Natural England Technical Information Note TIN095

A national climate change vulnerability assessment

This note sets out a methodology for evaluating the biophysical vulnerability of key biodiversity assets to climate change in England. The methodology has been used to evaluate the vulnerability of 10 different priority Biodiversity Action Plan (BAP) habitats that have been identified as being at risk from climate change. It has led to the creation of two new sources of geographical information that will significantly enhance the ability of Natural England to advise on climate change adaptation measures in a robust, spatially explicit manner. It will help to inform conservation management choices through the direct association that has been made between particular habitats and changes in specific, seasonal climate variables. In practical terms this might be used to review site management objectives for a protected area, to help target the creation of new habitat in areas where it is likely to remain viable in the future or to identify areas where increased surveillance of climate-mediated change may be necessary. This note contains some geographical metadata that will allow Natural England users to access information more readily through Geographical Information Systems (GIS).

Introduction

The definition of climate vulnerability used follows the conceptual framework that was laid out in the fourth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (Houghton, *et al*., 2001; McCarthy, *et al*., 2001). The report defines vulnerability in the following manner:

The degree to which a system is susceptible to, or 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity.

In general terms this definition provides an integrated measure of the expected magnitude of adverse effects on systems that might be caused by specific levels of external stress, ie climate change. It assumes that some systems will be more sensitive to change than others and that there are varying degrees of resilience to change inherent within these systems. The definition of adaptive capacity and sensitivity, especially in second generation vulnerability assessments, has increasingly included non-climatic factors relating to socio-economic and political factors (for example, Brooks, 2003). In this piece of work, however, adaptive capacity and sensitivity has been strictly limited to natural systems in order to make the analysis tractable and more easily understood.

The core aim of this work was to identify specific areas of landscape where there is:

- a high degree of exposure to climate change;
- a low adaptive capacity; and
- the presence of potentially sensitive habitats.

Adaptive capacity in this instance was defined through a biophysical assessment of landscape heterogeneity and permeability to species movement.

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Further detail on the different elements of the assessment will be provided in the following sections. The approach provides a nationally consistent, systematic framework through which further, more local, evaluations of the potential risks to critical natural capital can occur. It has been deliberately structured so that other sources of geographically explicit information can be readily incorporated by anyone who is able to use a geographical information system (GIS).

Methods

A one kilometre, grid-based method was used to analyse different sources of geographic information. The scale of the analysis was determined by a mixture of computational processing capacity and operational utility. A simple, un-weighted, additive model was used to integrate the three different elements of vulnerability, ie biophysical adaptive capacity; sensitivity of semi-natural habitats; and the degree of climate change exposure. Before this could be done, it was necessary to standardise the data so that it could be aggregated to give a single vulnerability score for each grid cell. No weighting of the different variables was undertaken as this can seldom be done in a repeatable, objective manner.

The standardisation method was based on dividing the distribution of grid cell scores into percentiles. A percentile is simply the rank of a particular value, in a dataset, on a percentage scale from 1 to 99. The 1st percentile represents the lowest value (minimum) and the 99th percentile represents the highest value (maximum). Percentiles are often divided into percentage intervals, for example,

- 4 classes = 25% intervals = quartiles;
- 5 classes = 20% intervals = quintiles; and
- 10 classes = 10% intervals = deciles, etc.

Consequently, a decile is any of the nine intervals that divide a dataset, sorted in ascending order, into ten equal parts based on the frequency of observations. Each part represents 1/10 of the sample. This means that: the 1st decile cuts off the lowest 10% of data (ie the 10th percentile); the 5th decile cuts off lowest 50% of data (ie the 50th percentile, 2nd quartile or median); and the 9th decile cuts off lowest 90% of data (ie the 90th percentile).

It is important to understand that these intervals are unequal and determined by the underlying frequency distribution of the data. This means that the deciles that are shown on a vulnerability map that uses the high emission scenario data will not contain the same range of observations as a map that uses the low emission scenario data.

Users of the data should be aware that it only indicates the range of habitat vulnerabilities for <u>individual</u> climate change scenarios. This means that results cannot be compared <u>between</u> scenarios only <u>within</u> scenarios.

Adaptive capacity

The definition of adaptive capacity was based on the assumption that permeable, topographically heterogeneous landscapes, with a greater number of soil types and land cover diversity, will have a greater adaptive capacity to climate change. Essentially, this is a biophysical evaluation of factors that are known to have a direct influence on the viability of non-vertebrate species (Nichols, *et al*., 1998; Davies, *et al*., 2006; Jackson, 1966; Bryant, *et al*., 2002, Meyer & Sisk, 2001).

As most biodiversity falls into this category, it was important that the vulnerability assessment, and indeed any resulting climate change adaptation measures, consider factors that have some biological relevance to non-vertebrates. It was assumed that areas of high adaptive capacity will enable more species to persist in the future because a greater range of microclimates and environmental conditions will be accessible. Consequently, adaptation to a changing climate is likely to be as much about a ‘hop across a valley’ as it will be about a ‘long march north’. This assumption is currently being tested through comparing the rate of species turnover in butterfly populations between areas of high and low adaptive capacity (Catchpole and Lennon, 2011).

Adaptive capacity was quantified for each grid cell by measuring the extent of ecological networks to give an estimate of permeability (England Habitat Network 2.0); variation in height to give an estimate of topographic heterogeneity (UK Perspectives 10 m digital terrain model); the number of different soil types to give an estimate of soil diversity (NSRI National Soil Topography) and land cover dominance to give an estimate of land cover diversity (LCM2000). These measurements were then combined using the method described above which gave a score between one and ten for each grid cell. Land cover dominance was measured using Simpson's Index, see Equation 1.

Equation 1 Simpson's Index

$$1 - D = \sum \frac{n_i(n_i - 1)}{N(N-1)}$$

where n_i = the number of land cover classes of the ith polygon and N = the total number of land cover classes.

Simpson's index is a commonly used information statistic that quantifies the relative importance of contributions from different elements. It is often applied to species data in combination with species richness metrics, for example, the number of species occurring in an area, but can readily be applied to other sources of information, such as geospatial data. In this particular case, a high dominance value for an individual grid cell indicates a limited number of land cover types and thus a lower landscape heterogeneity. It was assumed that less heterogeneity would limit future adaptation because of the lower level of 'species packing' (ie Buttel, *et al*., 2002) that would be possible in a given area. This, of course, implies that the general conservation aim in England will be the long-term maintenance of biodiversity rather than the preservation of extensive, single habitat, monocultures.

The information that was used to measure permeability, within each grid cell, was derived from an earlier piece of work that defined ecological networks for a number of priority BAP habitat types (England Habitat Network - EHN 2.0). This work used a least-cost algorithm (eg Adrieansen, *et al*., 2003) to simultaneously compare the distribution of habitat patches and the hostility of the intervening land use matrix. The analysis produced a series of overlapping, weighted buffers that indicated areas where movement between existing habitat patches may still be possible. The analysis used current land cover information, expert judgement and empirical data on species dispersal as the main model parameters. See Figure 1 for an example of some results for grassland networks in the north west of England.

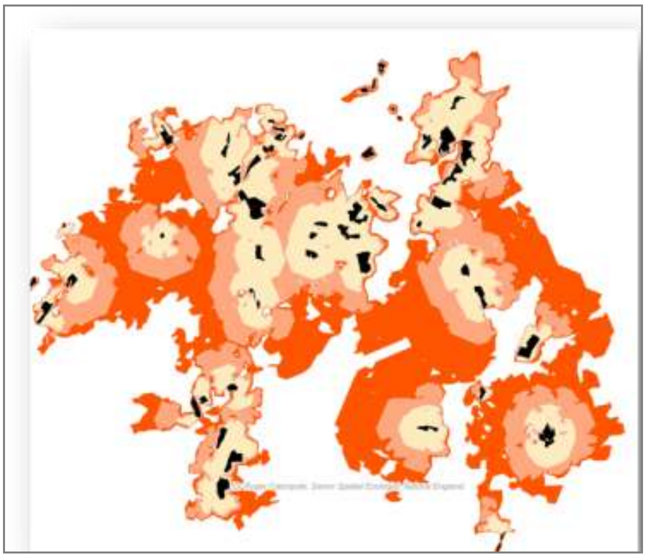

Figure 1 Grassland ecological networks at three different scales of dispersal. Black areas indicate existing grassland patches

Owing to data attribution issues associated with the national habitat inventories and the practicalities of land use planning, the network analysis was stratified into four broad habitat categories rather than applied to individual priority BAP habitats. These were:

- mire, fen and bog;
- grassland;
- heathland; and
- deciduous woodland.

Table 1 on page 10 below shows how the individual habitat inventories were aggregated.

A recent analysis of these data indicated that approximately 18% of England may be functioning as an ecological network and potentially capable of supporting regular species movement. See Catchpole (2006) for further details on the methodology.

Sensitive habitats

A review commissioned by Defra (Mitchell, *et al*. 2007) on behalf of the England Biodiversity Group, was used to identify habitats that may be sensitive to climate change. Although a wider range of information could have been used from the primary literature, this piece of work represented a broad consensus of the potential impacts of climate change on specific semi-natural habitats of conservation importance.

In this work, a combination of expert opinion and literature review identified potential causal links between specific climate variables and individual priority BAP habitats. This meant that it was possible to identify geographically explicit areas containing these habitats. See Table 2 on page 11 for details of the specific relationship between different habitats and climate variables.

The extent of each of these priority BAP habitats was quantified for each grid cell to give a coverage-based weighting, ie cells with a higher proportion of sensitive habitat scored higher than cells with a lower proportion. This means that even though grid cells with very little of the specified habitats will appear in the analysis, they will have a lower score and not bias the results which would be the case if presence/absence was used.

This means that the vulnerability assessment only applies to areas where the specified sensitive habitats already occur, ie it does not apply to every 1 km grid cell in England. An example of how this works in practice can be seen in Figure 2.

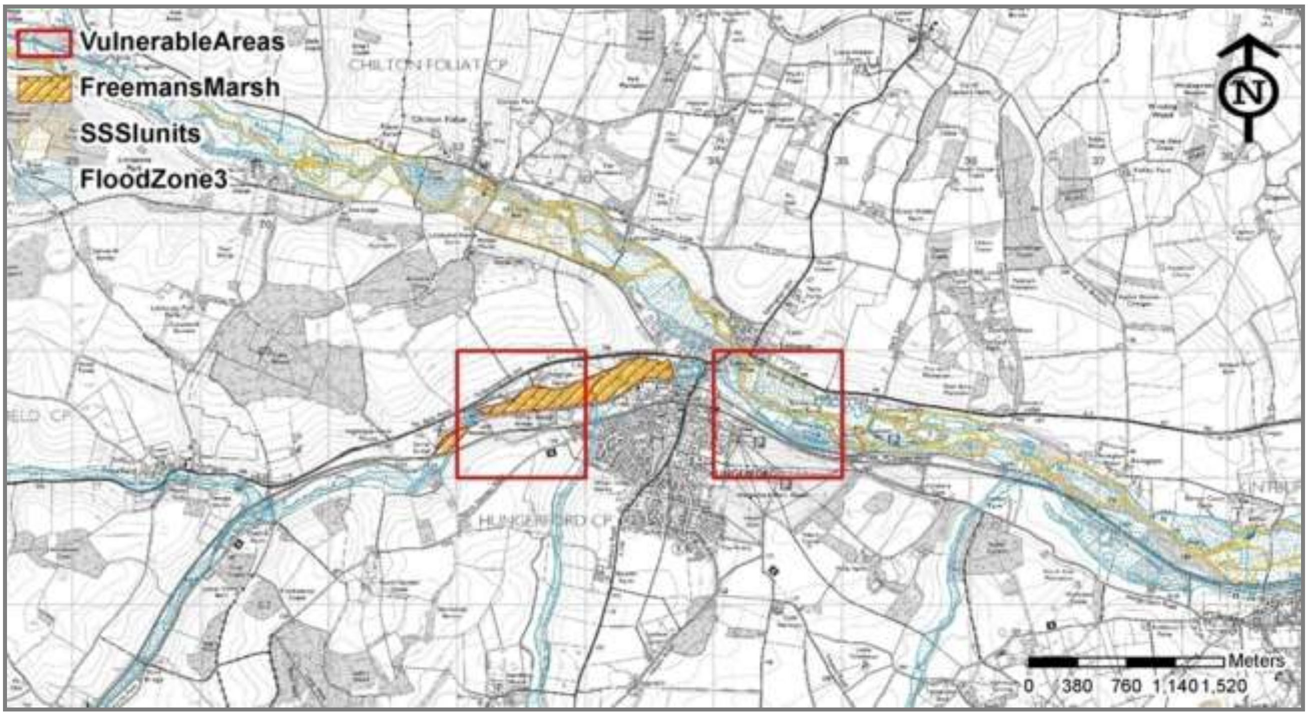

Figure 2 Climate Vulnerability of Freeman's Marsh SSSI in Berkshire. The two red squares from the national vulnerability assessment indicate that the lowland meadow plant communities on this site might be vulnerable to climate change. At larger scales these grid cells are not ranked as highly as other cells that might have a greater coverage of habitat, a lower adaptive capacity or a higher risk of climate change exposure

Clearly there may be other habitats that are sensitive to climate change outside the areas that have been analysed, for example, freshwater and coastal habitats. Although a range of coastal and freshwater habitats were identified in Mitchell, *et al*. (2007), they were excluded from the analysis because of the complexity of the modelling that would have been required; the high degree of uncertainty associated with future changes in sea defences/water abstraction and the fact that the primary responsibility for this work rests with the Environment Agency, rather than Natural England.

Climate change

The assessment has used the 2080 UKCP09 projections in order to provide a ‘signpost’ that indicates the overall direction of travel that might be experienced rather than an overly pessimistic or alarmist view of the future. The national vulnerability assessment uses the best and worst case future projections in the form of the IPCC Special Report on Emissions Scenarios (SRES) high (A1F1 fossil fuel, energy intensive future) and low (B1 efficient, clean technology future) scenarios to give an indication of the range of possible outcomes. Temporally averaged, seasonal data showing the relative change in different climate variables from an observed 30 year baseline (1961-1990) were used in the vulnerability analysis rather than the data on the absolute change in the climate variables.

The climate projection data were downloaded as a 25 km^2 grid and subsequently disaggregated to populate the 1 km^2 grid that was used for the vulnerability assessment. This downscaling consisted of capturing the value from the 25 km^2 cell that had the greatest overlap with individual 1 km^2 cells. This means that all the 1 km^2 cells broadly within a given 25 km^2 cell will have identical values. As the 25 km^2 grid had a ‘rotated pole’, the resulting 1 km^2 climate variable grid appears to be skewed, even though it is geo-referenced to a standard Ordnance Survey Great Britain (OSGB) map projection. A rotated pole gives a grid orientation that appears to be rotated anti-clockwise relative to true north. This was used by the Met Office so that the climate modelling could be applied to Northern Ireland, which has a different national map grid projection. A sample of this data can be seen in Figure 3.

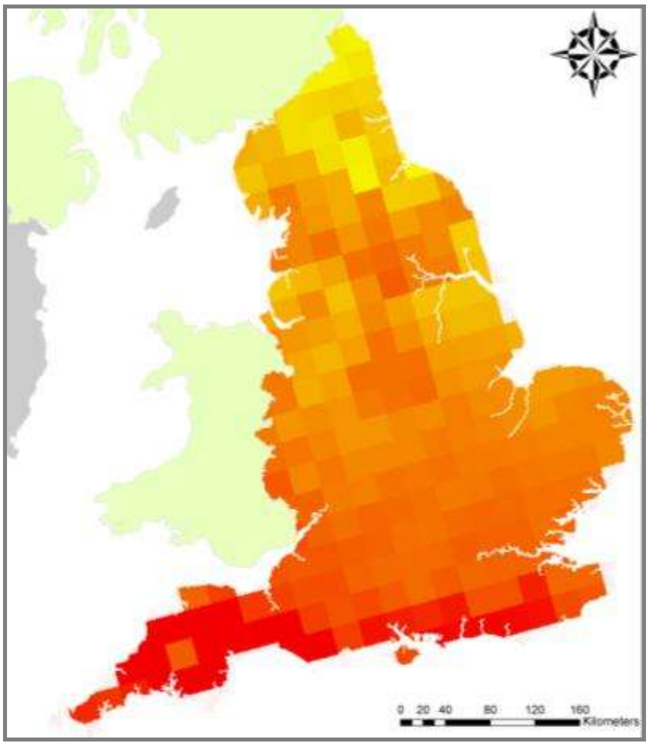

Figure 3 Changes in summer precipitation from baseline under the 2010 (CDF10) high emission scenario (range = -36 to -74mm)

Defining vulnerability

The three different variables that have been outlined in the previous sections were brought together to give an overall score of vulnerability for each grid cell. As each of these had already been standardised as percentiles, this process simply consisted of adding up the grid scores for each variable to give a new grid. These 'raw' scores were then converted into deciles, ie nine equal intervals, so that areas with higher scores indicated high exposure, high sensitivity and low adaptive capacity. This was done for each of the sensitive habitats that were identified in Mitchell, *et al*. (2007), as previously discussed. A schematic representation of this process can be seen in Figure 4.

When grid cells contained more than one habitat, the percentile-based habitat sensitivity scores were simply summated. This was done to highlight grid cells where there may be more than one habitat at risk from climate change as this might represent a higher conservation priority in comparison to a grid cell with a small area of just one habitat. Users should be aware that cells which contain complete coverage of an individual habitat will always score higher even with this additive scoring, all other variables being equal.

Results

The results of this analysis have been expressed as a series of raster-based, 1 km^2 grids for each habitat. This has been done so that the information can be mapped in a variety of different ways, to suit operational needs, but more importantly so that other sources of information can be easily incorporated into the analysis. For example, this might consist of an evaluation of the potential impact of climate change on other priority BAP habitats, ecosystem services or socio-economic factors.

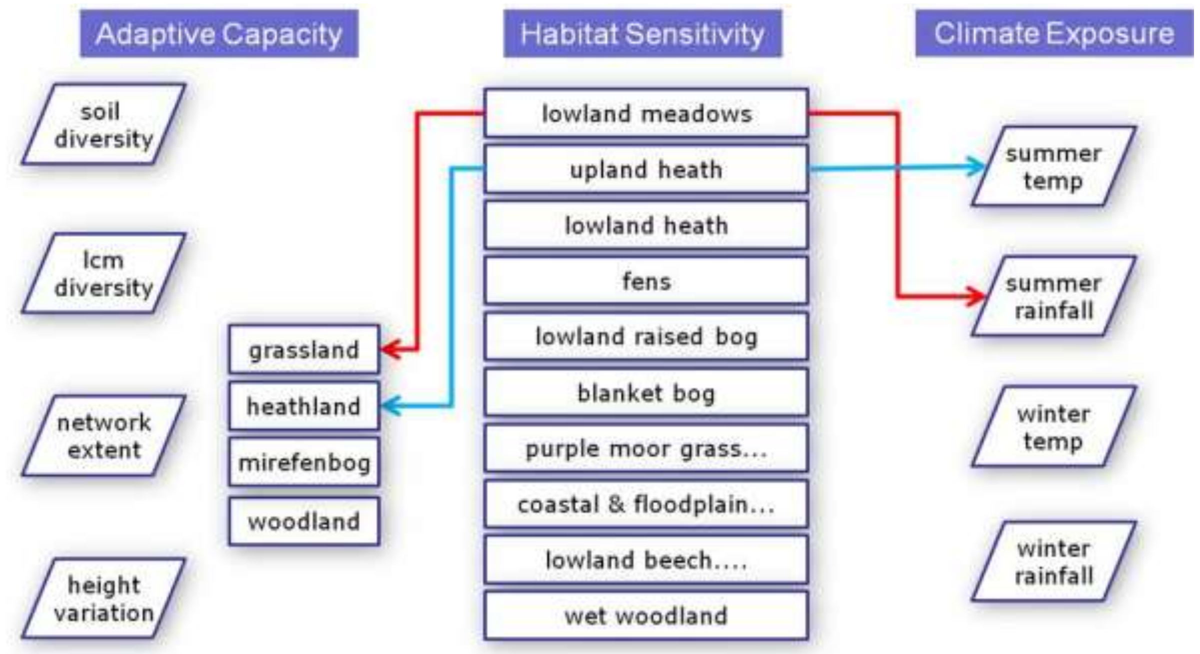

Figure 4 Schematic representation of the National Vulnerability Assessment data model. The arrows indicate how the vulnerability of two of the habitat types were scored. In the case of lowland meadows the percentile score of extent was added to the percentile score for grassland adaptive capacity and the percentile score of change in summer rainfall. The reason why adaptive capacity has been stratified into four different habitat types arises from the permeability of specific landscapes and the associated grid cells as defined from the England Habitat Network

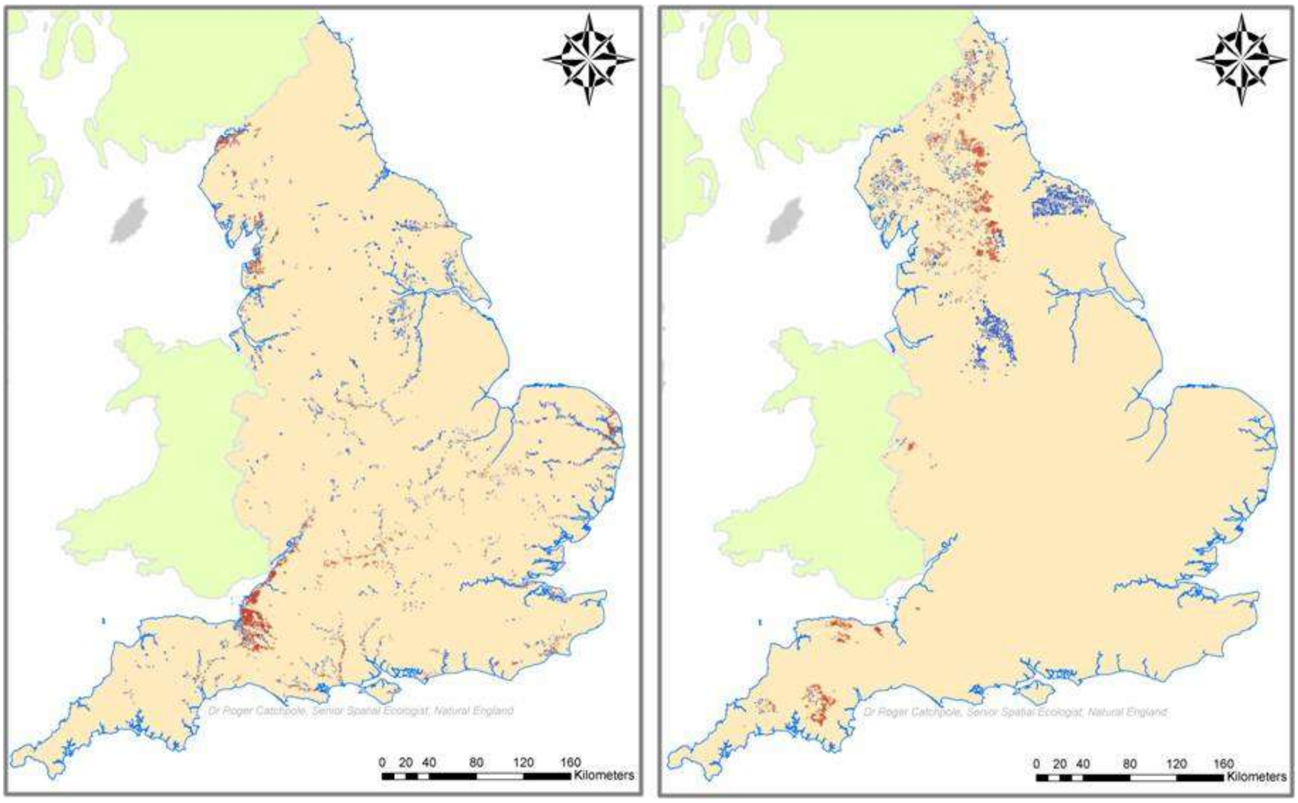

Figure 5 Climate vulnerability assessment for coastal and floodplain grazing marsh (left) and upland heath (right) under the 2080 (CDF 10) high emission scenario. Vulnerability is shown on a blue-red colour ramp. Dark red grid cells indicate the highest degree of vulnerability while light blue grid cells indicate the lowest degree of vulnerability. Beige areas indicate an absence of these habitats and a consequent lack of vulnerability

Users can either aggregate the data at whatever level is necessary to provide more strategic assessments or they can look at the pattern of vulnerability of each habitat as Figure 5 shows.

Caveats

As with any ecological model and geographical representation, caveats apply. Ideally the practical application of this information should be led by someone who has significant expertise in spatial ecology, geographical modelling as well as an in-depth understanding of practical conservation delivery. The use of this data without such informed judgement risks an over-prescriptive and potentially misleading application. The following paragraphs will attempt to identify some of the more obvious limitations that users should bear in mind.

One of the most obvious limitations is that the vulnerability assessment excludes some coastal and esturine areas because the coverage of the UKCP09 data and the grain at which it was possible to implement the vulnerability analysis, ie 1 km^2. The former can be seen in Figure 3 where missing areas have been shown in a red stipple. This is due to the fact that the UK Climate Impacts Programme removed any 25 km^2 grid cells from the land-based assessment which overlapped with marine areas. This is in contrast to the UKCIP02 data where such cells were retained. The UKCIP02 data have also been captured and could be used instead of UKCP09 should the need arise. Users should also be aware that the use of a 1 km^2 grid has led to the exclusion of some areas along national borders, ie Wales and Scotland.

Representation is limited to a specific range of priority BAP habitats and does not currently apply to freshwater systems or to most coastal habitats in spite of the high degree of sensitivity associated with these areas (Mitchell, *et al*. 2007). This was due to the fact that different methodologies, that take coastal erosion processes and ecohydrological models into account, would have required development which was beyond the scope of this project and arguably the responsibility of other NDPBs.

If users want to work with partners and disseminate the raw data then this should comply with the licensing restrictions so that it is only used by organisations that have the appropriate legal permissions for the use of soil, land cover and digital terrain data. Consequently, the primary development of this resource will need to occur through Natural England rather than through any third parties. It should be assumed that this information will not be made available to contractors unless they are working on Natural England's behalf.

Although the most recent version of the national habitat inventories were used to evaluate habitat sensitivity (circa 2009), these are incomplete and there will be some grid cells that contain habitats which have not been evaluated.

National inventories are subject to continuous revision and improvement but they are only as accurate as the data that local partners choose to make available. Consequently this work should not, in any way, be viewed as a comprehensive assessment of climate change vulnerability for the specified habitats but rather a first step. Further improvements may be possible through the incorporation of local data sources, showing the extent of sensitive habitats, but the use of national data on the location of County Wildlife Sites is not recommended because of a lack of consistency in their notification and classification.

In general terms, all information arising from this project should be treated as provisional and subject to revision as new information becomes available.

Concluding remarks

Much uncertainty remains about the effects of climate change on the natural environment and this will be the case for the foreseeable future. Over time this assessment will be refined as we learn more about the underlying science and further develop the methodology. In the meantime, this work should be seen as a spatially explicit guide to vulnerability that is based on the best, currently available evidence. It will provide a useful tool both in the development of adaptation strategies and in future conservation planning.

More specifically the geospatial products that accompany this technical document should only be viewed as a first draft. This is because an ongoing process of validation and testing may require a re-weighting of factors or the modification of the basic approach in the light of developing knowledge. In the meantime, with the anticipation that it will remain largely unchanged, sense-checking and local modification is encouraged. Although a range of national interpretive products will be developed in due course, it is hoped that regional climate change and biodiversity specialists will take the lead in identifying application opportunities and in explaining the approach to a wider audience after appropriate training cascades have occurred.

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Further reading

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Further information

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Table 1 National habitat inventory aggregations used in the England Habitat Network Analysis (EHN 2.0). Classification shown in brackets is the BAP broad habitat type

Broad Habitat Type	Priority Habitat Type
Grassland (Calcareous + Neutral + Acid Grasslands)	Lowland meadows
	Lowland calcareous grasslands
	Lowland dry acid grasslands
	Upland calcareous grasslands
	Upland hay meadows
Heathland (Dwarf Shrub Heath)	Upland heaths
	Lowland heaths
Mire, Fen & Bog (Fen, Marsh & Swamp + Bogs)	Fens
	Lowland raised bogs
	Blanket bogs
	Reedbeds
	Purple moor grass and rush pastures
Woodland (Broadleaf, Mixed & Yew Woodland)	Upland oakwood
	Upland mixed ashwood
	Upland birchwood
	Lowland beech and yew woodland
	Wet woodland

Table 2 Habitats identified as sensitive to climate change in Mitchell *et al*. (2007)

Priority Habitat Type	Negatively Impacting Climate Variables
Lowland meadows	Summer drought
Upland heath	Increased summer temperature
Lowland heath	Summer drought
Fens	Increased summer temperature; increased winter temperature; Summer drought
Lowland raised bog	Increased summer temperature; increased winter temperature; Summer drought
Blanket bog	Increased summer temperature; increased winter temperature; Summer drought
Purple moor grass and rush pastures	Summer drought
Coastal and floodplain grazing marsh	Increased summer temperature; summer drought
Lowland beech and yew woodland	Increased summer temperature; summer drought
Wet woodland	Summer drought