53 However, while all priority habitats are important, their regional, national and international significance will vary with both habitat type and quality. For the purposes of the assessment it has been assumed that these differences in significance and hence value are well represented by national and international nature conservation designations (SSSI, SAC, SPA, Ramsar).

Calculation and scoring

2.54 This metric was calculated for each cell by identifying where priority habitat falls within national and internationally designated sites. The exception to this method was the Deciduous Woodland habitat that used the presence of Ancient Woodland Inventory habitat within a designated site in place of the presence of the national priority habitat inventory for woodland. This is because many SSSIs and Natura 2000 sites contain deciduous woodland that is not a designated feature within the site and the priority woodland habitat definition used within the national inventory is very wide. Therefore, Ancient Woodland was seen as a better way to identify woodland habitats with a designated Conservation Value.

2.55 The above approach is set out in Tables 8 and 9 below.

Table 8 Conservation Value metric scores for all priority habitats excluding Deciduous Woodland

Priority habitat	SSSI	(SAC/SPA/Ramsar)	Metric score
Y	Y	Y	3
Y	Y	N	2
Y	N	N	1

Table 9 Conservation Value metric scores for the Deciduous Woodland priority habitat

Deciduous woodland	ASNW	SSSI	(SAC/SPA/Ramsar)	Metric score
Y	Y	Y	Y	3
Y	Y	Y	N	2
Y	Y	N	N	1
Y	N	N	N	1

2.56 Scores for the Conservation Value metric are assigned as set out below.

Table 10 Scoring for the Management and Condition metric

Conservation Value metric score	Conservation Value metric classification
3	High
2	Med
1	Low

Outputs

Overall Vulnerability

Rationale

High	Coloured red, these areas have been assessed as having highly sensitive habitats with low adaptive capacity.
Medium	Coloured orange, these areas could have a greater range of scores, for example, the squares could have been assessed as having medium sensitivity and medium adaptive capacity or potentially low sensitivity but also low adaptive capacity.
Low	Coloured light orange, these areas have been assessed as having low sensitivity habitats and high adaptive capacity.

Figure 9 An overview of the Overall Vulnerability calculation, showing the general principles that confer climate change vulnerability and the colours used to represent them in the map illustrations

2.57 Each metric represents an independent factor affecting the vulnerability of the habitat at a given location. The metrics can be used independently or variously combined to provide a range of outputs. For the NBCCV Assessment it was assumed that where the adverse factors represented by the different metrics coincide the relative vulnerability will be higher. The scores for the four individual metrics identifying vulnerability were therefore summed to obtain an overall score for relative vulnerability to climate change.

2.58 The NBCCV Assessment Tool allows for variable weightings to be applied to the individual metrics before they are combined. For the NBCCV Assessment there was no evidence available to indicate that any one factor was more important than any other and so the metrics were evenly weighted.

2.59 If, as we progress our understanding, one or more factors emerge as having greater influence it would be possible to adapt the model by applying an appropriate relative weighting to reflect this. It should however be remembered that this is intended as a first assessment of large scale patterns in vulnerability to help suggest broad adaptation action. A more detailed assessment is needed to design specific adaptation actions in a particular place.

Calculations and scoring

2.60 The Overall Vulnerability score for each cell was calculated by summing the equally weighted metrics together and then dividing the result by the sum of the weights.

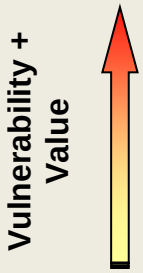
2.61 The majority of cells in the model contain only one habitat and therefore have a unique vulnerability score. However, where a cell contains more than one habitat there will be a score for each habitat present. In the case of this assessment the habitat with the highest Overall Vulnerability score provides the score for that cell. As the model assesses relative vulnerability, some habitat types in the assessment will tend to be more vulnerable than others. The NBCCV Assessment Tool allows the assessment of relative vulnerability across a single habitat type or any grouping of habitats. The scores for Overall Vulnerability are as follows.

Table 11 Scoring for the Overall Vulnerability Assessment

Overall Vulnerability score range	Overall Vulnerability classification
2 - 3	High
1 - 2	Med
0 - 1	Low

Vulnerability + Value: an example of prioritisation

Rationale



High	Coloured red, the highest scores will occur where internationally designated sites are assessed as highly vulnerable.
Medium	Coloured orange, these areas will include Priority habitats outside of international designations with medium to high vulnerability and habitats within international designations with medium to low vulnerability.
Low	Coloured yellow, the lowest scores will occur where Priority habitats outside of national/international designations are assessed as having a low vulnerability.

Figure 10 An overview of the Overall Vulnerability calculation plus the Conservation Value, showing the general principles that confer climate change vulnerability added to the scores for Conservation Value and the colours used to represent them in the map illustrations

2.62 The Conservation Value metric can be combined with one or more of the vulnerability component metrics to assist in determining priorities for action to build biodiversity resilience to climate change. In the NBCCV Assessment an example output was created which combined Conservation Value with Overall Vulnerability.

Calculations and scoring

2.63 In a similar way to for the Overall Vulnerability Score, the Overall Vulnerability Plus Conservation Value score for each cell was calculated by summing the five equally weighted metrics together and then dividing the result by the sum of the weights.

Table 12 Scoring for the Overall Vulnerability Assessment plus Conservation Value prioritisation

Overall Vulnerability Plus Value score range	Overall Vulnerability Plus Value classification
2 – 3	High
1 – 2	Med
0 – 1	Low

3 Model automation

3.1 A bespoke GIS tool was developed to automate the geoprocessing steps in the spatial analysis required by the NBCCVM. This allows the NBCCVM analysis to be re-run and updated as new data becomes available. It also facilitates the creation of user defined scenarios focused on specific locations or different aspects of vulnerability, by employing local data and different metric combinations and weightings. An overview of the functionality of the NBCCV Assessment Tool is provided below, along with a flow diagram (Figure 11).

Overview of National Biodiversity Climate Change Assessment Tool functionality

3.2 The NBCCV Assessment Tool provides the following functionality.

Data preparation

3.3 The generation of 'raster grids' in the format required for the spatial analysis from a variety of vector source data with the grid resolution and extent specified by the user. This facilitates the update of the national datasets used in the assessment or, for example, allows local habitat data to be converted and incorporated in the analysis.

3.4 The creation of hypothetical 'raster grids' to allow analysis of habitat creation and management scenarios.

3.5 The specification of different grid cell sizes (resolutions), for example, 200m, 100m and 50m for the input rasters and subsequent analysis.

Input data

3.6 Customisation of the Land Cover Matrix to select which land cover types are treated as permeable in the landscape surrounding the Priority habitat under analysis.

3.7 The grouping of habitats within the analysis so that closely associated habitats which commonly occur in an intimate matrix one with another can be treated as a single habitat where required.

3.8 Selection of the input datasets to the Management and Condition metric and the Conservation Value metric in order to vary the criteria defining metric values.

3.9 Reclassification of Priority habitats' Sensitivity to Climate Change allowing relative values for this metric to be modified to reflect emerging evidence.

Parameters

3.10 The ability to differentially weight the contributions of the components (sub-metrics) of the Habitat Fragmentation and Topographic Heterogeneity metrics. For example, if evidence shows that, in a particular context, variation in aspect is more important than variation in height, these sub-metrics can be variably weighted or used individually in the analysis.

3.11 The ability to weight the contributions of the five metrics to the Overall Vulnerability score. Or to exclude selected metrics by setting the weighting to zero.

3.12 Recording of model parameters used in a run of the analysis in a CSV file to allow them to be saved, reloaded and modified.

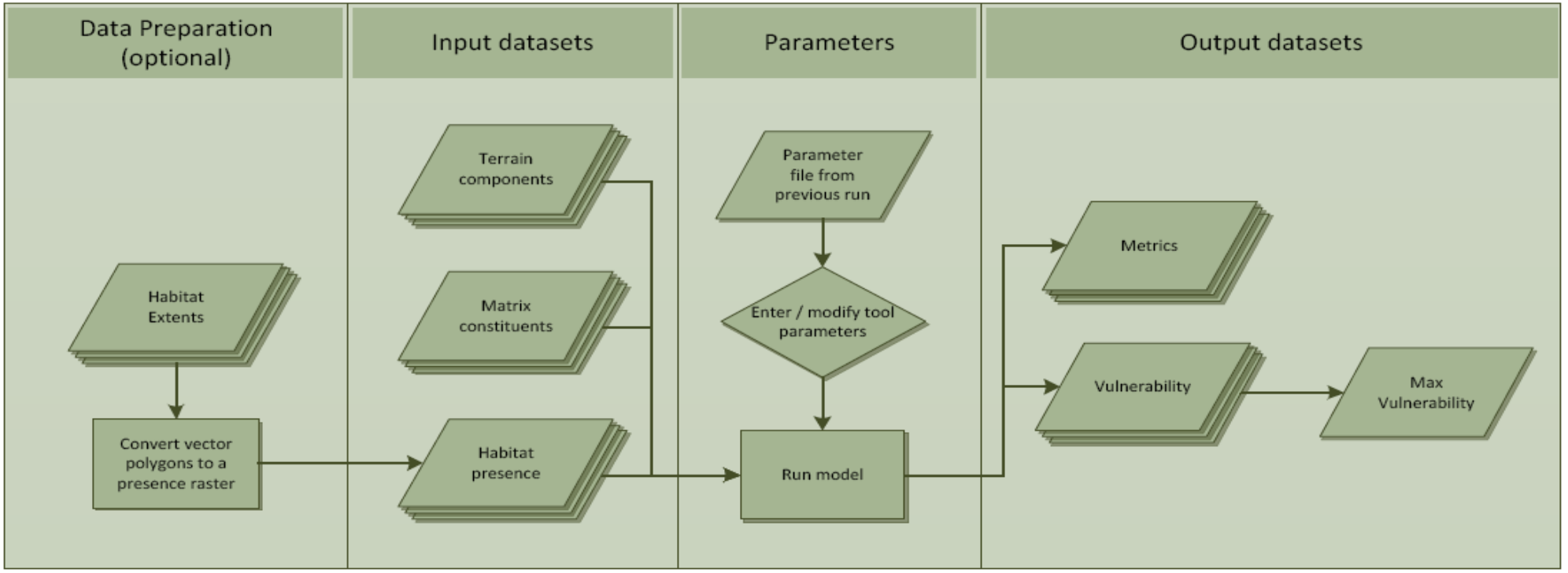


Figure 11 National Biodiversity Climate Change Vulnerability Assessment Tool workflow

Output datasets

3.13 Raster data layers are generated for individual habitats for each metric.

3.14 A vector data layer ESRI Shapefile format for a combined “All Habitats” layer containing the output scores for all metrics and sub-metrics.

3.15 Figure 12 shows a screenshot of the NBCCV Assessment Tool.

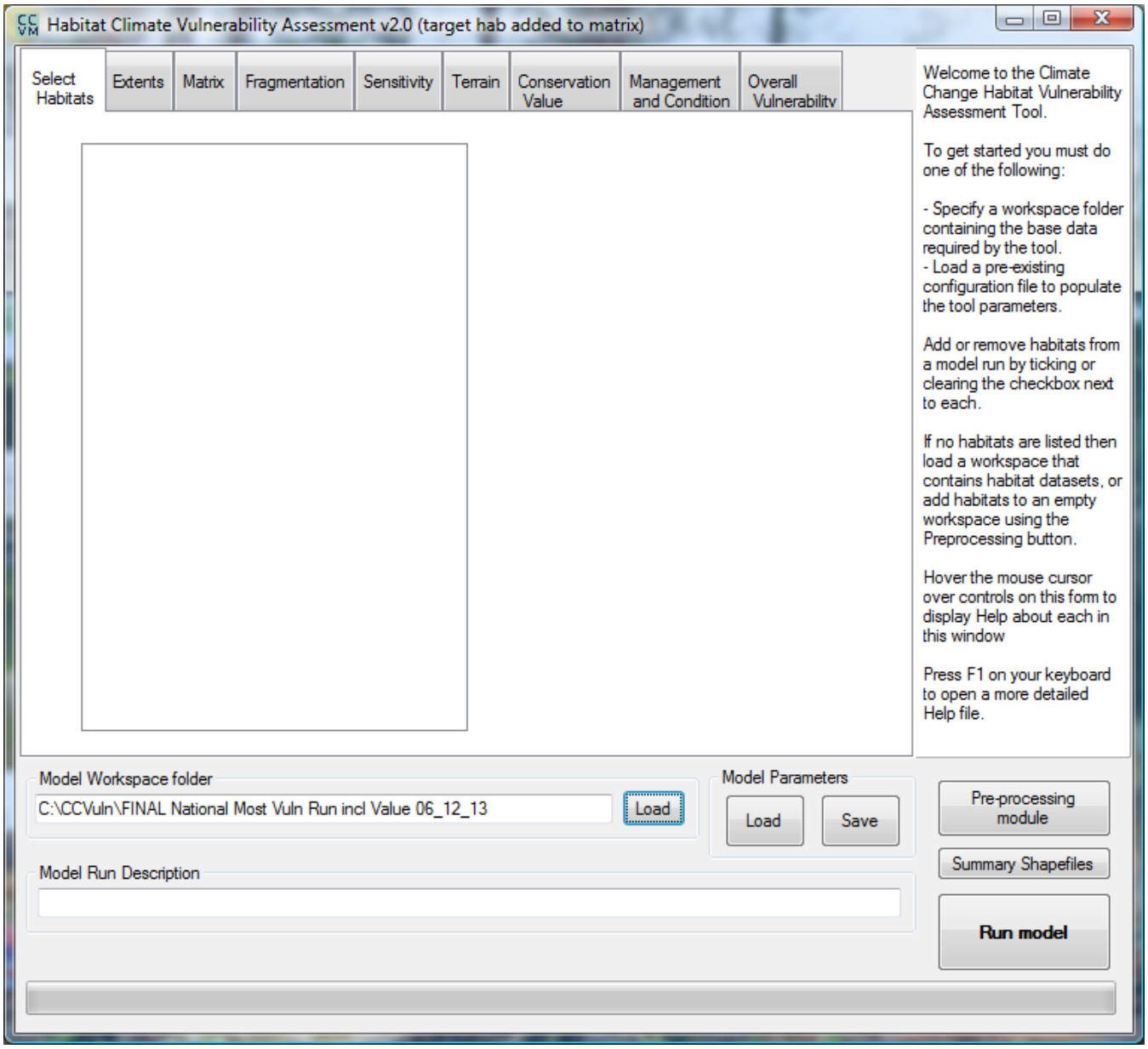


Figure 12 A screenshot of the NBCCV Assessment Tool user interface

4 Results

4.1 The results of the NBVCC assessment consist of a set of data layers containing the output scores for each metric and the combined Overall Vulnerability score. These are presented as a series of thematic maps and can be used in GIS applications in combination with other spatial data. The following example maps show each metric and the Overall Vulnerability assessment mapped for an area on the South Coast of England.

Sensitivity to Climate Change

4.2 The map below (Figure 13) shows the results of the Sensitivity to Climate Change metric for an example area on the South Coast. The three colours represent the high, medium and low classifications for relative sensitivity of habitats to direct impacts from climate change. The example map shows where habitats that have each classification exist. This will help to identify areas that are particularly sensitive to climate change impacts and where further assessment and information on appropriate actions to manage for this might be needed. In this case, the sensitivity of the sensitivity of some coastal habitats and wetlands along water courses is clear. The GIS data can be interrogated to show the habitats present in each square and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

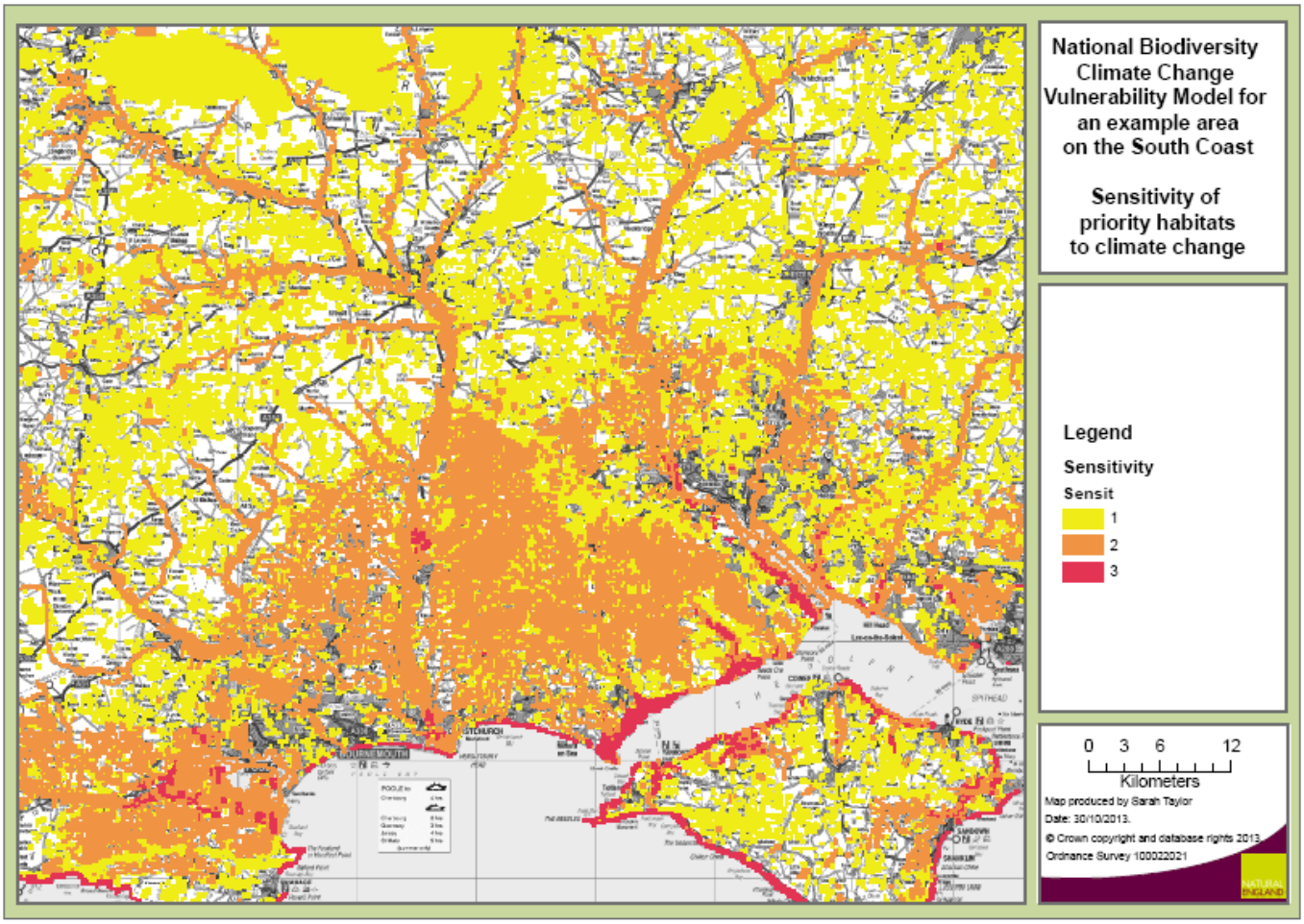


Figure 13 A map showing the Sensitivity to Climate Change metric results for an area on the South Coast of England

Habitat Fragmentation

4.3 The map below (Figure 14) shows the results of the Habitat Fragmentation metric for an example area on the South Coast. The range of colours represent the range of fragmentation of habitats, showing the results for the most vulnerable habitat overall in that cell. This illustrates the structural nature of the assessment used in this metric and broadly shows that more semi-natural habitat in consecutive cells leads to less fragmented habitats. For example the larger contiguous areas of priority habitat in Salisbury Plain and the New Forest are highlighted as being of low fragmentation. This metric can help to identify areas that may benefit from greater concentration on reducing Habitat Fragmentation. The GIS data can be interrogated to show the habitats present in each cell and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

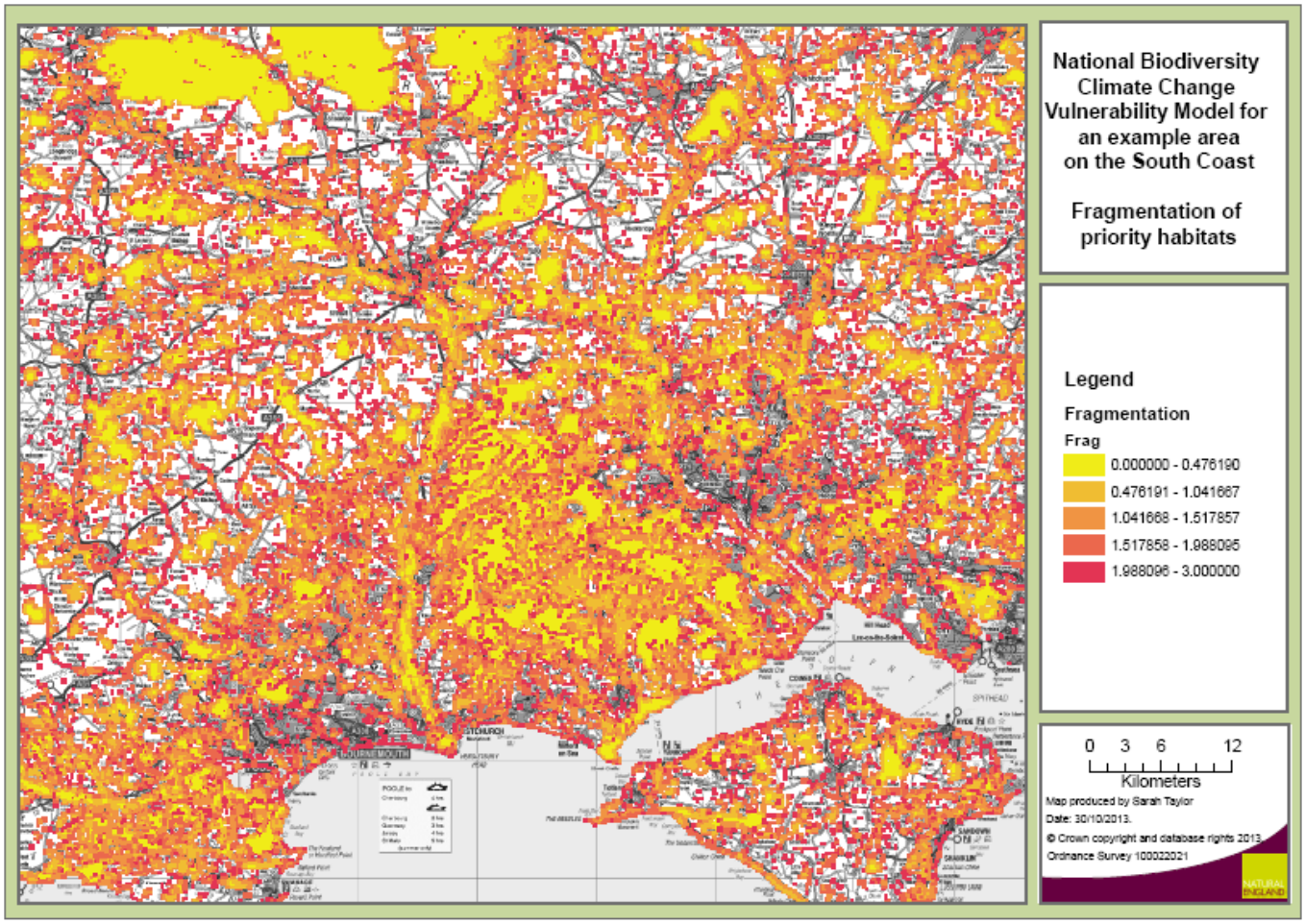


Figure 14 A map showing the Habitat Fragmentation metric results for an area on the South Coast of England

Topographic Heterogeneity

4.4 The map below shows the results of the Topographic Heterogeneity metric for an example area on the South Coast. The range of colours represent the range of variation of height and aspect over aggregated habitat patches and the wider Land Cover Matrix, showing the results for the most vulnerable habitat overall in that cell. This broadly shows that more variation in Topographic Heterogeneity across cells with both priority habitats and other semi-natural habitats leads to a more heterogeneous landscape and lower vulnerability. This helps to identify areas that may benefit from greater concentration on increasing the Topographic Heterogeneity that some habitats cover. The GIS data can be interrogated to show the habitats present in each cell and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

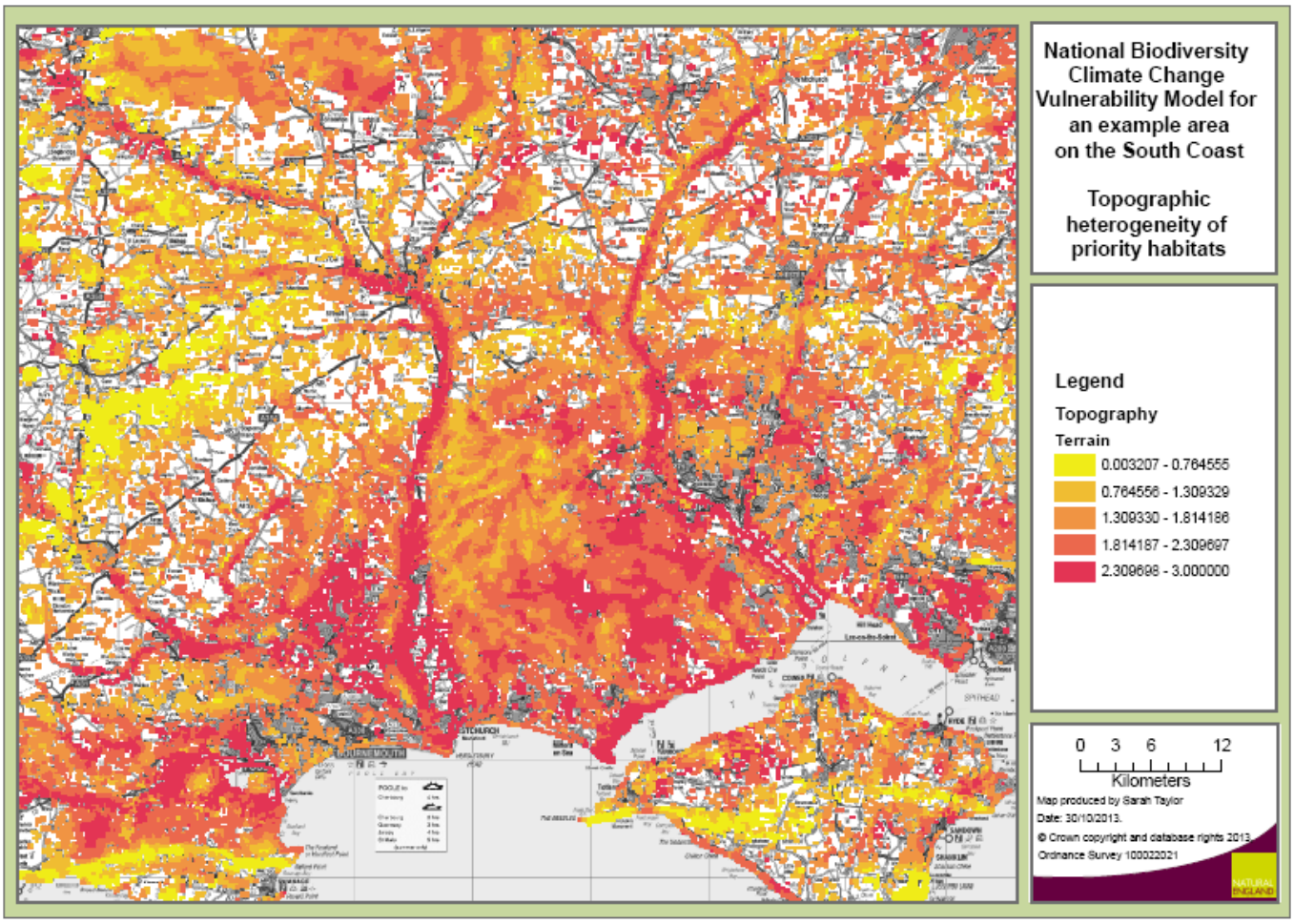


Figure 15 A map showing the Topographic Heterogeneity metric results for an area on the South Coast of England

Management and Condition

4.5 The map below shows the results of the Management and Condition metric for an example area on the South Coast. The two colours represent where habitats meet their criteria for good Management and Condition (yellow cells) and where they don't (the red cells). The example map shows where habitats are of concern as they are in poor condition or under managed according to the scoring within the assessment. This helps us to identify areas that may benefit from greater concentration on habitat management. The GIS data can be interrogated to show the habitats present in each square and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

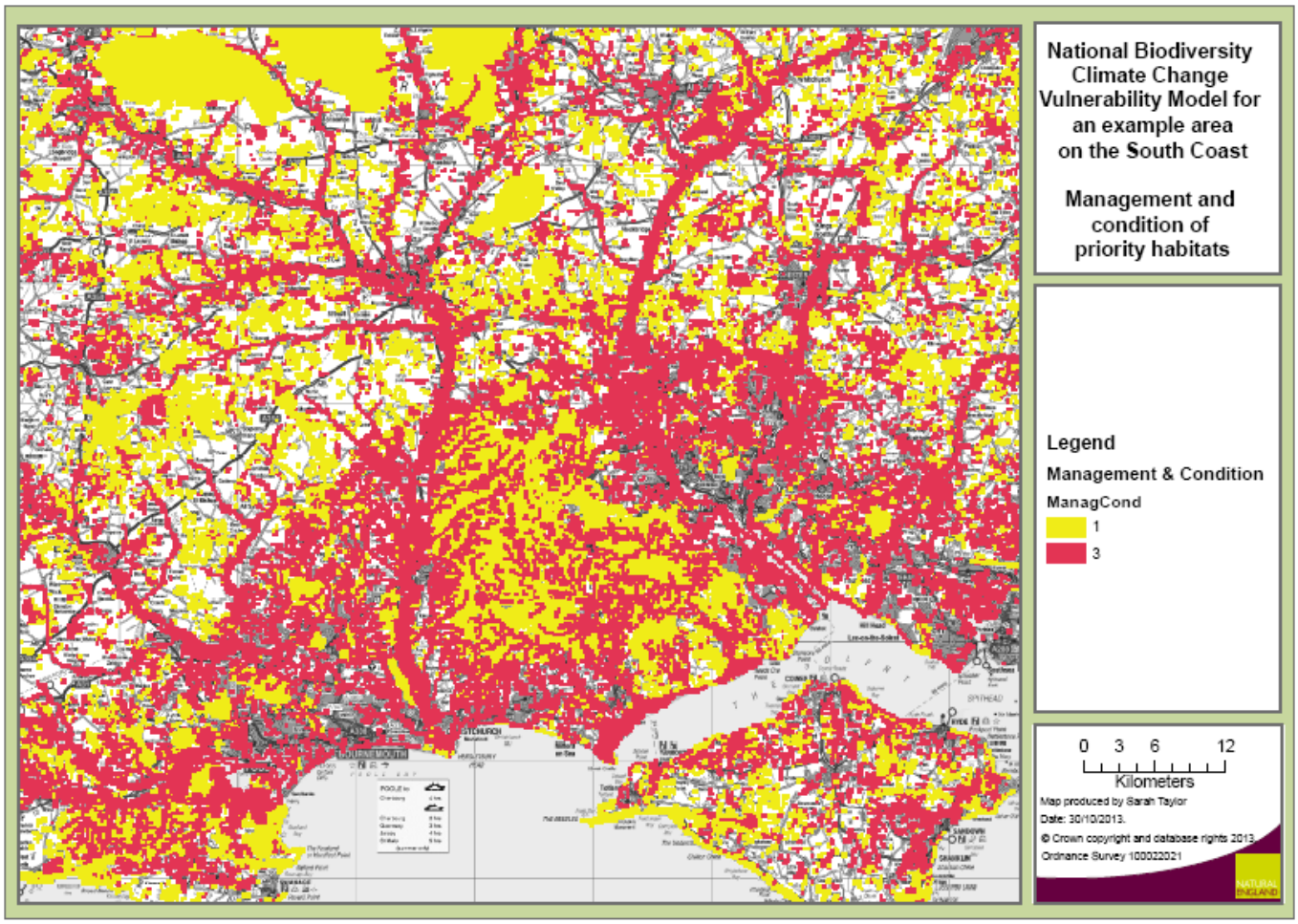


Figure 16 A map showing the Management and Condition metric results for an area on the South Coast of England

Conservation Value

4.6 The map below shows the results of the Conservation Value metric for an example area on the South Coast. The three colours represent the high, medium and low classifications for Conservation Value of habitats based on designation status. The example map shows where habitats that have each classification exist. In this case the European designations on large areas of the New Forest stand out. This metric can be used to help prioritise action at designated sites which form a large part of our core habitat network in England. The GIS data can be interrogated to show the habitats present in each square and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

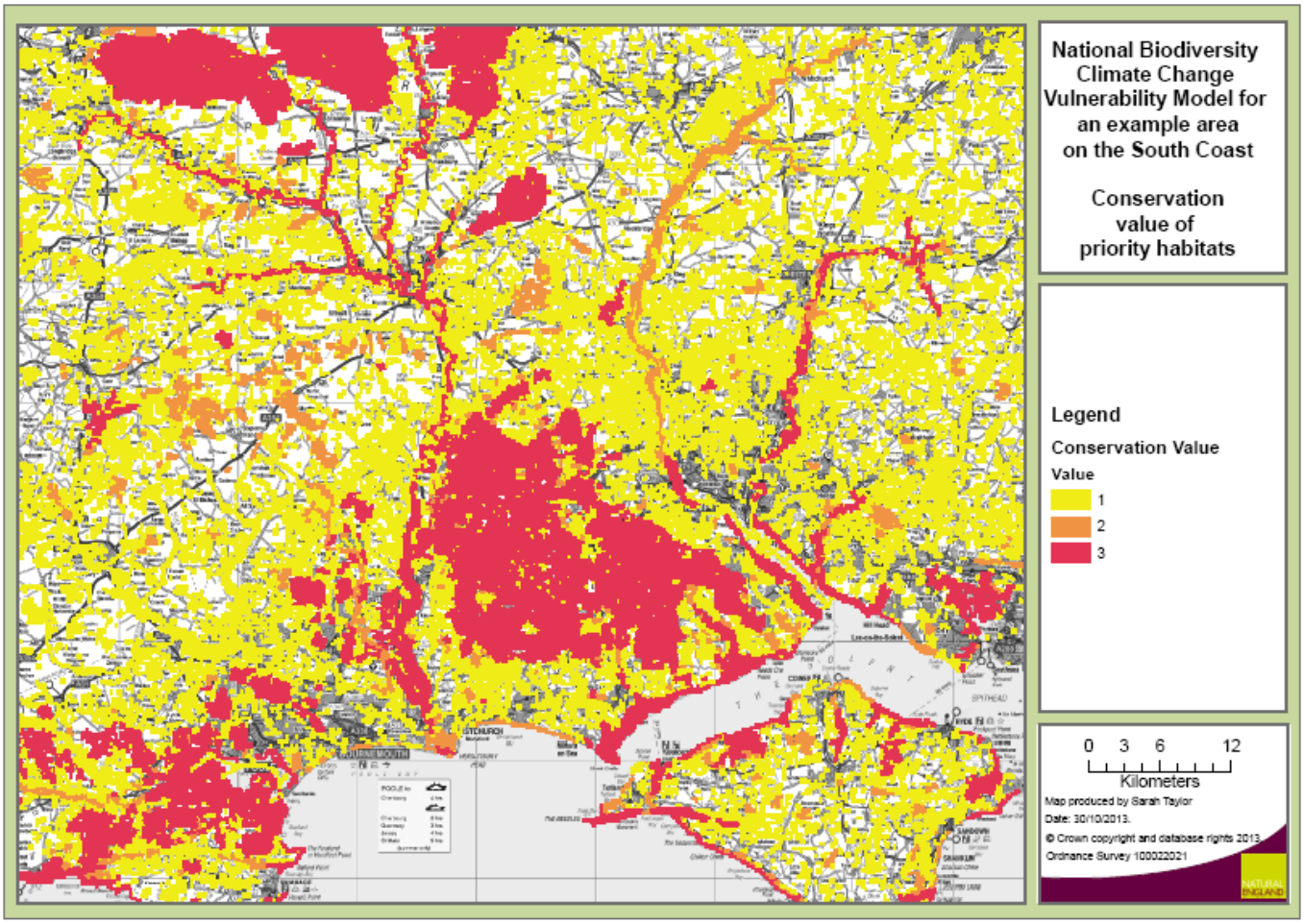


Figure 17 A map showing the Conservation Value metric results for an area on the South Coast of England

Overall Vulnerability

4.7 The map below shows the results of the Overall Vulnerability assessment (Sensitivity + Fragmentation + Topographic Heterogeneity + Management and Condition with equal weighting) for an example area on the South Coast. The range of colours represent the range of vulnerability to climate change for the most vulnerable habitat overall in that cell taking in to account the sensitivity and adaptive capacity metrics in the model. The red cells are the most vulnerable across the metrics and the yellow cells are the least vulnerable. This helps to identify areas that may benefit from adaptation action across a range of broad actions. The GIS data can be interrogated to show the habitats present in each square and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

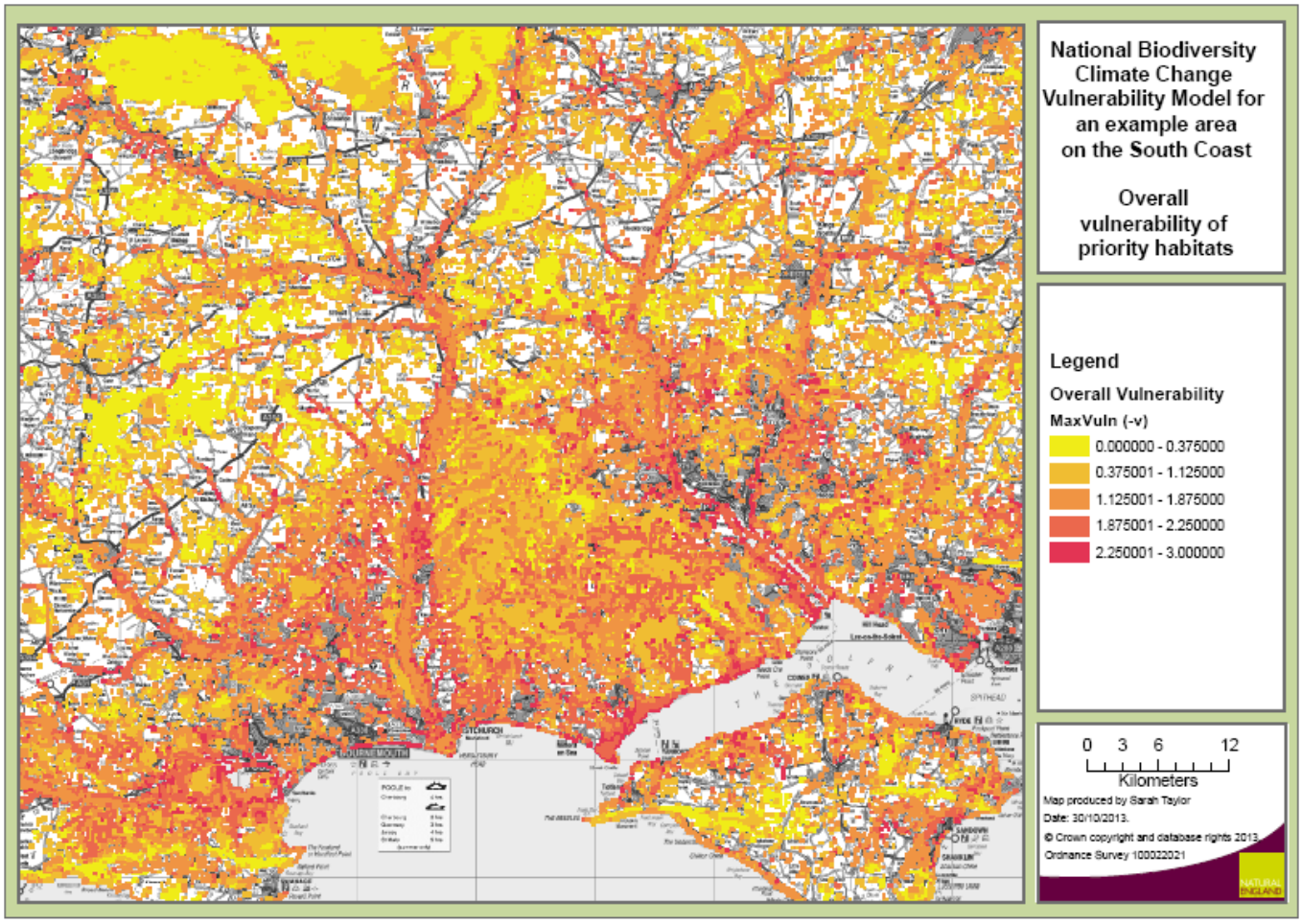


Figure 18 A map showing the Overall Vulnerability Assessment results for an area on the South Coast of England

Overall Vulnerability Plus Conservation Value

4.8 The map below shows the results of the Overall Vulnerability assessment plus the Conservation Value metric (Sensitivity + Fragmentation + Topographic Heterogeneity + Management and Condition + Conservation Value with equal weighting) for an example area on the South Coast. The range of colours represent the range of vulnerability to climate change for the most vulnerable habitat overall in that cell taking in to account the sensitivity and adaptive capacity and Conservation Value metrics in the model. The red cells are the most vulnerable across the metrics and the yellow cells are the least vulnerable. The inclusion of the Conservation Value metric helps to identify areas that may benefit from adaptation action across a range of broad actions but also prioritise this action based on conservation designation requirements. The GIS data can be interrogated to show the habitats present in each square and, in the case of this assessment which includes all priority habitats, show which priority habitat is giving the overall score for the cell.

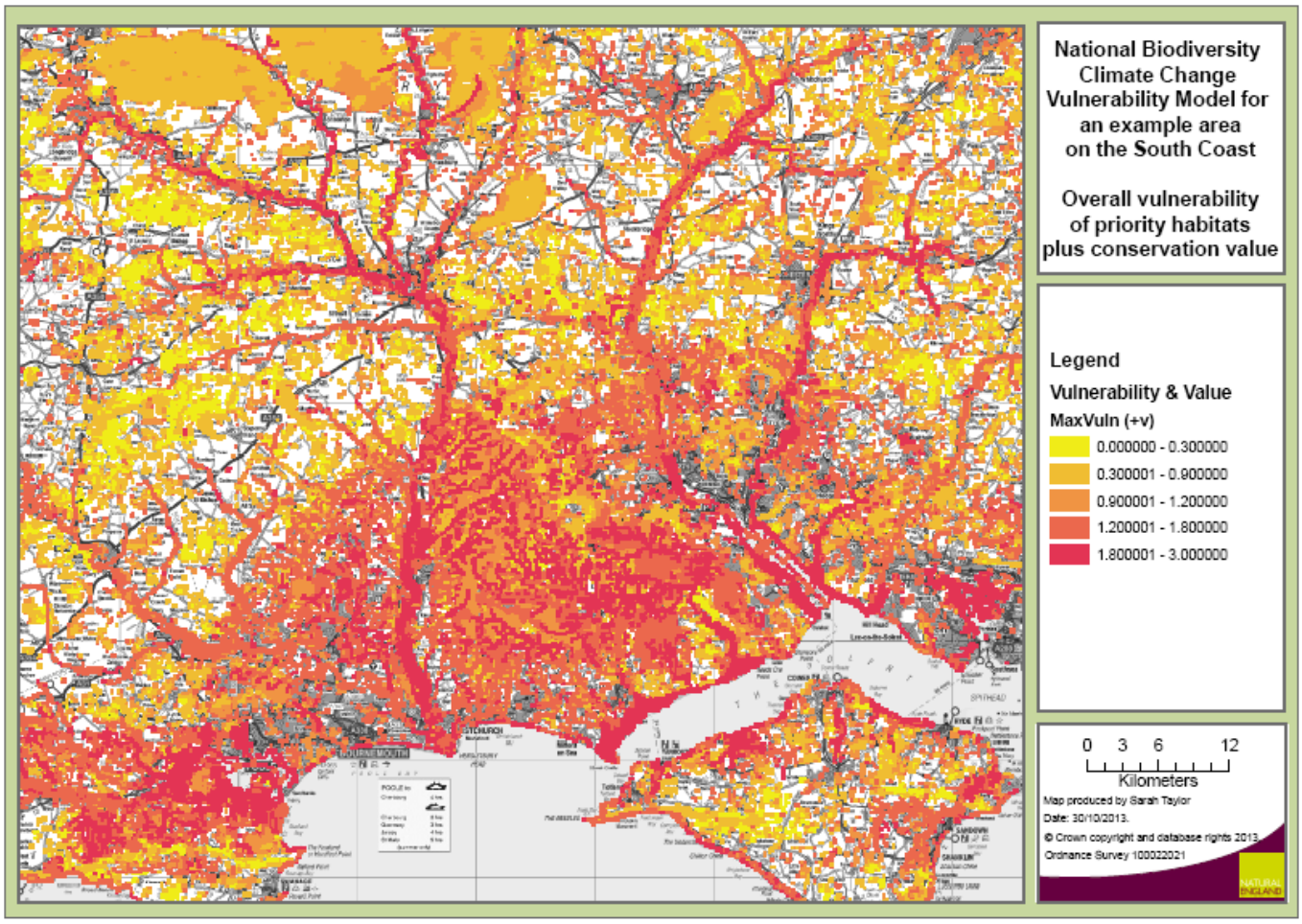


Figure 19 A map showing the Overall Vulnerability plus the Conservation Value metric assessment results for an area on the South Coast of England

5 Discussion

Users, products and uses

Audience

5.1 The potential users of the national biodiversity climate change vulnerability model are varied. It is envisaged that the outputs of the model will be an invaluable tool for Natural England staff to demonstrate climate change vulnerability at strategic and local levels. For example, Natural England staff may use the model outputs as part of the evidence base for deciding national scale strategic planning in a number of projects, such as targeting agri-environment schemes. Our staff may also use the model at a more local scale, for example, as part of the evidence base used to advise on local decisions on spatial planning.

5.2 We will work closely with our partners, such as the Environment Agency, the Forestry Commission and the RSPB, to provide products that are useful to their work. We will also work to provide evidence and information to partnerships and landscape scale projects, such as Nature Improvement Areas (NIAs).

Trialling with partners

5.3 We conducted a series of trials to test the usefulness of the model for our partners. In these trials preliminary datasets and draft documentation were provided to partners and feedback sought. The trialling period has enabled us to raise awareness of the existence of the NBCCVM, to carry out work to amend the products to better suit our partners, and to enhance the functionality of the NBCCV Assessment Tool. We carried out this trialling in both formal and informal ways.

Trialling with Nature Improvement Areas

5.4 A formal approach to testing was through the Adaptation to Climate Change in Nature Improvement Areas project (van Dijk *et al*., 2013), through which we tested ways of delivering climate change adaptation advice for practitioners and evaluated the effectiveness of our information and tools with NIAs. This included trialling the use of the NBCCV Assessment. The project was funded by Defra and the steering group consisted of Natural England, the Environment Agency, the Forestry Commission and Defra.

5.5 The feedback was positive and constructive and provided potential uses and improvements that have been incorporated, where appropriate, in to the final version of the NBCCV Assessment Tool and documentation. For example, feedback was received and implemented regarding the approach to the Land Cover Matrix sub-metric, the use of local or substitute datasets, the need to update products when new national data is available and the inclusion of a limitations section in user documentation.

5.6 Much feedback on the use of national datasets within the NBCCV Assessment was received. This is due to the inaccuracies often inherent within national scale data. This issue can be overcome by using local data to re-run the assessment using the NBCCV Assessment Tool at a local scale where possible. This, of course, comes with its own challenges, as the partners need a GIS capability if they are to run it themselves and they need to have a process to determine appropriate input or classification changes, for example, an expert workshop.

5.7 The full write up of the NIA climate change adaptation project can be found in the report (Natural England, 2013).

Trialling with Local Authorities

5.8 We also carried out a less formal trial with a small group of Local Authorities. The focus of this trial was to gather some specific input from Local Authorities on the NBCCVM, and, more importantly, on the range of uses they might have for the data, with a specific focus on green infrastructure strategy production.

5.9 Again, the feedback was positive and constructive, with many of the council representatives envisaging the data from the model being useful in a range of ways, including contributing to the evidence base for spatial planning documents, such as green infrastructure strategies, and contributing to the wide range of natural environment projects Local Authorities are involved in, for example, through their Local Nature Partnerships.

5.10 Some of the constructive feedback from Local Authorities reflects similar themes to that received from the NIAs and as such are addressed through the same actions. Communication on the use of the model with Local Authorities is ongoing and will continue to contribute to the creation of partner focussed products and collaborative work with Local Authorities on the natural environment.

Strengths and limitations

5.11 The following strengths of the model have been identified through the trialling period:

- It provides additional, objective evidence that can strengthen the support for decisions.
- As the model exists at a national scale, is based on established principles and uses nationally verified data, this gives credibility to the outputs (for some, the use of national data was a weakness as they felt that national habitat inventories did not represent their area accurately, see the below limitations).
- The ability to alter the model, by tweaking metrics or using local datasets, to suit local requirements and conditions was seen as an advantage.
- The broad range of datasets included in the model was recognised as a strength (there were suggestions for other data which could be used, see the below limitations).
- The quality of visual outputs, ie. maps) was seen as a particular strength of the model and many of the trial partners felt that they would like to share the outputs with other partners.

5.12 The following limitations of the model were identified through the trialling period:

- The main barrier to using the NBCCVM identified through trialling is the quality of datasets. This includes concerns about: the accuracy of national scale habitat data; the availability of desirable datasets; and, as highlighted at the Meres and Mosses of the Marches NIA, cross boundary issues (the NIA boundary crosses the Wales-England border). However these concerns can be addressed by using more accurate local datasets to run the model.
- The use of priority habitats as a focus makes sense for many partners, but it does not for all. In urban areas where there is little priority habitat it may be less useful than in areas where there is greater priority habitat coverage. In these areas, other habitats such as parks and gardens can be of high importance, and these habitats could also be vulnerable to the impacts of climate change. As with other data issues raised, this limitation can be overcome at a local level if GIS data on urban green infrastructure exists. Consideration as to whether the overall approach used by the model applies to these land use types (for example, if the Habitat Fragmentation metric would apply in the same way) would be needed. If the approach is deemed to be applicable, local decisions would need to be made for some of the parameters, for example, the relative sensitivity classifications for these different habitat types.
- Some partners expressed differences of opinion on the classifications within the model. For example, the Dark Peak NIA partnership were concerned that blanket bog habitat did not

show up as highly vulnerable. They were concerned that there was a risk that using the model with metrics and data set nationally will result in maps which challenge local conservation priorities and potentially undermine local efforts. It is possible to address these concerns by re-running the model with local data; changing classifications within metrics such as Sensitivity to Climate Change or Management and Condition to better reflect local conditions, and using single habitat relative vulnerability outputs. However, any changes in the parameters would have to be justified and based on current local evidence. We will periodically conduct our own national review of all habitats to ensure we take any new evidence available within the classifications in to account. In the case of Blanket Bog evidence provided by Natural England's Upland Evidence Review and the Adaptation Sub-Committee report, 'Managing the land in a changing climate' (2013) would be used to provide up-to-date evidence on which to base classifications within the assessment.

Links to other work

5.13 The '**Making Space for Nature**' review (Lawton, *et al*., 2010) concluded that England does not currently have a coherent ecological network and suggests a number of approaches to address this. The NBCCV Assessment can provide spatial representations of where we might think about prioritising action on the Lawton 'principles' of 'bigger, better and joined' in the following ways.

5.14 **Better** management – we can use the NBCCV Assessment to help prioritise action on managing habitats to reduce current sources of harm and increase resilience to climate change. An example of how we could do this would be to highlight the squares within the NBCCV Assessment that do not currently meet the habitat condition criteria but score well on the Habitat Aggregation sub-metric of the Habitat Fragmentation metric. This would identify the squares that are in large habitat patches but that lack management, and might lead to a prioritisation of management action, at first, in the larger habitat patches.

5.15 **Bigger** areas of habitat – the NBCCV Assessment can help highlight priorities for increasing habitat size. A suggestion as to how this can be done is to identify squares that score poorly in the Habitat Aggregation sub-metric (small single habitat 'patches') but score well in the Land Cover Matrix sub-metric (good 'permeability' in the surrounding landscape) to identify where habitat could be expanded. The Topographic Heterogeneity metric could also be used here to identify areas that also have a good range of topography.

5.16 More **joined** up networks – the NBCCV Assessment can help to identify priorities for joining up fragmented habitats by identifying squares that are currently scoring poorly for Land Cover Matrix, suggesting that measures to increase landscape permeability could be put in place in these squares and their surrounding areas. Again, the Topographic Heterogeneity metric could also be used here to identify areas that also have a good range of topography.

5.17 The Conservation Value metric could be also used to create a two-tier prioritisation, by differentiating between designated and non-designated habitat.

5.18 The parameters for including grid squares in the above prioritisation exercises can be set locally. In other words, the decision on which squares you include in any prioritisation exercise is subjective and can be changed depending on how many squares you want to include, or could be set by a local or project specific methodology. This would require thought to be given to what threshold is set for the inclusion of squares. The example maps below have used thresholds of 50% or 30% (half or a third) of the relevant scores to provide illustrative examples of how you might highlight squares where action could be taken on Lawton priorities. See Figures 20, 21 and 22 below for explanations.

5.19 The map in Figure 20 highlights the 200m grid squares that contain habitat that doesn't meet the Management and Condition metric criteria and that score within the best half of the scores for the Habitat Aggregation sub-metric. This highlights the squares that are relatively large same habitat 'patches' but lack some form of management or condition.

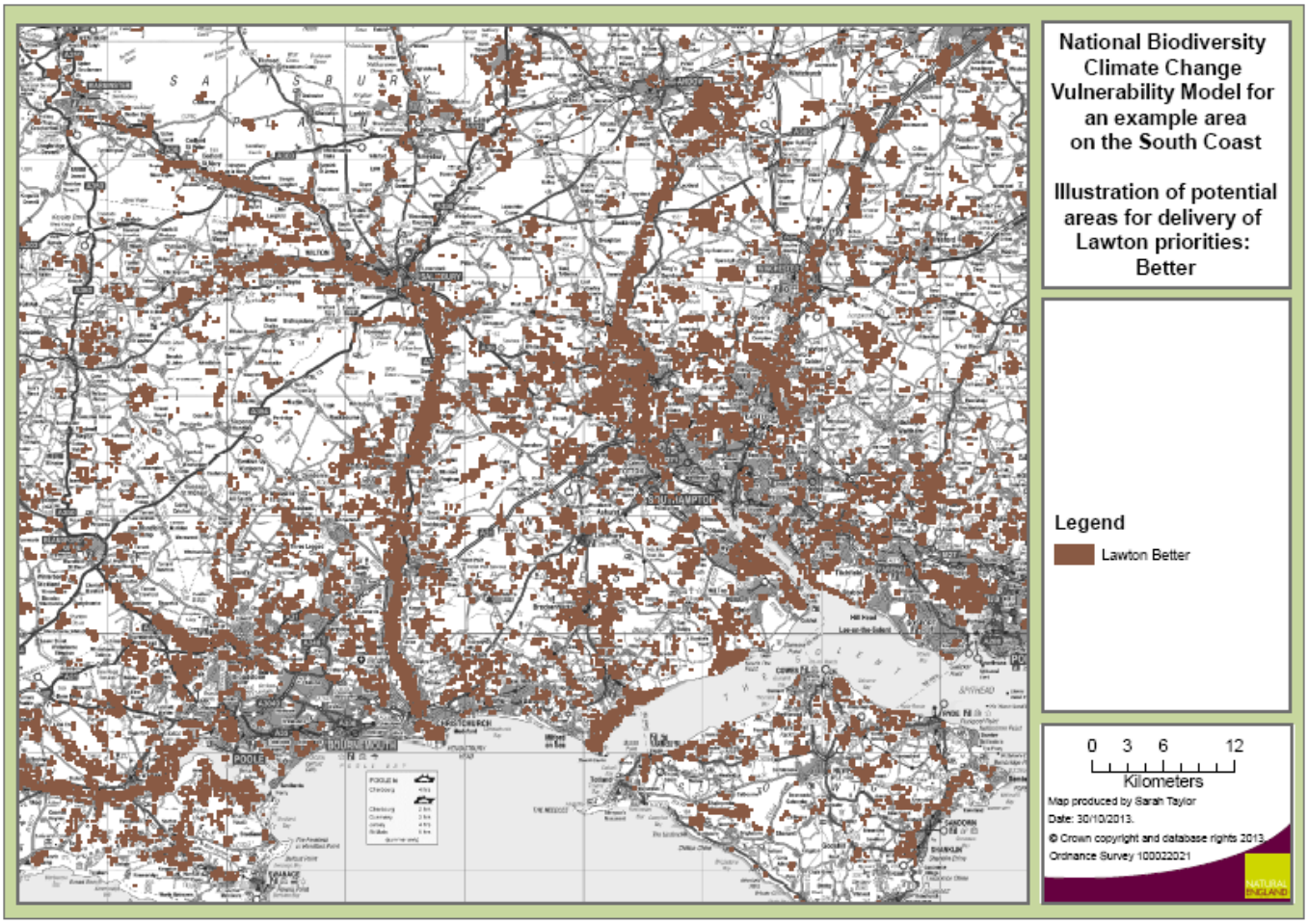


Figure 20 NBCCV Assessment data used to provide an illustration of potential areas for delivery of the Lawton review priority Better

5.20 The map in Figure 21 highlights the 200m grid squares that contain habitat that scores within the worst third of scores for the Habitat Aggregation sub-metric but the best half of scores for both the Land Cover Matrix Aspect Variance and the Land Cover Matrix Height Variance sub-metrics. This highlights the squares that are relatively small same habitat 'patches' within a relatively 'permeable' Land Cover Matrix that exists over a good range of topographic variation. The Conservation Value metric could also be used to further prioritise within an area. The other data displayed here (the green patches) are examples of biodiversity opportunity mapping for the South East and South West of England. This provides an example of other data that can be used to further prioritise areas for resilience building.

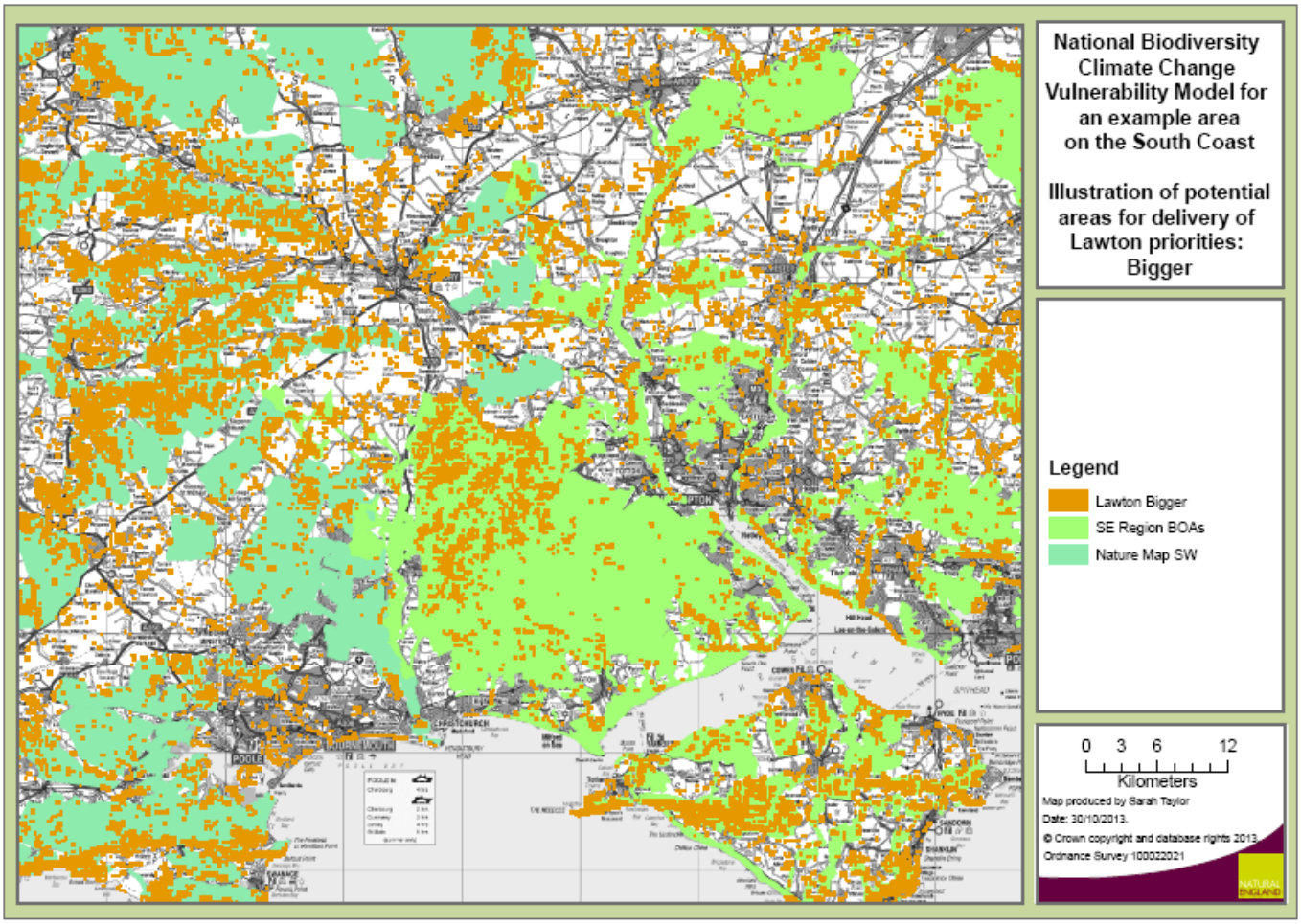


Figure 21 NBCCV Assessment data used to provide an illustration of potential areas for delivery of the Lawton review priority Bigger

5.21 The map in Figure 22 highlights the 200m grid squares that contain habitat that scores within the worst half of scores for the Land Cover Matrix sub-metric. This highlights the squares that exist within a relatively 'impermeable' Land Cover Matrix, suggesting that actions could be carried out to increase the connectivity across the Land Cover Matrix. Topographic Heterogeneity and Conservation Value could also be used to highlight these attributes within an area. Again, biodiversity opportunity mapping is shown as an example of other data that can be used to further prioritise areas for resilience building.

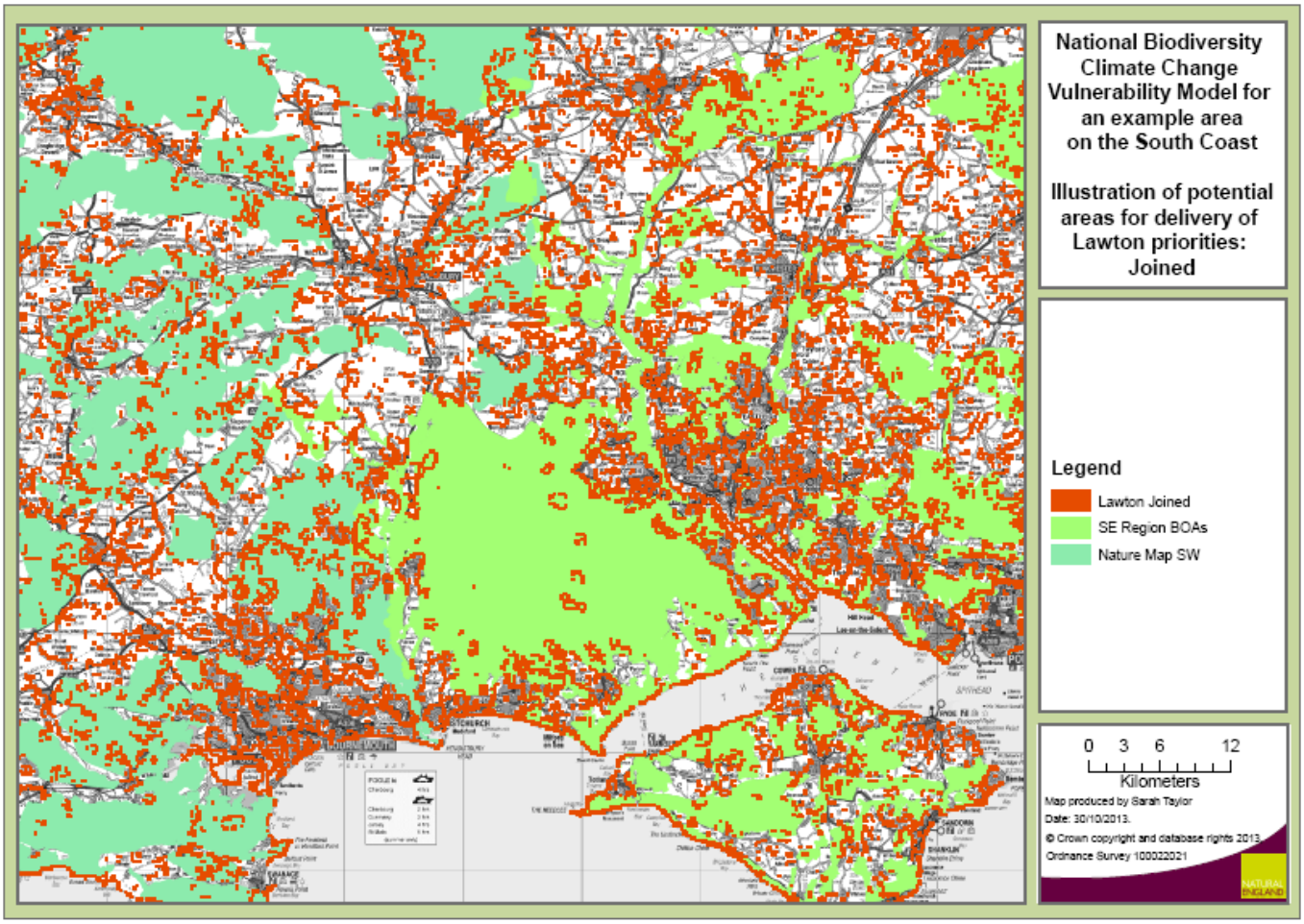


Figure 22 NBCCV Assessment data used to provide an illustration of potential areas for delivery of the Lawton review priority Joined

5.22 These outputs can be used to highlight areas for further consideration by conservation planners and practitioners using their own local knowledge to interpret the results. Local knowledge and experience is vital to compliment the NBCCV Assessment outputs and assess the areas for the opportunities and practicalities of carrying out conservation action to enhance habitat resilience in these areas.

5.23 The NBCCV Assessment Tool is also capable of trialling adaptation action scenarios. These scenarios may be based on actual opportunities on the ground or can explore the range of potential opportunities and help to evaluate the best options for a given location. See the section 'Potential of the tool' below for more information.

5.24 The NBCCVM is relevant to other climate change adaptation programmes. It forms part of the Land Use function's actions, identified in Natural England's **climate change risk assessment**, and will contribute to a range of different actions by Natural England to address climate change adaptation actions.

5.25 It is also included as part of Natural England's actions in the National Adaptation Programme (NAP), which is the government's response to the **UK Climate Change Risk Assessment** (HM Government, 2012 and 2013).

Use ideas and case studies

5.26 The model outputs are designed to be an addition to the current evidence base. To be used alongside the wealth of local data, knowledge and experience already being used to make

decisions. For example, this data can be used alongside other targeting approaches, such as biodiversity opportunity mapping [as illustrated above] to further prioritise action and enhance decision making.

5.27 As an example of how Natural England may use the model, we highlighted the vulnerability assessment results for grid squares within the South East England Biodiversity Forum's **Biodiversity Opportunity Areas** that have either high or medium scores for Habitat Fragmentation or low Management and Condition metric scores (see Figures 21 and 22 above). This identified areas that are vulnerable to climate change but where there is potential to implement adaptation action for increasing habitat management or connectivity. Using the Biodiversity Opportunity Areas highlights where the greatest potential opportunities for action exist. This illustrates a way in which two parts of the evidence base used for targeting action can be brought together. There will be many more ways in which data can be integrated like this. The examples below show some of the ideas and intentions that have come from the partner trialling period.

Case studies of uses of the NBCCV Assessment to date

Northern Devon NIA – the model is being used alongside other models and tools to develop an ecological network map. The NBCCVM structure is being used with local data sets to add greater resolution and assist in developing locally specific habitat networks. A network map is seen as key advocacy aid but the objective is to develop a decision support tool which assists with longer term targeting. The partners have found it useful to use the NBCCVM in combination with data from other sources by overlaying GIS layers with climate change vulnerability information.

The Adaptation Sub Committee (ASC) – The ASC produces annual progress reports to assess the main risks identified by the **UK Climate Change Risk Assessment**. The ASC have used the NBCCV Assessment data within their **report** to assess the preparedness of England's natural resources and ecosystems to adapt to climate change. The report used indicators to identify where England's natural resources and ecosystems are particularly vulnerable to climate impacts, both now and in the future. The NBCCV Assessment data was used in the indicators assessing biodiversity resilience.

Defra Synergies Project – The data has been incorporated in to the suggested approach to prioritise areas for multiple benefits from agri-environment schemes and water management options for WFD priorities across three themes – biodiversity, water and historic environment.

Potential uses suggested by partners

Informing high level conservation strategy – The model cannot make decisions about conservation strategy but it can be used to inform these decisions and provide an evidence base. For example, it could inform approaches to conservation resource allocation.

Prompting discussions at local level about climate change vulnerability and adaptation benefits - the model outputs could be used to prompt discussions about difficult strategy decisions and the effects of climate change on the natural environment. For example, Local Nature Partnerships (LNPs) could use the data to open up discussions with Local Economic Partnerships (LEPs) about the potential benefits of adaptation in terms of ecosystem service delivery. Model outputs could also be used to raise awareness among elected members.

Assessing the vulnerability of NIA objectives and other plans to the impacts of climate change - The model could be used to screen conservation plans to investigate the vulnerability of outcomes to the impacts of climate change.

Planning the next stage of the NIA project – Model outputs could be used to develop plans for the next stage of the NIA initiative or its successors. NIAs represent longer term partnerships and initiatives that expect to continue conservation work in the area in the longer term. The model will provide information about the relative vulnerability of habitats within NIAs which can be used to inform future plans and set longer term conservation strategy for the area.

Spatial identification and **prioritisation of areas for habitat creation** – The model can be used to prioritise areas for habitat creation and develop spatial adaptation plans. Single habitat vulnerability results can be used to investigate the relative vulnerability of habitats, which can then be used to inform adaptation plans and to direct effort.

The data can be **overlaid with opportunity maps** to help identify priority areas for habitat creation. By overlaying the two sets of data, vulnerability and opportunity can be viewed together to target effort in areas where it is likely to be most successful.

Scenario testing – The model could be used to investigate the effect of potential actions on vulnerability of habitats. 'Synthetic data' sets can be run through the model to test the impact of potential actions on habitats. Actions might include possible adaptation strategies (for example, buffering protected sites, linking up patches), in which case the model could be used to assess the extent to which the potential actions reduce habitat vulnerability.

Spatially target agri-environment agreements – The model could be used to target agri-environment agreements to areas of high vulnerability, or could be used to tailor agreements to include measures beneficial to adaptation for specific habitats.

Evidence base for planning – A number of potential uses for the model in a planning context have been suggested. These include informing the development of planning strategy, and contributing to the evidence base for policy making.

Justification of existing projects and actions – The model can be used to provide additional justification of existing projects and actions by demonstrating their value in terms of improving resilience to the impacts of climate change.

Monitoring and evaluation – It may be possible to use the model to monitor change in an area, for example, an NIA, as a result of action taken. Specific elements of the model could be used. For example, it may be possible to use the Habitat Fragmentation metric to provide an indicator of habitat connectivity before and after the NIA initiative, as required by Defra in the NIA monitoring and evaluation framework.

Supporting funding applications – Many funding applications now require projects to demonstrate how they will contribute to climate change adaptation. The model can be used as part of the evidence base for applications, to demonstrate the need for the project and show how the project could have adaptation benefits.

Requirements for use – GIS capacity

5.28 Many of the uses suggested by the partners involve tailoring the model outputs, either changes to the metrics or the use of local datasets. The NBCCV Assessment Tool enables users to make changes to the metrics and the underlying datasets, where the appropriate expertise exists. However, making these changes locally will require a degree of GIS expertise and resource.

5.29 Specific maps and model alterations identified by NIA partners at workshops and through the survey include single habitat vulnerability model results, local area relative vulnerability results cut to local area or project boundaries, changes to some metrics including Sensitivity to Climate Change and Management and Condition, use of local datasets and overlaying other datasets within GIS. Some partners possess the GIS capabilities to carry this out themselves. Natural England will continue communications with partners as to how this might be supported, for example, through new projects and partnerships.

Potential of the tool

5.30 The NBCCV Assessment Tool has been designed to maximise functionality and flexibility and can produce a range of outputs. The following are examples of this flexibility:

- **Changes to the weighting of metrics** – the model, as presented in this document, has been set to weight the contributing metrics equally. However, the weightings for the metrics and sub-metrics can be changed. The equal weighting was chosen as we do not feel, given current evidence, that one metric is more or less important with regard to vulnerability. When we have evidence that any of the metrics provide a greater contribution to a habitat's vulnerability than others we can increase the weight of that metric when contributing to the Overall Vulnerability score.
- **Use of other data** – some of the national datasets used in the examples shown here have limitations – as identified in partner feedback. Partners that have more accurate local habitat data, or data on other habitats not currently included in the model results, can use those datasets in place of the national habitat inventories displayed in the examples in this document. Local data can also be used in the other metrics. For example, in the Management and Condition metric alternative management data could be used to express the current condition of habitats in an area based on local conditions. If other data was substituted the local partners would have to carry out exercises to assign appropriate classifications to use within the metrics affected.
- **Changes to metric classifications** – as mentioned above, the classifications within some of the metrics can be changed. This could be in response to new evidence available at a national level, if changes to input data are made, or if local partners have evidence to support a change in classification for a habitat due to specific local conditions. For example, the sensitivity classifications could be changed as we gather more evidence on impacts from climate change. The Management and Condition and Conservation Value metrics also have classifications that can be changed.
- **Carry out local scale model runs and single or grouped habitat runs** – as mentioned above, local partners may want to use their own local datasets to carry out a local scale run of the model, producing local relative vulnerability scores. The examples shown in this document from the NBCCVM are the 'all habitats' results, where all priority habitats are included in the grid and where, if a grid square has more than one habitat within it, the habitat with the highest Overall Vulnerability score provides the score for that square. In many projects it will be useful to see the range of metrics and Overall Vulnerability results for individual habitats or groupings of habitats.
- **Different metric combinations** – the Overall Vulnerability result is an example of a result produced by combining all metric scores weighted equally. The metrics and sub-metrics can be brought together in any combination and using any weighting required to produce other combination results.

5.31 All of the above amendments would require users to carry out exercises to provide the justification and evidence to support any changes.

5.32 Another potential application of the NBCCV Assessment Tool would be in the costing of climate change adaptation action plans and comparative cost benefit analysis of alternative adaptation strategies. For example, if an NIA wished to target action to increase the resilience of 50% of the most vulnerable patches of chalk grassland, the model could be used to map where improved management or habitat creation could be best applied to achieve this and then, by applying known costs of management options, the most cost effective strategy to meet targets could be identified.

Possible extensions to the model

5.33 There is a range of potential future work that could be carried out to further develop the model. A few ideas are presented here.

5.34 Many factors were considered for inclusion in the adaptive capacity metrics of the model (fragmentation, topographic variety and habitat condition). It felt particularly intuitive that where disturbance and development pressure is a source of harm to habitats, the further the habitat is from urban areas the less disturbed or impacted it would be. There are specific examples of where increased pressure from new developments near to SSSIs or Natura 2000 sites have led

to the need for compensation from the developers to spread the access pressure (for example, the Thames Basin Heaths). This suggests that greater populations nearby lead to greater pressure on a site. Proximity to an urban area was, therefore, considered for inclusion in the Habitat Condition metric. For example, if the habitat was over 1km from an urban area it would be mitigated from disturbance. However, it was not fully supported in the process used to identify sources of harm and their mitigation. There was no generalisation that could be made, in fact some experts made the point that habitats close to communities can be highly valued and, therefore, well protected and managed. However, this discussion shows that there may be other metrics that could be brought in to the model in the future.

5.35 The vulnerability model currently focuses on terrestrial and coastal habitats. The potential exists to use the model framework, or adapt it, to cover other sectors such as: the vulnerability of ecosystem services; natural environment access and recreation assets; geology and soils; and expansions on the area of coastal vulnerability. This would need significant further work, but the framework of the model may provide a useful starting point.

5.36 Further automation of the model could also be carried out. For example, there is the potential to score the grid squares that currently don't contain priority habitat to identify which squares would be best for prioritising habitat creation. Another idea would be to create a web based user interface to increase user accessibility and remove the reliance on GIS software and expertise.

5.37 Finally, the model only covers England. A future development would be the expansion of the model area across the rest of the UK.

The NBCCVM in context

5.38 The NBCCV Assessment can be used alongside a range of other Natural England tools and information available to assist our staff and our partners in considering the impacts of climate change. For example the **Landscape scale climate change adaptation methodology** (aka the NCA approach) and the Natural England Adaptation Manual.

5.39 The socio-economic and indirect impacts of climate change have not been addressed through this work, but would need to be taken in to account when planning adaptation action, for example, the possibility of unsustainable engineering responses to climate change or changes in agriculture. Growth and land use change in response to climate change and other factors, such as agricultural markets, will be important considerations and may be responsible for greater impacts on the natural environment than direct impacts from climate change (Smithers *et al*., 2008). We need to continue the debate with partners to identify where potential long-term changes in future land use and demand for natural resources increase the vulnerability of the natural environment to climate change, taking account of national and local futures scenarios and land use strategies.

5.40 Delivering measures to assist the natural environment to adapt to climate change will have wider benefits for society both in terms of general functions and services and adaptation. For example, green infrastructure and ecosystem services provide society with many essential functions now, which will become ever more important as the climate changes. Many of the measures to create and enhance habitats will have knock on benefits for society such as; flood protection, climate regulation, carbon sequestration, and tourism and recreation benefits. These issues should be included in discussions when planning adaptation action.

5.41 In order to build resilience and accommodate changes associated with climate change, Natural England will take specific actions and work with our partners as a response to our Climate Change Risk Assessment (Natural England 2011) and the National Adaptation Plan (HM Government 2013). The National Biodiversity Climate Change Vulnerability Assessment will form part of that response.

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7 Glossary

The definitions in this glossary are taken from the National Adaptation Programme (HM Government 2013), Managing the land in a changing climate (Adaptation Sub-Committee 2013), Climate adaptation: risk, uncertainty and decision making (Willows and Connell (2003) the UKCIP Glossary and the IPCC (Parry *et al*., 2007).

Adaptation – a change in natural or human systems in response to the impacts of climate change. These changes moderate harm or exploit beneficial opportunities and can be in response to actual or expected impacts.

Adaptive capacity – the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, ie. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions.

Climate and microclimate – climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO). Microclimate is the local climate at or near the Earth's surface (this is from IPCC).

Climate change scenario – is a plausible description of the change in climate by a certain time in the future. These scenarios are developed using models of the Earth's climate. Climate models and are based upon scientific understanding of the way that the land, ocean and atmosphere interact and their responses to factors that can influence climate in the future, such as greenhouse gas emissions.

Climate variables – these are surface variables such as temperature, precipitation, and wind.

Landscape scale conservation – a term commonly used to refer to action that covers a large spatial scale, usually addressing a range of ecosystem processes, conservation objectives and land uses.

Resilience – describes the ability of a social or ecological system to absorb disturbances while retaining the same basic ways of functioning, and a capacity to adapt to stress and change.

Sensitivity – the degree to which a system is affected, either adversely or beneficially, by climate variability or change.

Uncertainty – situation where the current state of knowledge is such that (1) the order or nature of things is unknown, (2) the consequences, extent, or magnitude of circumstances, conditions, or events is unpredictable, and (3) credible probabilities to possible outcomes cannot be assigned.

Vulnerability – the degree to which an individual or a system is susceptible to adverse effects. In this context, the adverse effects of climate change, including extreme events. Vulnerability is influenced by the system's sensitivity and its adaptive capacity, as well as the magnitude of the change.

Appendix 1 Input datasets

Habitat data

The primary source of data for the priority habitats which were the focus of the NBCCVM was Natural England's Priority Habitats Inventory for England. For some habitats – lakes, rivers, coastal and floodplain grazing marsh and lowland meadows – other datasets were used to substitute or supplement the inventory, as detailed below.

Table A Habitat data

Habitat	Abbreviation used in the GIS data	Dataset description
Blanket bog	BLB	Natural England priority habitat inventory
Coastal grazing marsh	CGM	Based on the Natural England priority habitat inventory for Coastal and Floodplain Grazing Marsh - polygons with overlap with Environment Agency tidal flood zone 3 were used to identify coastal grazing marsh.
Coastal saltmarsh	SM	Natural England priority habitat inventory
Coastal sand dunes	CSD	Natural England priority habitat inventory
Coastal vegetated shingle	CVS	Natural England priority habitat inventory
Deciduous woodland	DW	Natural England broad habitat inventory (individual priority habitat woodland inventories do not exist)
Floodplain grazing marsh	FGM	Based on Natural England priority habitat inventory for Coastal and Floodplain Grazing Marsh - polygons with overlap with Environment Agency tidal flood zone 3 were used to exclude coastal grazing marsh.
Lakes	WAT	Water Framework Directive - Lake Waterbodies (waterbodies with good ecological status used as a proxy for priority habitat) provided by the Environment Agency **www.geostore.com/environment-agency/WebStore?xml=environment-agency/xml/ogcDataDownload.xml**
Limestone pavements	LP	Natural England priority habitat inventory
Lowland calcareous grassland	LCG	Natural England priority habitat inventory
Lowland dry acid grassland	LDA	Natural England priority habitat inventory
Lowland fens	LF	Natural England priority habitat inventory
Lowland heathland	LHT	Natural England priority habitat inventory

Table continued…

Habitat	Abbreviation used in the GIS data	Dataset description
Lowland meadows – dry	LMD	Based on Natural England priority habitat inventory for Lowland Meadows – dry meadows identified by excluding Environment Agency Flood zone 2.
Lowland meadows – wet	LMW	Based on Natural England priority habitat inventory for Lowland Meadows – wet meadows extracted using Environment Agency Flood zone 2.
Lowland raised bogs	LRB	Natural England priority habitat inventory
Maritime cliffs and slope	MCS	Natural England priority habitat inventory
Montane	MHW	Natural England priority habitat inventory for Mountain Heath & Willow Scrub habitat dataset (July 2012).
Mudflats	MDF	Natural England priority habitat inventory
Purple moor grass and rush pasture	PMG	Natural England priority habitat inventory
Reedbeds	RDB	Natural England priority habitat inventory
Rivers	RIV	Extracted from Environment Agency Detailed River Network using lookup from JNCC.
Saline lagoons	SLG	Natural England priority habitat inventory
Upland calcareous grassland	UCG	Natural England priority habitat inventory
Upland hay meadows	UHM	Natural England priority habitat inventory
Upland heathland	UHT	Natural England priority habitat inventory
Upland fens and flushes	UFF	Natural England priority habitat inventory
Food zone data		Environment Agency Flood zone 2 data used to differentiate coastal and floodplain grazing marsh and wet and dry lowland meadows.

The Land Cover Matrix

The Land Cover Matrix is used in the model to represent the nature of land cover in the landscape surrounding cells containing priority habitat. For the NBCCVA the following datasets were combined to produce a single grid layer mapping the presence of semi–natural land cover. The Land Cover Map 2007 land cover classes are not used separately within the assessment, they form one dataset which contains all land cover classes selected for use in the Land Cover Matrix metric.

Table B Land Cover Matrix data

Dataset	Abbreviation used in the GIS data	Description
Priority habitats		See above table
Acid grassland	LCM	Land Cover Map 2007 Land Cover Class
Bog	LCM	Land Cover Map 2007 Land Cover Class
Broadleaved woodland	LCM	Land Cover Map 2007 Land Cover Class
Calcareous grassland	LCM	Land Cover Map 2007 Land Cover Class
Fen, marsh and swamp	LCM	Land Cover Map 2007 Land Cover Class
Freshwater	LCM	Land Cover Map 2007 Land Cover Class
Heather	LCM	Land Cover Map 2007 Land Cover Class
Heather grassland	LCM	Land Cover Map 2007 Land Cover Class
Inland rock	LCM	Land Cover Map 2007 Land Cover Class
Littoral rock	LCM	Land Cover Map 2007 Land Cover Class
Littoral sediment	LCM	Land Cover Map 2007 Land Cover Class
Montane habitats	LCM	Land Cover Map 2007 Land Cover Class
Neutral grassland	LCM	Land Cover Map 2007 Land Cover Class
Rough grassland	LCM	Land Cover Map 2007 Land Cover Class
Saltmarsh	LCM	Land Cover Map 2007 Land Cover Class
Supralittoral rock	LCM	Land Cover Map 2007 Land Cover Class
Supralittoral sediment	LCM	Land Cover Map 2007 Land Cover Class
Countryside Stewardship Scheme Beneficial Options Data	AGR	Agri-environment options that are beneficial for biodiversity identified initially to form part of the previous National Indicator 197 reporting and now updated annually. Only live agreements including Countryside Stewardship, Environmental Stewardship and Environmentally Sensitive Areas schemes included.
Traditional orchards	TOR	Natural England Traditional Orchards Priority Habitats Inventory dataset.
Major roads	RD	An extract from the Ordnance Survey Open Data Meridian 2 dataset of Motorways and dual carriageways.

Each dataset was converted to a presence/absence grid.

Cells that contained major roads were excluded from the Land Cover Map 2007 presence grids.

The individual grids were combined to form the Land Cover Matrix grid in which presence of semi-natural land cover was indicated by a value of 1 and its absence by a value of 0.

The NBCCV Assessment Tool allows the user to choose the datasets combined to form the Land Cover Matrix. In this way it is possible to create a matrix tailored to reflect the dispersal characteristics of particular species or groups of species in order to reflect the relative permeability of the landscape surrounding a cell.

Terrain data

Terrain data in the form of a digital elevation model was used in the NBCCVM to allow the analysis of both height and aspect variance within habitats and the surrounding landscape.

Table C Terrain data

Dataset	Description
NextMap Digital Terrain Model	Bare-earth elevation raster dataset for England with a cell size of 5m and a vertical precision of 1cm, provided by Natural England

An aspect grid was generated from the NextMap dataset using the ArcGIS Spatial Analyst. The aspect grid had data values representing each cell's aspect in degrees clockwise from North.

To reduce the effect of the very high vertical precision 'noise' on aspect calculations the data was rounded to 1m vertical precision prior to further processing.

Condition and Management data

Additional datasets reflecting Management and Condition of habitats were used to indicate the degree to which their adaptive capacity may be affected by sources of harm other than climate change.

Table D Management and Condition data

Dataset	Abbreviation used in the GIS data	Description
Sites of Special Scientific Interest (SSSI) unit condition	UNTN2K	Condition status of Sites of Special Scientific Interest by unit using only site units in 'Favourable' or 'Unfavourable Recovering' condition. Data provided by Natural England.
Woodland Grant Schemes	WGS	English Woodland Grant Scheme data from the Forestry Commission.
Countryside Stewardship Scheme Beneficial Options	AGR	Agri-environment options that are beneficial for biodiversity identified initially to form part of the previous National Indicator 197 reporting and now updated annually. Only live agreements including Countryside Stewardship, Environmental Stewardship and Environmentally Sensitive Areas schemes included.
Catchment Abstraction Management Strategy	CAM	Water availability data provided from the Environment Agency Catchment Abstraction Management Strategies, all Water Resource Management Units with a status of 'water available' were used to denote positive water availability.
Water Framework Directive (WFD) linear or lake water bodies	RWQ	Environment Agency Water Framework Directive linear or lake water bodies with an ecological status of 'Good' or 'High' were used to denote good water quality for terrestrial habitats.
Water Framework Directive (WFD) coastal or transitional water bodies	CWQ	Environment Agency Water Framework Directive coastal or transitional water bodies with an ecological status of 'Good' or 'High' were used to denote good water quality for coastal habitats.

Conservation Value data

Additional datasets reflecting the conservation status of habitats were used to indicate the Conservation Value of habitats and are used in the calculation of the Conservation Value metric.

Table E Conservation Value data

Dataset	Abbreviation used in the GIS data	Description
Sites of Special Scientific Interest (SSSI)	S3I	Presence of SSSIs in England, provided by Natural England.
Ancient Woodland Inventory	AWI	Presence of ancient woodlands in England, provided by the Forestry Commission.
Natura 2000 and Ramsar Sites	N2K	Presence of Special Areas of Conservation (SACs) and Special protection Areas (SPAs), collectively known as Natura 2000 sites, and Ramsar Wetland sites in England, provided by Natural England.

Appendix 2 Vector to raster area thresholds

Each priority habitat dataset was generalised to produce a set of binary presence/absence grids (habitat presence grids). This was done as follows:

- The area of overlap between the input polygons and the 200m x 200m cells of the model grid was calculated for each cell.
- The distribution of area overlap values was analysed for each habitat and used to set a lower cut off threshold.
- The top 80% of cells (based on their area overlap value) were given a value of 1 to indicate presence of that habitat.
- The bottom 20% of cells where the area overlap was very small received a value of 0 and hence were not included in the presence grid.
- As a result approximately the same proportion of the total area of each habitat was included.

The same process was used to generate similar presence/absence grids for the other input vector datasets used in the NBCCVM analysis apart from conservation designations where we used 100%.

Appendix 3 Assessment of sources of harm using SSSI condition reports, BARS reporting, literature and expert opinion

The following process was used to identify the indicators of management and condition for each priority habitat for use within the assessment:

1) Identify 1-3 most important sources of harm from SSSI condition reports, BARS reporting, literature and expert opinion.
2) Are they nationally significant? Y/N
3) Are they nationally widespread? Y/N
4) Are they mitigated or indicated by the management and condition factors identified?

Table F Assessment of sources of harm for habitats

Habitats	Source of harm (not including climate change linked harm, for example, coastal squeeze)	Is it significant? (affected unit area)	Is it widespread? (Mid, N, SE, SW)
Rivers and streams	Water pollution – agriculture/run off	>5300ha	all 4 regions
	Water pollution – discharge	>4000ha	all 4 regions
	Inappropriate weirs dams and other structures	>1900ha	all 4 regions
Acid grassland	Undergrazing	>1300ha	all 4 regions
	Inappropriate weed control	>600ha	3/4 regions
	Inappropriate scrub control	>500ha	all 4 regions
Broadleaved, mixed and Yew woodland	Forestry and woodland management	>20300ha	all 4 regions
	Undergrazing	>2100ha	all 4 regions
	Inappropriate scrub control	>3000ha	all 4 regions
Calcareous grassland	Undergrazing	>4900ha	all 4 regions
	Inappropriate scrub control	>4900ha	all 4 regions
	Overgrazing	500ha	all 4 regions
Dwarf shrub heath	Inappropriate scrub control	>10400ha	all 4 regions
	Undergrazing	>9300ha	all 4 regions
	Inappropriate cutting/mowing	>1400ha	3/4 regions
Fen, marsh and swamp – lowland	Inappropriate ditch management	>2000ha	all 4 regions
	Inappropriate scrub control	2700ha	all 4 regions
	Undergrazing	>1500ha	all 4 regions

Table continued…

Habitats	Source of harm (not including climate change linked harm, for example, coastal squeeze)	Is it significant? (affected unit area)	Is it widespread? (Mid, N, SE, SW)
Neutral grassland – lowland	Undergrazing	>4800ha	all 4 regions
	Inappropriate water levels	>5200ha	all 4 regions
	Inappropriate ditch management	>3200ha	all 4 regions
Standing open water and canals	Water pollution – agriculture/run off	>4800ha	all 4 regions
	Invasive freshwater species	>2500ha	all 4 regions
	Siltation	>690ha	all 4 regions
Supralittoral rock (cliff and slope)	Inappropriate scrub control	68ha	1/4 regions
	Undergrazing	63ha	1/4 regions
	Other	1640ha	3/4 regions
Supralittoral sediment (Dunes)	Inappropriate coastal management	>1200ha	3/4 regions
	Inappropriate weed control	>250ha	3/4 regions
	Military	>90ha	1/4 region
	Inappropriate scrub control	>2100ha	all 4 regions
	Agriculture – other	>70ha	2/4 regions
	Inappropriate cutting/mowing	>200ha	3/4 regions
	Public access/disturbance	>350ha	2/4 regions
	Coastal squeeze	>400ha	3/4 regions
Littoral rock	Coastal squeeze	>100ha	1/4 region
	Military	n	1/4 region
	Public access/disturbance	>350ha	1/4 region
Littoral sediment (salt marsh)	Coastal squeeze	>26000ha	all 4 regions
	Water pollution – agriculture/run off	>8000ha	3/4 regions
	Water pollution – discharge	>7000	2/4 regions
	Inappropriate coastal management	>4300	3/4 regions
	Inappropriate weirs dams and other structures	10ha	1/4 region
Fen, marsh and swamp – upland (upland fens and flushes)	Overgrazing	>299ha	3/4 regions
	Undergrazing	>160ha	3/4 regions
	Drainage	>160ha	3/4 regions

Table continued…

Habitats	Source of harm (not including climate change linked harm, for example, coastal squeeze)	Is it significant? (affected unit area)	Is it widespread? (Mid, N, SE, SW)
Upland acid grassland (upland hay meadow)	Overgrazing	>8100ha	3/4 regions
	Undergrazing	>540ha	3/4 regions
Bogs – upland (blanket bog)	Air pollution	>19000ha	2/4 regions
	Drainage	>28700ha	3/4 regions
	Ditch management	>10800ha	2/4 regions
	Moor burning	>52300ha	3/4 regions
	Overgrazing	>57600ha	3/4 regions
Upland calcareous grassland	Scrub control	>50ha	2/4 regions
	Weed control	>520ha	2/4 regions
	Overgrazing	>1800ha	1/4 region
	Undergrazing	>300ha	2/4 regions
Dwarf shrub heath – upland	CSS/ESA prescription	>7900ha	2/4 regions
	Scrub control	>1900ha	3/4 regions
	Weed control	>1500ha	3/4 regions
	Moor burning	>71000ha	3/4 regions
	Overgrazing	>47800ha	3/4 regions
Montane	CSS/ESA prescription	>100ha	1/4 region
	Overgrazing	>400ha	1/4 region
Neutral Grassland – upland (upland hay meadows)	Cutting/mowing	>280ha	2/4 regions
	Overgrazing	>80ha	2/4 regions
	Fertiliser use	>280ha	2/4 regions
	Undergrazing	>320ha	3/4 regions
Broadleaved mixed and yew woodland – upland	Deer grazing/browsing	>1300ha	3/4 regions
	Forestry and woodland management	>2250ha	3/4 regions
	Overgrazing	>2650ha	3/4 regions
Limestone pavement	Deer grazing/browsing	>100ha	1/4 region
	Forestry and woodland management	>130ha	1/4 region
	Overgrazing	>1300ha	1/4 region

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

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