Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network

Task 2a – An assessment framework for climate change vulnerability: methodology and results

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1 Introduction

The aim of this task is to identify species of Community interest[1] that are considered vulnerable to climate change in the European Union. This will form part of the assessment of likely impacts of climate change on the EU's ability to halt biodiversity loss by 2010 and beyond and will contribute also to Task Report 3a (assessment of impacts of climate change on the Natura 2000 network) and the formulation of policy responses to protect the integrity of the Natura 2000 network [Task Report 2b & 3b].

As noted in this study's' review of adaptation principles (see Task Report 2b & 3b, Section 2), the assessment of vulnerability of species to climate change underpins many strategies for biodiversity adaptation (e.g. IUCN, 2004). The rationale for this is that there is a limited capacity for implementing biodiversity adaptation measures in addition to existing conservation measures. Therefore, it is necessary to identify and prioritise species and habitats that require measures to support climate change adaptation. Vulnerability assessments can inform decisions on such priorities. There is accordingly a specific action in *The European Union's Biodiversity Action Plan "Halting the loss of biodiversity by 2010 – and beyond"* (2008)[2] to "make a preliminary assessment of habitats and species in the EU most at risk from climate change [by 2007], detailed assessment and appropriate adaptation measures prepared [by 2009], commence implementation [by 2010]". This task, therefore, aims to contribute to this action by carrying out an assessment of the vulnerability of species of Community Interest to climate change. The results also form the basis of the Task 3a assessment of the importance of individual Natura 2000 sites for vulnerable species.

Vulnerability assessments should include an examination of climate change impacts and the ability of species and habitats to successfully respond to these impacts. The magnitude of the climate change experienced by a species or habitat (**exposure**) and the degree to which the species or habitat is affected (**sensitivity**) must first be identified. Then the ability of impacted species or habitats to successfully respond to climate change (**adaptive capacity**) must be considered to establish a robust indication of vulnerability. Standardised data types and metrics for exposure, sensitivity and adaptive capacity are required in order to apply the vulnerability assessment framework across the EU and across a range of taxonomic groups.

Research into the exposure and sensitivity of EU species to climate change is fairly abundant in the scientific literature, particularly for species in the northern and western EU (see Task 1 Report). These studies utilised a variety of approaches to understand climate change impacts on species, including analyses of observed data and modelled projections, and knowledge-based expert assessments. However, despite the diversity of species' attributes that have been studied (e.g. changes to population size, climate space, phenology etc.), it is necessary to select abundant and consistent data types and metrics to ensure coherence at the scale required for this study.

Various individual species and taxonomic groups have been used in models that project how they might be impacted by climate change in the future. The emphasis on species has been driven in part by the availability of spatial distribution data sets for a large number of species across taxonomic groups. The spatial data are used in conjunction with Global Climate Models (GCMs) to model the climatic envelope of a species or the range of climatic conditions that enable the species continued existence. Climatic envelope models are used to depict how a species' potential suitable climate space might shift geographically in response to climate change. Climate envelope data sets are becoming increasingly available for a wide range of species (e.g. Berry *et al.* 2005; Berry *et al.* 2007; Araujo *et al.* 2006;

[1] These are defined here as species that are listed in Annex II of the Habitats Directive and birds listed in Annex I of the Birds Directive. Other migratory species of birds covered by the Birds Directive (i.e. all naturally and regularly occurring migratory wild birds) are not included in this study.
[2] http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/bio_brochure_en.pdf

Thuiller *et al.* 2005; Huntley *et al.* 2007, Settele *et al.* 2008). Climate envelope models use various emissions scenarios to capture the range of possible climate futures. Other data types can be used to potentially assess impacts and vulnerability, however most are specific to a narrow range of species.

While a large number of studies have considered the impacts of climate change on species, to date only a limited number of projects have moved beyond the assessment of exposure and sensitivity to a structured approach that considers adaptive capacity and thereby vulnerability. Thuiller *et al.* (2005) used climate envelope models for more than 1350 plant species to assess the amount of climate space lost (sensitivity) under a range of climate change (exposure) and dispersal scenarios (adaptive capacity: no migration vs. full migration). The amount of climate space lost was then compared to IUCN threat categories (IUCN, 2001) to assign threat category labels. The work of Thuiller *et al.* (2005) implicitly blends the assessments of exposure, impact and adaptive capacity in its methods.

Settele *et al.* (2008) used the World Organisation for Animal Health’s risk assessment process (OIE, 2000) for butterflies to identify hazards and assess risks from climate change. Generally, this is a similar approach to that of Thuiller *et al.* (2005), however the thresholds of lost climate space and risk categories are different. As with the Thuiller *et al.* (2005) approach, Settele *et al.* do not separate the assessment of impacts from that of adaptive capacity.

Harrison *et al.* (2001) and Hossell *et al.* (2000) used expert knowledge to assess vulnerabilities of species and habitats in Great Britain and Ireland. This work did not use a structured semi-quantitative framework to assess impact and vulnerabilities, but instead used detailed knowledge of the ecology and current status of species and habitats to qualitatively identify those species most vulnerable to climate change.

Very little work has been done to develop a structured approach to adaptive capacity. However, IUCN held a Species Vulnerability Traits workshop that was broadly focused on the identification of life history traits that might pre-dispose species to extinction, including vulnerability to climate change. This database is currently under revision and was not available for the present study, but as Berry (2008) notes “in the longer-term [the Species Vulnerability Traits] could provide a good framework for assessing species' vulnerability to climate change and provide a globally applicable, consistent approach.”

The vulnerability of habitats and ecosystems has been considered through a range of approaches, including expert knowledge, the use of surrogate plant and animal species and the development of quantitative indices for specific impacts or habitats. The vulnerability of broad global ecosystem types has been qualitatively assessed using expert knowledge by Berry (2004) and Berry (2008). Berry (2008) notes studies from WGBU (2003) and EEA (2004) that have used expert knowledge to highlight key vulnerabilities of European biogeographical regions.

Other approaches to assess habitat vulnerability have included the use of expert knowledge of habitats and their vulnerability, and the use of selected species as indicators of climate change impacts on habitats. Harrison *et al.* (2001) considered the impacts and vulnerabilities of characteristic species as surrogates for habitat vulnerability to climate change in Great Britain and Ireland. This approach is a simple and effective means of using the abundant species data sets to bypass the significant difficulties associated with modelling habitat responses to climate change. Hossell *et al.* (2000) used expert knowledge to assess the impacts and adaptive capacity of UK habitats to climate change to assign an overall vulnerability ranking. The application of this approach to all of the EU habitats would necessitate consultations with a large number of ecologists and landscape managers across the EU. The BRANCH project developed the Coastal Habitat Vulnerability Index (CHVI) as a means of identifying those coastal habitat types especially vulnerable to sea-level rise (Berry *et al.*, 2007a). This is one of the few quantitative approaches used for habitat vulnerability, but is unfortunately restricted to coastal habitats.

The approach used in the present study capitalises on the existence of modelled climate space data for 212 individual Natura 2000 species. The methods described in subsequent sections use a semi-quantitative approach to the assessment of climate impacts and subsequently to the assessment of vulnerability. The work described above (Thuiller *et al*., 2005; Settele *et al*. 2008) combine the assessment of impacts with that of adaptive capacity. Here we use methods for identifying adaptive capacity that are similar to those used by IUCN in a recent assessment of species susceptibility to climate change (Foden *et al.*, 2008) and developed at the Species Vulnerability Traits workshop (above). These methods use expert knowledge of each species' life history, population trends and dispersal capacity to estimate their relative adaptive capacity.

2 Overview of methodology and data sets

The impact and vulnerability assessment methodology is defined in accordance with guidance provided by the IPCC's Fourth Assessment Report (IPCC, 2007). The relevant definitions include:

- Sensitivity - the degree to which a system is affected, either adversely or beneficially, by climate change (Glossary, IPCC, 2007).

- Exposure - the nature and degree to which a system is exposed to significant climatic variations (Glossary, IPCC, 2007).

- Impact - all impacts that may occur given a projected change in climate, without considering adaptation; **impact is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed and its sensitivity** (Glossary, IPCC, 2007).

- Adaptive capacity - the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Glossary, IPCC, 2007).

- Vulnerability - 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** (Glossary, IPCC, 2007).

- Resilience – amount of change a system can undergo without changing state (Glossary, IPCC, 2007).

The methodology developed to assess the vulnerability of species to climate change comprises a two-part process (see Figures 1a & 1b). Firstly, information on the degree of **exposure** to climate change experienced by a species is plotted against its **sensitivity** to that exposure to give a measure of **impact** (i.e. with no adaptation). Secondly, **impact** is plotted against the **adaptive capacity** of that species to give a measure of **vulnerability**.

The above-mentioned terminology was followed in a recent assessment of vulnerability of the species and habitats listed in the Bern Convention (Berry, 2008). However, this approach differs from that taken by IUCN in a recent assessment of species susceptibility to climate change (Foden *et al.*, 2008). The IUCN approach incorporates a blended assessment of adaptive capacity with sensitivity to identify susceptible species. In the approach taken here, it was considered to be more appropriate to keep the assessment of sensitivity and adaptive capacity separate, the logic being that a species' adaptive capacity is only a significant issue if it is sensitive and exposed to climate change. The adaptive capacity of each species subject to significant impacts is then assessed before making a final assessment of vulnerability.

Within the project proposal, the starting point for the vulnerability assessment was cited as those species and habitats identified in Task 1 that were supported by abundant, quantitative datasets sufficient for use in the assessment process. The appraisal of dataset suitability was essentially subjective and based on expert opinion.

Figure 1a: Impact and vulnerability assessment framework

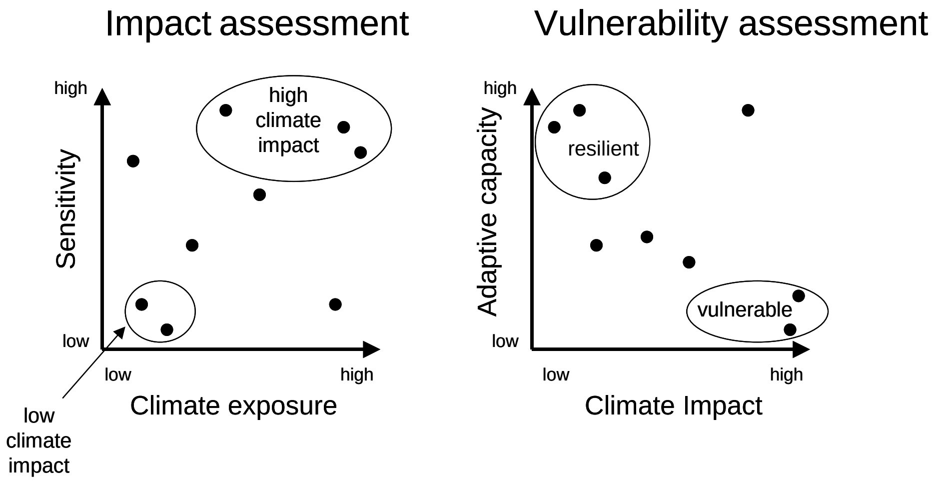
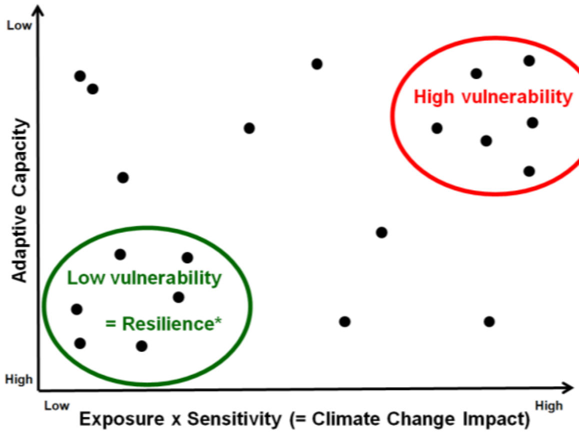


Figure 1b: Impact and vulnerability assessment framework



However, the information available from Task 1 on the exposure, sensitivity and adaptive capacity of species and habitats to climate change varied considerably amongst taxa and regions. Considerable variation was observed in the types of studies used to examine climate change. These included experimental manipulations, observed data correlated to climatic variables, and modelled impacts of climate change. Similarly, the variables used as surrogates for climate exposure and sensitivity were equally diverse. For example, climate exposure was measured variously as observed temperature and/or precipitation increases, modelled climate change scenarios, and increased atmospheric CO_2 concentrations. Examples of sensitivity to climate change included changes in plant species diversity, phenological changes, changes in species abundance, and changes in potential suitable climate space. The diversity and variability of these data, therefore, deemed them unsuitable for the impact and vulnerability assessment process.

The project team hence decided to base assessments on the results of climate space modelling for a range of Natura 2000 species within several taxonomic groups. Climate space modelling utilises a range of algorithms (i.e. linear regression to artificial neural networks) and climate–hydrological process models to identify bioclimatic envelopes for species and predict changes to the potential distribution of species under a range of climate change scenarios. The overlap between current suitable climate space and that in the future is important as it represents areas where the species may be able to remain most easily. It must be remembered that bioclimatic envelope maps only indicate potential suitable climate space; this does not equate to a new, expanded distribution, but only to where suitable climatic conditions for that species exist. The ability to take advantage of new potential suitable climate space will depend on a range of factors, including the availability of suitable habitat and the dispersal ability of the species in question (Berry *et al.*, 2007).

The application of bioclimatic envelope modelling is commonly constrained to only those species for which large amounts of data exist with which to train, validate and test the model. This constraint can be overcome through the use of geographically extensive data sets to increase the number of records available for use in the model. However, rare or geographically restricted species often cannot be modelled due to small sample sizes and limited data availability (Pearson & Dawson, 2003; Pearson *et al.*, 2006).

The model outputs used here include those by Huntley *et al.* (2007) on breeding birds, Araujo *et al.* (2006) on reptiles and amphibians, Settele *et al.* (2008) on butterflies, and Thuiller (2004) and Thuiller *et al.* (2005) on vascular plants. This choice simplifies the impact and vulnerability assessment dramatically: **all are modelling studies utilising the standard greenhouse gas emission scenarios from the IPCC Special Report on Emissions Scenarios[3] (i.e. SRES, incl. A1F1, A2, B1, B2)**. This approach provides a large and consistent dataset for use in the impact and vulnerability assessment process. However, differences between the modelling projects are apparent. While all of the modelling data used for this report have utilised the Hadley Centre HadCM3 coupled atmosphere–ocean general circulation model (Gordon *et al*. 2000), the projects have employed different emission (i.e. SRES) scenarios to drive the model, different time horizons (2050, 2080, 2100) and modelling algorithms (artificial neural networks, linear models, ensemble techniques). For this reason, and the obvious ecological differences amongst the taxa groups, the analyses have been carried out for each taxonomic group separately. Overall conclusions with respect to the Natura 2000 network will be an output of Task 3a and these will be based on combined analyses of average relative vulnerabilities of each group across sites and regions.

Similar modelling data are unfortunately not yet available for habitats. The considerable computational challenges involved in building models to integrate the complex interactions between species as well as between species and ecosystem processes, have still to be resolved. Projects such as BRANCH and MONARCH have used indicator species as surrogates in habitat assessments. Our hope was to use this approach and assign each of the species in our data set to one or more habitats. In particular, we intended to cross-reference the plants data (1300+ species) with habitats of Community Interest using extracts from the EUNIS database, which was believed to make the necessary linkages between species and habitats. Unfortunately, the database extract we received was not structured appropriately to permit such an assessment. An alternative approach involving the selection of essential indicator species was similarly unfeasible as the identification of suitable indicators for each habitat of Community Interest would be a complex and time-consuming process and outside the remit of this study. For these reasons, we have focussed only on species in this study.

[3] http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

3 Impact assessment framework

The assessment of climate change **impacts** on species utilises two data variables: **exposure to climate change and sensitivity to climate change**. When considered together, these provide a qualitative measure of impact. Since there are no direct measures of exposure or sensitivity to climate change, surrogates for these variables must be chosen.

The greenhouse gas emission scenarios (SRES scenarios; IPCC, 2000) and time horizons used to drive global climate models (GCMs) were used as the **surrogate for climate change exposure** (see Table 1; the A1F1, A2, B2 and B1 SRES scenarios can be viewed in a descending order of climate exposure).

Table 1: SRES greenhouse gas emission scenarios and time horizons used in the different impact and vulnerability assessments of different taxa groups.

Taxon	No. of species of Community Interest	Model	No. of species modelled & assessed	% of species modelled & assessed	Model time horizon	Model SRES Scenarios
Amphibians	25	Araujo et al. 2006	12	48.0 %	2050	A1F1, A2 B1, B2
Reptiles	24	Araujo et al. 2006	12	50.0 %	2050	A1F1, A2 B1, B2
Butterflies	38	Settele *et al.* 2008	13	34.2 %	2050	A1F1, A2 B1
					2080	A1F1, A2 B1
Vascular plants	588	Thuiller 2004; Thuiller *et al.* 2005	26	4.4 %	2050	A1F1, A2 B1, B2
					2080	A1F1, A2 B1, B2
Birds	194	Huntley *et al.* 2007	149	76.8 %	2070-2099	B2

Nevertheless, it seems important to keep in mind that modelling results and the underlying standardised climate variables can only provide an approximation to the real exposure experienced by a particular species or habitat; limiting factors are prone to be species-specific and so variable that surrogates cannot fully represent climate exposure.

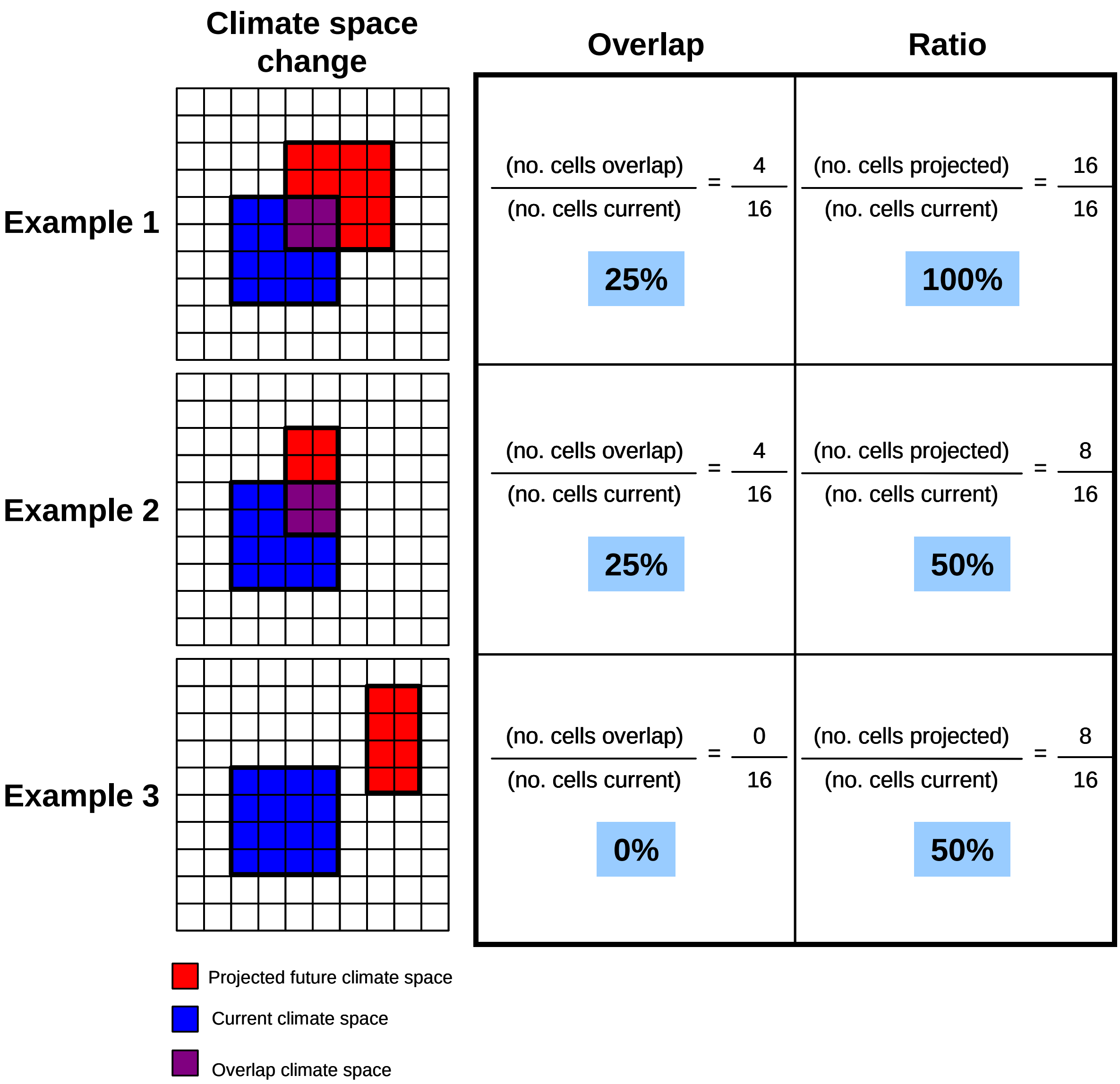
With the modelling algorithms implicitly contributing the climate sensitivity component, the resulting **surrogate for climate change impact** consisted in the changes in potential suitable climate space from current predicted distribution to projected future distribution. This surrogate is described by two metrics (see also Fig. 2):

1) "**Overlap**" is calculated as the number of grid cells within the intersection between the projected and simulated recent ranges divided by the number of squares in the simulated recent range (see Figure 2). This metric is expressed as a percentage where 100% overlap indicates that all current climate space is covered by the projected future climate space. An overlap of 0% indicates that none of the current climate space is contained within the projected future climate space of that species.

2) "**Ratio**" is calculated as the number of grid cells in the projected future range divided by the number in the simulated recent range. While this metric is difficult to depict graphically it describes the relative change in total suitable climatic space. This metric is also expressed as a percentage where values less than 100% indicate a decrease in total suitable climatic space. Values greater than 100% suggest an expansion of total suitable climatic space. .

Both climate impact metrics are important. A projected reduction in suitable climate space (i.e. a low ratio) suggests that a reduction in range is likely (at least to some extent). A projected low overlap between current and future modelled climate space suggests that the species will need to move to new areas of suitable climate to maintain the total area of their range. Although there is some evidence that species can move in response to climate change (e.g. Hickling *et al.*, 2006), many may be limited by dispersal and colonisation constraints (e.g. limited dispersal abilities, physical barriers to movement, low levels of breeding productivity, or lack of suitable habitat). Such constraints on range expansion into suitable climate space have been observed in butterflies (Hill, 2001, 2002). In some situations, suitable habitats may develop in areas of suitable and accessible climate space. However, this may take a long time (perhaps decades), causing a lag effect if species move more rapidly than required habitats can develop. Furthermore, some new areas of climate space may not be able to support suitable habitats (e.g. because of incompatible soil or hydrological conditions). Moreover, the community composition of many habitats is unlikely to remain intact or be replicated, but will change because their constituent species will be impacted to varying degrees by climate change (Williams and Jackson, 2007). Thus, low levels of overlap may result in substantial range and population impacts on some species.

Figure 2: Sample overlap and ratio calculations for current and projected future species ranges



3.1 Sensitivity thresholds

The combined effects of sensitivity and exposure were quantified in terms of projected changes in modelled climate space or overlap in climate space. The threshold values and impact categories for climate ratio and climate overlap are defined in Table 2a.

Table 2a: Categories and threshold values for the two metrics of climate impact: Overlap and Ratio (the number codes are used in the Annexes and some of the table in the text). The percentage values in the 2nd row define the Overlap Impact category and Ratio Impact category. For example: for a Ratio value of <30% (a small Ratio) the impact category is "Very High / -4".

	OVERLAP AND RATIO SENSITIVITY THRESHOLDS DEFINING THE IMPACT CATEGORY							
	<30%	30-50%	50-70%	70-100%	100-130%	130-150%	150-170%	>170%
***Overlap* Impact Category & Code**	Very High -4	High -3	Moderate -2	Low -1				
***Ratio* Impact Category & Code**	Very High -4	High -3	Moderate -2	Low -1	Low Robustness +1	Moderate Robustness +2	High Robustness +3	Very High Robustness +4

To illustrate the assessment process, Table 2b contains the overlap and ratio metrics (climate impact) for four SRES scenarios (climate exposure) within the 2050 time horizons. The overlap and ratio metrics are then assessed against the thresholds described above to assign an impact category label. In this example, the A1F1 and B1 SRES scenario produce the greatest reductions in the overlap and ratio metrics suggesting the total suitable climate space for the species would shrink (i.e. ratio is reduced) and the projected future climate space will share a smaller portion of the current climate space (i.e. reduced overlap). The A1F1 scenario often produces the most significant changes in climate and is expected to have the most dramatic impacts on climate space models; however this is not always the case.

Table 2b: A worked example of the impact assessment for the Meadow Viper (*Vipera ursinii*). For instance: under A1F1, by 2050, Overlap is 62.8%, hence a Moderate (-2) Overlap Impact Category; Ratio is at 125% wherefore the Ratio Impact Category is "Low Robustness".

Time Horizon	SRES Scenario	Overlap	Overlap Impact Category	Ratio	Ratio Impact Category
2050	A1F1	62.8%	MODERATE	125.0%	LOW ROBUSTNESS
2050	A2	76.2%	LOW	164.0%	HIGH ROBUSTNESS
2050	B1	62.6%	MODERATE	125.2%	LOW ROBUSTNESS
2050	B2	72.5%	LOW	149.7%	MODERATE ROBUSTNESS

4 Vulnerability assessment framework

The assessment of vulnerability of species to climate change plots the outputs of the **impact assessment against their adaptive capacity**.

4.1 Adaptive capacity traits

The assessment of adaptive capacity is a new area of ecological thought and, as such, there are no existing assessments of the ability of species or habitats to adapt to the impacts arising from climate change. However, key ecological parameters can be identified that might constrain the autonomous ability of species to adapt to climate change impacts, including their distribution, population size and trend, fecundity, associations with habitats and other species, and dispersal ability. Certain traits can, therefore, be used to assess the likelihood that these factors will affect a given species. The importance of individual factors influencing adaptive capacity will vary across taxa, depending on the projected impact of each. In particular, factors affecting dispersal are not highly relevant to species with high modelled overlap between their current and projected climate space. Thus, adaptive capacity is assessed separately for the projected changes in climate space ratio and climate space overlap.

The general ecological traits that constrain the adaptive capacity of all species are:

- Small population and/or range in Europe
- Low survival and/or productivity rates
- Long generation times
- Declining population in Europe
- Low genetic diversity
- Specialised and uncommon habitat requirements
- Narrow niche
- Critical association with another vulnerable species.

These will hereafter be called **General Restrictions**.

For species with <70% overlap in projected climate space (i.e. a Moderate, High or Very High Climate Overlap Impact), an additional assessment is carried out of the following traits, indicating their likely colonisation ability:

- Barriers to dispersal (e.g. water, topography and man-made barriers)
- Limited dispersal and/or colonisation ability
- Mainly distributed in fragmented habitats that limit dispersal.

These will hereafter be called **Colonisation Restrictions**.

4.2 Scoring of traits

For each species, each adaptive capacity trait is scored on a scale that ranges from zero to two as follows:

0 = no constraint on adaptation
1 = moderate constraint
2 = severe constraint.

Various datasets and references have been used to score the traits for each species, according to consistent qualitative thresholds where possible. For example, the assessment of declines in bird populations is based on the decline thresholds and assessments in BirdLife International's latest assessment of the status of birds in Europe (BirdLife International, 2004a). However, several traits and some species cannot be assessed quantitatively, and these are therefore assessed by expert judgement, taking into account general published information on life histories, habitat use and other ecological characteristics, and comparing this with the modelled distributions of climate space and maps of habitat and topography.

To illustrate the process of scoring adaptive capacity constraints, the worked example of the Meadow Viper (*Vipera ursinii*) will be continued in Tables 3 and 4. Based on expert judgement and available life history data, the Meadow Viper was judged to have two General Restrictions to its adaptive capacity: a moderate constraint (score 1) attributed to its regional European range and a severe constraint (score 2) imposed by significant population declines. The Meadow Viper was also judged to have two Colonisation Restrictions to its adaptive capacity: a moderate constraint from its limited dispersal ability (score 1) and a moderate constraint attributed to significant habitat fragmentation (score 1).

Table 3: Adaptive capacity scoring for the Meadow Viper (*Vipera ursinii*). See text for explanations.

Adaptive Capacity Restriction	Ecological Trait	Adaptive Capacity Score
General restrictions	Small population and/or range in Europe	1
	Low survival and/or productivity rates	
	Long generation times	
	Declining population in Europe	2
	Low genetic diversity	
	Specialised and uncommon habitat requirements	
	Narrow niche	
	Critical association with another vulnerable species	
	Subtotal	3
Colonisation restrictions	Barriers to dispersal (e.g. water, topography and man-made barriers)	
	Limited dispersal and/or colonisation ability	1
	Mainly distributed in fragmented habitats that limit dispersal	1
	Subtotal	2

Using the above adaptive capacity constraint calculations, the sum of trait scores (excluding Colonisation Restriction traits for species with >70% overlap in climate space, i.e. with a low Overlap Impact) is calculated and used to define an **Adaptive Capacity Constraint Score** as follows:

Low = score < 2
Moderate = 2-4
High = >4.

Bringing the above together, Table 4 complements the Meadow Viper's *impact assessment* from the previous section with the scoring of its *adaptive capacity*, producing Adaptive Capacity Constraint Scores for several GHG emission scenarios (SRES A1F1, A2, B1, B2). Each Adaptive Capacity Constraint Score is calculated as follows: when the *Overlap Impact Category* is moderate or greater, the score equals the sum of the *General Restriction* and the *Colonisation Restriction* scores; if the *Overlap Impact Category* is low (i.e. species with >70% overlap in climate space) only the *General Restriction* score is used. Because the Meadow Viper is projected to experience a moderate *Overlap Impact* to its suitable climate space under the A1F1 and B1 SRES scenario, the resulting Adaptive Capacity Constraint Score is "5" - a High constraint on its adaptive capacity. Under the A2 and B2 scenarios its total adaptive capacity score is "3" - a Moderate constraint on its adaptive capacity.

It is worth noting that in some cases there were insufficient data to adequately assess the degree of overlap between current and projected suitable climate space; in these cases, it is difficult to make firm conclusions about the amount of dispersal required to move to new areas.

Table 4: Impact and adaptive capacity scoring for the Meadow Viper (*Vipera ursinii*)

Impact Scoring						Adaptive Capacity Scoring			
Time Horizon	SRES Scenario	Overlap	Overlap Impact Category	Ratio	Ratio Impact Category	General Restriction Score	Colonisation Restriction Score	Total Adaptive Capacity Score	Adaptive Capacity Category
2050	A1F1	62.8%	MODERATE	125.0%	LOW ROBUSTNESS	3	2	3 + 2 = 5	HIGH
2050	A2	76.2%	LOW	164.0%	HIGH ROBUSTNESS	3	2	= 3	MODERATE
2050	B1	62.6%	MODERATE	125.2%	LOW ROBUSTNESS	3	2	3 + 2 = 5	HIGH
2050	B2	72.5%	LOW	149.7%	MODERATE ROBUSTNESS	3	2	= 3	MODERATE

4.3 Species vulnerability assessment

The overall vulnerability of each species is characterised according to categories based on the results of the impact and adaptive capacity assessments (see Tables 3 and 4). This is **calculated separately with respect to projected changes in the ratio of climate space and overlap in climate space**. The general assumption used in these categorisations is that there is little scope for adaptation where there is a reduction in range size; therefore, constraints on adaptive capacity will exacerbate the impacts of climate change. It is also assumed that many species have the potential to colonise new areas with suitable climate space (i.e. outside the areas of overlap). Therefore, unless critical constraints on adaptive capacity exist, the impacts of reduced overlap in climate space will be mitigated by some degree of adaptation. In other words, the **vulnerability assessment characterises a projected reduction in climate space as a higher level of vulnerability than a reduction of climate space overlap**.

The vulnerability assessment categories are as shown in Tables 5 and 6 and visualised in Figure 3.

Finally, the two separate vulnerability assessments (for ratio, overlap) are compared and the highest vulnerability category taken to be the species' overall measure of vulnerability. This simple rule is used because impacts are unlikely to be fully additional, and we do not have enough information to assess potential interactions.

To complete the example of the Meadow Viper, the impact and adaptive capacity categories are used to assign a vulnerability category. For example under the A1F1 scenario, the Meadow Viper exhibits a "moderate" impact category for overlap and a "high" adaptive capacity constraints category. When these are used with Table 6, the vulnerability assessment category is identified as "high" for overlap. The Meadow Viper has been assigned a "low robustness" for the climate ratio metric; however, Tables 5 and 6 do not illustrate the lookup values for this somewhat unusual outcome.

In this report, the additional vulnerability assessment categories "low positive" and "moderate positive" have been created and used to characterize those species with slight impacts on climate space overlap AND total gains in suitable climate space (i.e. ratio) AND low constraints to adaptive capacity. It applies to a small number of birds, herpetiles, plants and butterflies, discussed in Section 5.4.

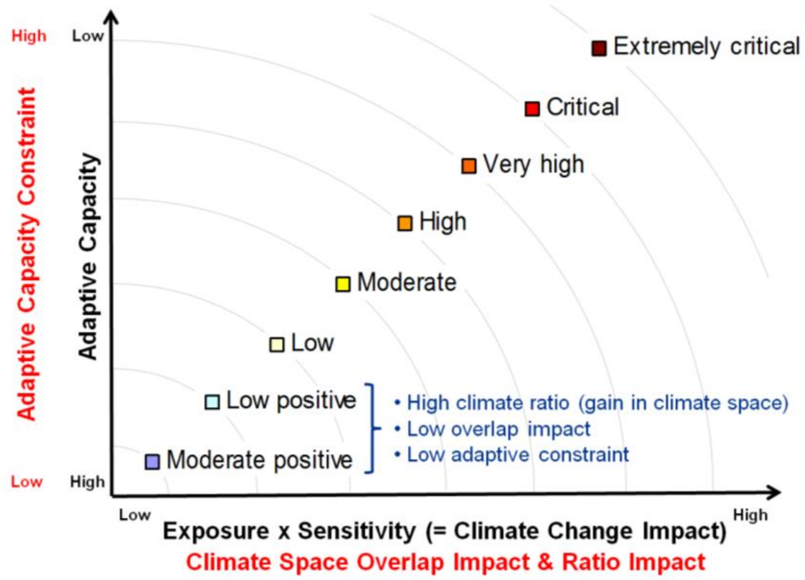
Table 5: Vulnerability assessment with respect to reductions in climate space (ratio). The Vulnerability Categories are defined by combining the Climate Ratio Impact Category with the Adaptive Capacity Constraint Score. For example, a Very High climate ratio impact combined with a Moderate adaptive capacity constraint means that Vulnerability is ranked as Critical.

Adaptive Capacity Constraint				
High	High	Very High	Critical	Extremely Critical
Moderate	Moderate	High	Very High	Critical
Low	Low	Moderate	High	Very High
	Low	**Moderate**	**High**	**Very High**
	Climate Ratio Impact Category			

Table 6: Vulnerability assessment with respect to reductions in climate space overlap. The Vulnerability Categories are defined by combining the Climate Overlap Impact Category with the Adaptive Capacity Constraint Score. For example, a High climate overlap impact combined with a Low adaptive capacity constraint means that Vulnerability is ranked as Moderate.

Adaptive Capacity Constraint				
High	Moderate	High	Very High	Critical
Moderate	Low	Moderate	High	Very High
Low	None	Low	Moderate	High
	Low	**Moderate**	**High**	**Very High**
	Climate Overlap Impact Category			

Figure 3: Vulnerability assessment, the vulnerability categories visually explained



5 Results

5.1 Impact assessment

The sample results presented below (see Table 7) illustrate the application of the impact assessment methodology to some of the reptile and amphibian, butterfly and breeding bird species considered in the study. The full analyses for all species are given in the appendices at the end of this report.

Considerable variation was observed in the results of the impact assessment and this was largely a function of the climate assumptions and time slices used in the modelling studies. Assessments for reptiles and amphibians were confined to the 2050s, butterflies and plants spanned the 2050s and 2080s, and the assessment for birds looked only at 2100.

The reptiles and amphibians show little variation in the degree of overlap and total change in climate space among SRES scenarios; this accords with GCM outputs which also show little variation between scenarios up to the 2050s (Jenkins and Lowe, 2003). Greater variance begins to emerge among butterflies and plants when assessing data for the 2080s; here the high (A1F1) SRES scenario typically produces the greatest change in potential suitable climate space. Data from 2100 further illustrates this trend; even the low (B1) SRES scenario produces large changes in potential suitable climate space, both in terms of overlap and total change in climate space.

Table 7: Impact assessment framework for three time horizons (2050, 2080 and 2100) and associated SRES scenarios (A1F1, A2, B1, B2), for a subset of species to illustrate the ranking process

		IMPACT ASSESSMENT					
		Exposure		Sensitivity			
Species	Scientific name	Horizon	Scenario	Overlap	Category	Ratio	Category
		Horizon 2050					
European Leaf-toed Gecko	*Phyllodactylus europaeus*	2050	A1F1	54%	Moderate	101%	Low robustness
European Leaf-toed Gecko	*Phyllodactylus europaeus*	2050	B1	51%	Moderate	91%	Low
European Leaf-toed Gecko	*Phyllodactylus europaeus*	2050	B2	53%	Moderate	88%	Low
Iberian Rock Lizard	*Lacerta monticola*	2050	A1F1	48%	High	51%	Moderate
Iberian Rock Lizard	*Lacerta monticola*	2050	B1	54%	Moderate	58%	Moderate
Iberian Rock Lizard	*Lacerta monticola*	2050	B2	56%	Moderate	61%	Moderate
Spectacled Salamander	*Salamandrina terdigitata*	2050	A1F1	25%	Very High	68%	Moderate
Spectacled Salamander	*Salamandrina terdigitata*	2050	B1	32%	High	85%	Low
Spectacled Salamander	*Salamandrina terdigitata*	2050	B2	25%	Very High	74%	Low
Great Crested Newt	*Triturus cristatus*	2050	A1F1	87%	Low	111%	Low robustness
Great Crested Newt	*Triturus cristatus*	2050	B1	87%	Low	110%	Low robustness
Great Crested Newt	*Triturus cristatus*	2050	B2	84%	Low	107%	Low robustness
Danube Clouded Yellow	*Colias myrmidone*	2050	A1FI	no data	Moderate	64%	Moderate
Danube Clouded Yellow	*Colias myrmidone*	2050	A2	no data	High	49%	High
Danube Clouded Yellow	*Colias myrmidone*	2050	B1	no data	Low	92%	Low
		Horizon 2080					
Danube Clouded Yellow	*Colias myrmidone*	2080	A2	no data	High	30%	High
Danube Clouded Yellow	*Colias myrmidone*	2080	A1FI	no data	High	37%	High
Danube Clouded Yellow	*Colias myrmidone*	2080	B1	no data	Moderate	55%	Moderate
Silver-spotted Skipper	*Hesperia comma catena*	2080	A1FI	no data	High	40%	High
Silver-spotted Skipper	*Hesperia comma catena*	2080	B1	no data	Moderate	61%	Moderate
Silver-spotted Skipper	*Hesperia comma catena*	2080	A2	no data	Moderate	54%	Moderate
Fenton's Wood White	*Leptidea morsei*	2080	A1FI	no data	Low	91%	Low
Fenton's Wood White	*Leptidea morsei*	2080	A2	no data	Low	87%	Low
Fenton's Wood White	*Leptidea morsei*	2080	B1	no data	Low	81%	Low
		Horizon 2100					
Cinereous Vulture	*Aegypius monachus*	2100	B2	8%	Very High	107%	Low robustness
Barbary Partridge	*Alectoris barbara*	2100	B2	1%	Very High	4%	Very High
Hazel Grouse	*Bonasa bonasia*	2100	B2	62%	Moderate	74%	Low
Moustached Warbler	*Acrocephalus melanopogon*	2100	B2	7%	Very High	158%	High robustness
Aquatic Warbler	*Acrocephalus paludicola*	2100	B2	0%	Very High	79%	Low
Boreal Owl	*Aegolius funereus*	2100	B2	58%	Moderate	68%	Moderate
Rock Partridge	*Alectoris graeca*	2100	B2	18%	Very High	183%	Very high robustness
Lesser White-fronted Goose	*Anser erythropus*	2100	B2	27%	Very High	28%	Very High
Tawny Pipit	*Anthus campestris*	2100	B2	35%	High	85%	Low
White-rumped Swift	*Apus caffer*	2100	B2	0%	Very High	89%	Low
Spanish Imperial Eagle	*Aquila adalberti*	2100	B2	12%	Very High	195%	Very high robustness

5.2 Adaptive capacity traits

Table 8 provides examples for the scoring of constraints on adaptive capacity and dispersal. The results were compatible with the general life history information for individual species. For example, many of the breeding bird species had either low to moderate constraints to dispersal, while those of reptiles and amphibians were routinely moderate to high. Information to support the assessment of adaptive capacity traits and constraints on dispersal was lacking for some categories, such as habitat fragmentation and levels of genetic diversity. A number of species were difficult to assess, as detailed life history data were not available to support judgements.

Table 8: Examples of adaptive capacity constraints

Species	Scientific name	Constraints to adaptive capacity	Constraints to dispersal
Cinereous Vulture	*Aegypius monachus*	Moderate	Moderate
Barbary Partridge	*Alectoris barbara*	Moderate	Moderate
Hazel Grouse	*Bonasa bonasia*	Low	Moderate
Moustached Warbler	*Acrocephalus melanopogon*	Low	Low
Aquatic Warbler	*Acrocephalus paludicola*	Moderate	Low
Boreal Owl	*Aegolius funereus*	Low	Moderate
Rock Partridge	*Alectoris graeca*	Low	Moderate
Lesser White-fronted Goose	*Anser erythropus*	Moderate	Low
Tawny Pipit	*Anthus campestris*	Moderate	Low
White-rumped Swift	*Apus caffer*	Low	Low
Spanish Imperial Eagle	*Aquila adalberti*	Moderate	Moderate
Golden Eagle	*Aquila chrysaetos*	Low	Low
Greater Spotted Eagle	*Aquila clanga*	Moderate	Low
Imperial Eagle	*Aquila heliaca*	Moderate	Low
Squacco Heron	*Ardeola ralloides*	Low	Low
Short-eared Owl	*Asio flammeus*	Low	Low
Ferruginous Duck	*Aythya nyroca*	Moderate	Low
Barnacle Goose	*Branta leucopsis*	Low	Low
Silver-spotted Skipper	*Hesperia comma catena*	Moderate	High
Fenton's Wood White	*Leptidea morsei*	High	Low
European Leaf-toed Gecko	*Phyllodactylus europaeus*	Moderate	Moderate
Iberian Rock Lizard	*Lacerta monticola*	Moderate	Moderate
Alpine Salamander	*Salamandra atra*	High	Moderate
Spectacled Salamander	*Salamandrina terdigitata*	Moderate	Moderate
Great Crested Newt	*Triturus cristatus*	Moderate	Moderate
Danube Clouded Yellow	*Colias myrmidone*	High	High

5.3 Vulnerability assessment

The full set of completed vulnerability assessments for all species is given in Annexes 1 to 4. To provide an example, vulnerability assessments for two species of plants are shown in Table 9.

Assessment data for breeding birds were only available for 2100 and for the medium-low (B2) SRES scenario. A large number exhibit ‘high’ or ‘very high’ vulnerability to climate change (see Table 10, see also Fig. 7 in Task Report 3a); 54% show less than 25% overlap between existing and projected suitable climate space. Therefore, significant range shifts would be required to colonise potential suitable climate space. Many birds are highly mobile and some are migratory, so the major constraint to dispersal is likely to be the availability of suitable habitat and the condition of their populations (e.g. whether recruitment is sufficient to support significant emigration).

Table 9: Sample vulnerability assessments for two selected species, with two time horizons (2050, 2080) and all four applied SRES scenarios (A1=A1F1, A2, B1, B2).

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
Plants	Aquilegia pyrenaica		2050	A1	0.589	0.820	0	0	-1	-1	-1	Low
			2050	A2	0.646	0.881	0	0	-1	-1	-1	Low
			2050	B1	0.650	0.873	0	0	-1	-1	-1	Low
			2050	B2	0.639	0.890	0	0	-1	-1	-1	Low
			2080	A1	0.296	0.639	0	0	-3	-2	-3	High
			2080	A2	0.460	0.714	0	0	-2	-1	-2	Moderate
			2080	B1	0.539	0.769	0	0	-1	-1	-1	Low
			2080	B2	0.539	0.761	0	0	-1	-1	-1	Low
Plants	Arabis scopoliana		2050	A1	0.561	1.010	1	1	-2	0	-2	Moderate
			2050	A2	0.675	1.090	1	1	-2	0	-2	Moderate
			2050	B1	0.696	1.146	1	1	-2	0	-2	Moderate
			2050	B2	0.645	1.113	1	1	-2	0	-2	Moderate
			2080	A1	0.349	1.163	1	1	-3	0	-3	High
			2080	A2	0.671	2.014	1	1	-2	3	-2	Moderate
			2080	B1	0.621	1.335	1	1	-2	1	-2	Moderate
			2080	B2	0.563	1.197	1	1	-2	0	-2	Moderate

Table 10: Vulnerability assessment of breeding birds to climate change (SRES Med-Low B2; Horizon 2070-99). See also Fig. 7 in Task Report 3a.

Breeding birds		
Vulnerability	**B2, 2070-2099**	
Category	**n**	**%**
Extremely Critical	2	1%
Critical	24	16%
Very High	51	34%
High	41	28%
Moderate	22	15%
Low	8	5%
(Low positive)	0	0%
(Moderate positive)	1	1%
Total	**149**	**100%**

Assessment data for reptile and amphibian species were only available for 2050. Variations between the medium-low (B2) and high (A1F1) SRES scenarios are small (see Table 11; see also Figs. 3 and 4 in Task Report 3a). This mirrors trends for other taxa modelled to 2050, where many exhibit 'low' vulnerability to climate change or even 'moderate positive'. For many reptiles and amphibians, there is broad overlap between current and projected climate space, accompanied by moderate to large amounts of newly suitable climate space. These species do not have large dispersal capabilities and have special habitat requirements (e.g. the cave-dwelling Olm, *Proteus anguinus*) and therefore cannot easily colonise new areas of habitat. Still others have restricted geographic distributions (e.g. Italian Agile Frog *Rana latastei*) and limited ability to take advantage of potential expansions of suitable climate space. Despite these restrictions, many reptiles and amphibians are not as dependent on specific habitat types as some taxonomic groups such as butterflies, and a small proportion of species might benefit from modest climate warming. These are species that exhibit three characteristics: 1) slight reductions of overlap between current and projected climate space, 2) significant gains in total suitable climate space (i.e. ratio > 100%), and 3) low or no constraints to dispersal; such species are discussed in Section 5.4.

Table 11: Summary of selected vulnerability assessments of reptiles and amphibians to climate change (SRES Med-Low B2, High A1F1; 2050; SRES A2 and B1 assessments were also conducted but are not summarised here). See also Figs. 3 and 4 in Task Report 3a.

Reptiles and amphibians				
Vulnerability	**B2, 2050**		**A1F1, 2050**	
Category	**n**	**%**	**n**	**%**
Extremely Critical	0	0%	0	0%
Critical	0	0%	0	0%
Very High	1	4%	1	4%
High	6	25%	9	38%
Moderate	4	17%	2	8%
Low	10	42%	9	38%
(Low positive)	0	0%	0	0%
(Moderate positive)	3	13%	3	13%
Total	**24**	**100%**	**24**	**100%**

Assessment data for butterflies were available for both the 2050s and 2080s. Small but noticeable trends were observed between the low (B1) and high (A1F1) SRES scenarios for both time horizons (see Table 12; see also Fig. 5 in Task Report 3a). Trends for butterflies are similar to other taxa modelled to 2050, where the majority exhibit ‘low’ or ‘moderate’ vulnerability to climate change. By 2080, increasing numbers of species exhibit a ‘high’ to ‘critical’ vulnerability. Interestingly, by 2080 a few species score ‘low positive’ to climate change, suggesting that they may be adaptable enough to cope with significant environmental change. However, there were insufficient data to adequately assess the degree of overlap between current and projected suitable climate space and, as such, it is difficult to make firm conclusions about the amount of dispersal required to move to new areas. Generalist species (e.g. *Lycaena dispar*) with minimal habitat or food plant dependencies might expand their ranges in response to climate change, while species restricted to particular habitats (e.g. *Erebia medusa polaris*) or with dependencies on plant species impacted by climate change may continue to decline.

Table 12: Summary of selected vulnerability assessments of butterflies to climate change (SRES Low B1, High A1F1; 2050, 2080). See also Fig. 5 in Task Report 3a.

Butterflies								
Vulnerability	**B1, 2050**		**A1F1, 2050**		**B1, 2080**		**A1F1, 2080**	
Category	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Extremely Critical	0	0%	0	0%	0	0%	0	0%
Critical	0	0%	0	0%	0	0%	1	8%
Very High	0	0%	1	8%	1	8%	1	8%
High	2	15%	3	23%	3	23%	5	38%
Moderate	5	38%	3	23%	3	23%	3	23%
Low	6	46%	5	38%	3	23%	1	8%
(Low positive)	0	0%	1	8%	3	23%	2	15%
(Moderate positive)	0	0%	0	0%	0	0%	0	0%
Total	**13**	**100%**	**13**	**100%**	**13**	**100%**	**13**	**100%**

Assessment data for vascular plants were available for both the 2050s and 2080s. Small but noticeable trends were observed from the medium-low (B2) to high (A1F1) SRES scenarios for both time horizons (see Table 13; see also Fig. 6 in Task Report 3a). Again, these trends were similar to other taxa modelled to 2050, with the majority showing ‘low’ vulnerability to climate change. Trends by 2080 shift towards ‘moderate’ to high’ vulnerability, with some species that exhibit a ‘moderate positive’ in the 2050s and under the medium-low (B2) SRES scenario for the 2080s becoming vulnerable under the high (A1F1) scenario. Many species exhibited small to moderate declines in overlap between existing and projected suitable climate space and, in some instances, significant increases in overall suitable climate space. However, data were not available to support the assessment of dispersal ability or to assess the importance of temperature cues for essential physiological processes.

Table 13: Summary of selected vulnerability assessments of vascular plants to climate change (SRES Med-Low B2, High A1F1; 2050, 2080). See also Fig. 6 in Task Report 3a.

Vascular plants								
Vulnerability	**B2, 2050**		**A1F1, 2050**		**B2, 2080**		**A1F1, 2080**	
Category	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Extremely Critical	0	0%	0	0%	0	0%	0	0%
Critical	0	0%	0	0%	0	0%	0	0%
Very High	0	0%	0	0%	1	4%	2	8%
High	2	8%	2	8%	2	8%	10	38%
Moderate	3	12%	8	31%	7	27%	9	35%
Low	17	65%	13	50%	12	46%	5	19%
(Low positive)	0	0%	0	0%	0	0%	0	0%
(Moderate positive)	4	15%	3	12%	4	15%	0	0%
Total	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**

5.4 Species that may benefit from climate change

Whilst the purpose of this study was to identify and assess the vulnerability of species of Community Interest to climate change, the assessment process also ranked some species as “low positive” or “moderate positive”, i.e. species that may benefit from climate change.

The individual species that were ranked “low positive” or “moderate positive” can be identified in the Annexes in the far right column, and are extracted again in Table 14.

Table 14: Assessed species across all taxa groups ranked either “low positive” or “moderate positive” (potentially benefitting from climate change), with the respective SRES scenarios and time horizons.

Taxon Group	Species	SRES	Time Horizon
Birds	*Alcedo atthis*	B2	2070-2099
Reptiles	*Lacerta schreiberi*	A1F1, A2, B1, B2	2050
Butterflies	*Coenonympha oedippus*	A1F1, A2, B1	2080
	Erebia medusa polaris	A2, B1	2080
	Melanargia arge	A1F1, A2, B1	2080
	Plebejus grandon	A1F1	2050
Vascular plants	*Asplenium adulterinum*	B1	2050
	Dianthus rupicola	A1F1, A2, B1, B2	2050
		A2, B1, B2	2080
	Hemiaria latifolia	A1F1, A2, B1, B2	2050
		A2, B1, B2	2080
	Paeonia oficinalis	A1F1, A2, B1, B2	2050
		A2, B1, B2	2080
	Sisymbrium supinum	A2, B1, B2	2050
		A2, B1, B2	2080

The impact assessment for reptiles and amphibians identified examples of high levels of overlap and relative increases in potential suitable climate space, with implicit potential benefits for the species concerned. This was mirrored in the vulnerability assessment, where 12.5% of species were ranked “moderate positive” under both the medium-low (B2) and high (A1F1) SRES scenarios for the 2050s.

Similarly for butterflies, where 23% of species assessed were ranked “low positive” under the low (B1) SRES scenario for the 2080s and 15% under the high (A1F1) scenario.

For vascular plants, 15% scored “moderate positive” under the medium-low (B2) SRES scenario for the 2050s and 2080s, and 11.5% under the high (A1F1) scenario for the 2080s.

However, the breeding birds that were assessed in the study did not follow these trends; only one species (<1%) was ranked “moderate positive” under the medium-low (B2) SRES scenario for 2100.

6 Discussion

This study has developed and applied an approach for assessing the overall vulnerability of species to projected changes in climate. The vulnerability assessments go beyond the estimation of potential impacts (i.e. the combined effects of exposure and sensitivity), which have been published for various taxa, by additionally considering each species' adaptive capacity. Thus the results provide for the first time a more complete, though preliminary, assessment of the effects of climate change on species populations.

It is, therefore, of **considerable concern that the results show that the vast majority of species from each taxonomic group are likely to be vulnerable to some extent**. In other words, it appears that very few species of Community Interest are likely to benefit overall from climate change, even when the modelled projections suggest there will be an expansion in their suitable climate space. This is because areas of potentially suitable climate space progressively move away from currently inhabited areas; species will therefore need to move to and colonise new areas of climate space. **For most species, the projected impacts from a reduction in suitable climate space are likely to be smaller than those from a reduction in overlap**.

The assessments show that **vulnerability primarily arises because many species will be constrained in their ability to move to and colonise new areas with suitable climate** (e.g. because of limited dispersal abilities, lack of suitable habitat, or low levels of emigration due to small population sizes etc). In fact, as a result of such constraints, this study suggests that a **significant proportion of species of Community Interest have a high or greater level of vulnerability** to climate change (particularly for projections beyond 2080). To some extent this is not surprising, as most species of Community Interest are rare and have specific habitat requirements or are otherwise threatened. Furthermore, evidence from Article 17 assessments under the Habitats Directive indicates that a large proportion of species of Community Interest currently have unfavourable conservation status[4]. Monitoring data for birds (BirdLife International, 2004a,b) shows a similar situation for those listed in Annex 1 of the Birds Directive, even though there is evidence that the Directive has had some beneficial impacts (Donald *et al.*, 2007).

The availability of suitable habitat within new areas of suitable climate is likely to be a particular problem for species of Community Interest. Many of such species are habitat specialists and are already constrained by habitat availability and/or condition; climate change is likely to exacerbate such threats, rather than create new opportunities. The protection of Natura 2000 sites that currently provide suitable habitat for such species should therefore be a priority (this is examined further in Task 3a). However, as described in the review of adaptation principles (see Task Report 2b & 3b, Section 2), it will be equally important to improve the resilience of existing populations by improved management of habitats, and where necessary expansion and reconnection of habitats to create a functionally coherent network. Such measures will also support the redistribution of species, which is likely to become increasingly important in the longer-term.

The results of this task should, however, be treated with some caution. This is firstly because there are many uncertainties and limitations concerning the use of climate models in projecting impacts on biodiversity (Ad Hoc Technical Expert Group on Biodiversity and Climate Change, 2008). Given that ecological constraints and limiting factors are prone to be species-specific, modelling and the underlying standardised climate variables can only provide an approximation to real impact experienced by a particular species or habitat. Secondly, and more importantly, this vulnerability assessment is of a preliminary nature as it

[4] The Article 17 assessment do not cover birds

has essentially relied on an expert-based subjective assessment of adaptation constraints. There is little information on the actual relationships between adaptation constraints and adaptation responses are largely unknown. Thus the scoring systems and thresholds for each category of vulnerability are arbitrary and they cannot be calibrated against projected changes in population or range.

It is, therefore, suggested that further research is needed to link species climate models with models of dispersal probability and currently and potentially available habitat. Although some research has been conducted using a similar approach (Vos *et al.*, 2008) this needs to be extended to more species and wider areas, and underpinned by more detailed ecologically meaningful spatial habitat data. Such studies also need to take into account the potential time lags between habitat establishment and species' needs for suitable habitats as they move to new areas of climate space.

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8 Appendices

Appendix 1: Vulnerability assessment tables: breeding birds

Appendix 2: Vulnerability assessment tables: reptiles and amphibians

Appendix 3: Vulnerability assessment tables: butterflies

Appendix 4: Vulnerability assessment tables: vascular plants

Appendix 1: Breeding birds

Model based vulnerability assessment for breeding birds in the EU listed on Annex I of the Birds Directive.

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
ANSERIFORMES	Anser erythropus	Lesser White-fronted Goose	2070-99	B2	0.06	0.06	2	2	-5	-6	-6	Extremely critical
ANSERIFORMES	Aythya nyroca	Ferruginous Duck	2070-99	B2	0.23	1.00	1	1	-4	0	-4	Very High
ANSERIFORMES	Branta leucopsis	Barnacle Goose	2070-99	B2	0.06	0.19	1	1	-4	-5	-5	Critical
ANSERIFORMES	Cygnus bewickii	Tundra Swan	2070-99	B2	0.11	0.11	0	0	-3	-4	-4	Very High
ANSERIFORMES	Cygnus cygnus	Whooper Swan	2070-99	B2	0.39	0.47	1	1	-3	-4	-4	Very High
ANSERIFORMES	Marmaronetta angustirostris	Marbled Teal	2070-99	B2	0.00	2.33	1	1	-4	3	-4	Very High
ANSERIFORMES	Mergus albellus	Smew	2070-99	B2	0.04	0.26	1	1	-4	-5	-5	Critical
ANSERIFORMES	Oxyura leucocephala	White-headed Duck	2070-99	B2	0.00	0.00	1	1	-4	-5	-5	Critical
ANSERIFORMES	Tadorna ferruginea	Ruddy Shelduck	2070-99	B2	0.19	1.01	1	1	-4	0	-4	Very High
APODIFORMES	Apus caffer	White-rumped Swift	2070-99	B2	0.00	1.27	0	0	-3	1	-3	High
CAPRIMULGIFORMES	Caprimulgus europaeus	Eurasian Nightjar	2070-99	B2	0.57	0.87	1	1	-2	-2	-2	Moderate
CHARADRIIFORMES	Burhinus oedicnemus	Eurasian Thick-knee	2070-99	B2	0.31	0.90	1	1	-3	-2	-3	High
CHARADRIIFORMES	Charadrius alexandrinus	Kentish Plover	2070-99	B2	0.54	1.56	1	1	-2	2	-2	Moderate
CHARADRIIFORMES	Charadrius morinellus	Eurasian Dotterel	2070-99	B2	0.23	0.43	1	1	-4	-4	-4	Very High
CHARADRIIFORMES	Chlidonias hybridus	Whiskered Tern	2070-99	B2	0.15	0.71	0	0	-3	-1	-3	High
CHARADRIIFORMES	Chlidonias niger	Black Tern	2070-99	B2	0.19	0.66	1	1	-4	-3	-4	Very High
CHARADRIIFORMES	Gallinago media	Great Snipe	2070-99	B2	0.21	0.38	1	1	-4	-4	-4	Very High
CHARADRIIFORMES	Gelochelidon nilotica	Gull-billed Tern	2070-99	B2	0.03	1.13	1	1	-4	0	-4	Very High
CHARADRIIFORMES	Glareola pratincola	Collared Pratincole	2070-99	B2	0.15	1.24	1	1	-4	0	-4	Very High
CHARADRIIFORMES	Himantopus himantopus	Black-winged Stilt	2070-99	B2	0.28	1.05	0	0	-3	1	-3	High
CHARADRIIFORMES	Larus audouinii	Audouin's Gull	2070-99	B2	0.00	0.14	1	1	-4	-5	-5	Critical
CHARADRIIFORMES	Larus melanocephalus	Mediterranean Gull	2070-99	B2	0.07	0.72	1	1	-4	-2	-4	Very High
CHARADRIIFORMES	Larus minutus	Little Gull	2070-99	B2	0.33	0.60	0	0	-2	-2	-2	Moderate
CHARADRIIFORMES	Limosa lapponica	Bar-tailed Godwit	2070-99	B2	0.08	0.25	1	1	-4	-5	-5	Critical
CHARADRIIFORMES	Phalaropus lobatus	Red-necked Phalarope	2070-99	B2	0.25	0.34	0	0	-3	-3	-3	High
CHARADRIIFORMES	Philomachus pugnax	Ruff	2070-99	B2	0.42	0.52	1	1	-3	-3	-3	High
CHARADRIIFORMES	Pluvialis apricaria	Eurasian Golden-plover	2070-99	B2	0.51	0.61	0	0	-1	-2	-2	Moderate
CHARADRIIFORMES	Recurvirostra avosetta	Pied Avocet	2070-99	B2	0.17	0.52	0	0	-3	-2	-3	High
CHARADRIIFORMES	Sterna albifrons	Little Tern	2070-99	B2	0.17	0.71	1	1	-4	-2	-4	Very High
CHARADRIIFORMES	Sterna caspia	Caspian Tern	2070-99	B2	0.17	0.51	1	1	-4	-3	-4	Very High
CHARADRIIFORMES	Sterna dougallii	Roseate Tern	2070-99	B2	0.41	1.04	1	1	-3	0	-3	High
CHARADRIIFORMES	Sterna hirundo	Common Tern	2070-99	B2	0.55	0.71	0	0	-1	-1	-1	Low
CHARADRIIFORMES	Sterna paradisaea	Arctic Tern	2070-99	B2	0.39	0.43	1	1	-3	-4	-4	Very High
CHARADRIIFORMES	Sterna sandvicensis	Sanwich Tern	2070-99	B2	0.30	0.63	1	1	-3	-3	-3	High
CHARADRIIFORMES	Tringa glareola	Wood Sandpiper	2070-99	B2	0.50	0.56	0	0	-1	-2	-2	Moderate
CHARADRIIFORMES	Xenus cinereus	Terek Sandpiper	2070-99	B2	0.11	0.18	1	1	-4	-5	-5	Critical
CICONIIFORMES	Ardea purpurea	Purple Heron	2070-99	B2	0.27	1.27	1	1	-4	0	-4	Very High
CICONIIFORMES	Ardeola ralloides	Squacco Heron	2070-99	B2	0.03	1.30	1	1	-4	1	-4	Very High
CICONIIFORMES	Botaurus stellaris	Bittern	2070-99	B2	0.34	0.75	1	1	-3	-2	-3	High
CICONIIFORMES	Ciconia ciconia	White Stork	2070-99	B2	0.49	0.94	0	0	-2	-1	-2	Moderate
CICONIIFORMES	Ciconia nigra	Black Stork	2070-99	B2	0.40	1.02	1	1	-3	0	-3	High
CICONIIFORMES	Egretta alba (Ardea alba)	Great White Egret	2070-99	B2	0.12	0.39	1	1	-4	-4	-4	Very High
CICONIIFORMES	Egretta garzetta	Little Egret	2070-99	B2	0.13	1.30	0	0	-3	2	-3	High
CICONIIFORMES	Ixobrychus minutus	Little Bittern	2070-99	B2	0.60	1.25	1	0	-2	1	-2	Moderate
CICONIIFORMES	Nycticorax nycticorax	Black-crowned Night-heron	2070-99	B2	0.19	1.30	0	0	-3	2	-3	High
CICONIIFORMES	Platalea leucorodia	Eurasian Spoonbill	2070-99	B2	0.01	0.92	1	1	-4	-2	-4	Very High
CICONIIFORMES	Plegadis falcinellus	Glossy Ibis	2070-99	B2	0.02	0.85	1	1	-4	-2	-4	Very High
CORACIIFORMES	Alcedo atthis	Kingfisher	2070-99	B2	0.79	1.13	0	0	0	1	0	Moderate positive
CORACIIFORMES	Coracias garrulus	European Roller	2070-99	B2	0.41	0.88	1	1	-3	-2	-3	High
FALCONIFORMES	Accipiter brevipes	Levant Sparrowhawk	2070-99	B2	0.29	1.14	1	1	-4	0	-4	Very High
FALCONIFORMES	Aegypius monachus	Cinereous Vulture	2070-99	B2	0.07	1.43	2	1	-5	1	-5	Critical
FALCONIFORMES	Aquila adalberti	Spanish Imperial Eagle	2070-99	B2	0.00	1.65	2	1	-5	2	-5	Critical
FALCONIFORMES	Aquila chrysaetos	Golden Eagle	2070-99	B2	0.36	0.83	2	1	-4	-2	-4	Very High
FALCONIFORMES	Aquila clanga	Greater Spotted Eagle	2070-99	B2	0.01	0.14	2	2	-5	-6	-6	Extremely critical
FALCONIFORMES	Aquila heliaca	Imperial Eagle	2070-99	B2	0.05	0.87	2	1	-5	-2	-5	Critical
FALCONIFORMES	Aquila pomarina	Lesser Spotted Eagle	2070-99	B2	0.22	0.96	1	1	-4	-2	-4	Very High
FALCONIFORMES	Buteo rufinus	Long-legged Buzzard	2070-99	B2	0.31	2.36	1	1	-3	3	-3	High
FALCONIFORMES	Circaetus gallicus	Short-toed Snake-eagle	2070-99	B2	0.38	1.14	1	1	-3	0	-3	High
FALCONIFORMES	Circus aeruginosus	Western Marsh-harrier	2070-99	B2	0.56	0.89	0	0	-1	-1	-1	Low
FALCONIFORMES	Circus cyaneus	Northern Harrier	2070-99	B2	0.38	0.51	1	1	-3	-3	-3	High
FALCONIFORMES	Circus macrourus	Pallid Harrier	2070-99	B2	0.02	0.06	2	1	-5	-5	-5	Critical
FALCONIFORMES	Circus pygargus	Montagu's Harrier	2070-99	B2	0.29	0.70	0	0	-3	-1	-3	High
FALCONIFORMES	Elanus caeruleus	Black-winged Kite	2070-99	B2	0.02	1.09	1	1	-4	0	-4	Very High
FALCONIFORMES	Falco biarmicus	Lanner Falcon	2070-99	B2	0.06	1.85	1	1	-4	3	-4	Very High
FALCONIFORMES	Falco cherrug	Saker Falcon	2070-99	B2	0.11	0.72	2	2	-5	-3	-5	Critical
FALCONIFORMES	Falco columbarius	Merlin	2070-99	B2	0.39	0.56	1	1	-3	-3	-3	High
FALCONIFORMES	Falco eleonorae	Eleonora's Falcon	2070-99	B2	0.36	2.94	1	1	-3	3	-3	High
FALCONIFORMES	Falco naumanni	Lesser Kestrel	2070-99	B2	0.70	1.49	1	1	-1	1	-1	Low
FALCONIFORMES	Falco peregrinus	Peregrine Falcon	2070-99	B2	0.53	1.06	0	0	-1	1	-1	Low
FALCONIFORMES	Falco rusticolus	Gyrfalcon	2070-99	B2	0.25	0.37	1	1	-4	-4	-4	Very High
FALCONIFORMES	Falco vespertinus	Red-footed Falcon	2070-99	B2	0.19	0.51	1	1	-4	-3	-4	Very High

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
FALCONIFORMES	Gypaetus barbatus	Lammergeier	2070-99	B2	0.09	0.46	2	2	-5	-5	-5	Critical
FALCONIFORMES	Gyps fulvus	Eurasian Griffon	2070-99	B2	0.19	0.38	1	1	-4	-4	-4	Very High
FALCONIFORMES	Haliaeetus albicilla	White-tailed Eagle	2070-99	B2	0.19	0.55	1	1	-4	-3	-4	Very High
FALCONIFORMES	Hieraaetus fasciatus	Bonelli's Eagle	2070-99	B2	0.52	1.33	2	2	-3	0	-3	High
FALCONIFORMES	Hieraaetus pennatus	Booted Eagle	2070-99	B2	0.25	0.79	1	1	-4	-2	-4	Very High
FALCONIFORMES	Milvus migrans	Black Kite	2070-99	B2	0.49	0.84	0	0	-2	-1	-2	Moderate
FALCONIFORMES	Milvus milvus	Red Kite	2070-99	B2	0.14	0.58	0	0	-3	-2	-3	High
FALCONIFORMES	Neophron percnopterus	Egyptian Vulture	2070-99	B2	0.30	0.97	2	2	-4	-3	-4	Very High
FALCONIFORMES	Pandion haliaetus	Osprey	2070-99	B2	0.48	0.58	1	1	-3	-3	-3	High
FALCONIFORMES	Pernis apivorus	European Honey-buzzard	2070-99	B2	0.62	0.82	0	0	-1	-1	-1	Low
GALLIFORMES	Alectoris barbara	Barbary Partridge	2070-99	B2	0.00	0.00	1	1	-4	-5	-5	Critical
GALLIFORMES	Alectoris graeca	Rock Partridge	2070-99	B2	0.16	1.95	1	1	-4	3	-4	Very High
GALLIFORMES	Bonasa bonasia	Hazel Grouse	2070-99	B2	0.56	0.68	1	1	-2	-3	-3	High
GALLIFORMES	Tetrao tetrix tetrix	Black Grouse	2070-99	B2	0.54	0.59	1	1	-2	-3	-3	High
GALLIFORMES	Tetrao urogallus	Capercaillie	2070-99	B2	0.57	0.62	1	1	-2	-3	-3	High
GAVIIFORMES	Gavia arctica	Black-throated Diver	2070-99	B2	0.46	0.55	0	0	-2	-2	-2	Moderate
GAVIIFORMES	Gavia stellata	Red-throated Diver	2070-99	B2	0.46	0.54	0	0	-2	-2	-2	Moderate
GRUIFORMES	Crex crex	Corncrake	2070-99	B2	0.47	0.71	1	1	-3	-2	-3	High
GRUIFORMES	Fulica cristata	Red-knobbed Coot	2070-99	B2	0.00	1.67	1	1	-4	2	-4	Very High
GRUIFORMES	Grus grus	Common Crane	2070-99	B2	0.46	0.58	1	1	-3	-3	-3	High
GRUIFORMES	Otis tarda	Great Bustard	2070-99	B2	0.05	0.34	2	1	-5	-4	-5	Critical
GRUIFORMES	Porphyrio porphyrio	Purple Swamphen	2070-99	B2	0.00	0.34	1	1	-4	-4	-4	Very High
GRUIFORMES	Porzana parva	Little Crake	2070-99	B2	0.21	0.65	0	0	-3	-2	-3	High
GRUIFORMES	Porzana porzana	Spotted Crake	2070-99	B2	0.33	0.62	0	0	-2	-2	-2	Moderate
GRUIFORMES	Porzana pusilla	Baillon's Crake	2070-99	B2	0.00	0.22	1	1	-4	-5	-5	Critical
GRUIFORMES	Tetrax tetrax	Little Bustard	2070-99	B2	0.14	0.61	1	1	-4	-3	-4	Very High
PASSERIFORMES	Acrocephalus melanopogon	Moustached Warbler	2070-99	B2	0.04	1.80	0	0	-3	4	-3	High
PASSERIFORMES	Acrocephalus paludicola	Aquatic Warbler	2070-99	B2	0.00	0.78	1	1	-4	-2	-4	Very High
PASSERIFORMES	Anthus campestris	Tawny Pipit	2070-99	B2	0.32	0.84	1	1	-3	-2	-3	High
PASSERIFORMES	Bucanetes githagineus	Trumpeter Finch	2070-99	B2	0.00	0.00	1	0	-4	-4	-4	Very High
PASSERIFORMES	Calandrella brachydactyla	Greater Short-toed Lark	2070-99	B2	0.65	1.15	1	1	-2	0	-2	Moderate
PASSERIFORMES	Chersophilus duponti	Dupont's Lark	2070-99	B2	0.00	0.00	1	1	-4	-5	-5	Critical
PASSERIFORMES	Emberiza caesia	Cretzschmar's Bunting	2070-99	B2	0.53	2.82	0	0	-1	4	-1	Low
PASSERIFORMES	Emberiza cineracea	Cinereous Bunting	2070-99	B2	0.00	1.38	1	1	-4	1	-4	Very High
PASSERIFORMES	Emberiza hortulana	Ortolan Bunting	2070-99	B2	0.57	1.03	1	1	-2	0	-2	Moderate
PASSERIFORMES	Ficedula albicollis	Collared Flycatcher	2070-99	B2	0.20	0.76	0	0	-3	-1	-3	High
PASSERIFORMES	Ficedula parva	Red-breasted Flycatcher	2070-99	B2	0.34	0.63	0	0	-2	-2	-2	Moderate
PASSERIFORMES	Ficedula semitorquata	Semi-collared Flycatcher	2070-99	B2	0.03	1.83	1	1	-4	3	-4	Very High
PASSERIFORMES	Galerida theklae	Thekla Lark	2070-99	B2	0.05	0.50	1	1	-4	-3	-4	Very High
PASSERIFORMES	Hippolais olivetorum	Olive-tree Warbler	2070-99	B2	0.49	2.96	0	0	-2	4	-2	Moderate
PASSERIFORMES	Lanius collurio	Red-backed Shrike	2070-99	B2	0.81	0.99	0	0	0	-1	-1	Low
PASSERIFORMES	Lanius minor	Lesser Grey Shrike	2070-99	B2	0.52	1.38	1	1	-2	1	-2	Moderate
PASSERIFORMES	Lanius nubicus	Masked Shrike	2070-99	B2	0.02	3.04	0	0	-3	4	-3	High
PASSERIFORMES	Loxia scotica	Scottish Crossbill	2070-99	B2	0.00	2.86	2	1	-5	3	-5	Critical
PASSERIFORMES	Lullula arborea	Wood Lark	2070-99	B2	0.60	0.94	1	1	-2	-2	-2	Moderate
PASSERIFORMES	Luscinia svecica	Bluethroat	2070-99	B2	0.31	0.48	0	0	-2	-3	-3	High
PASSERIFORMES	Melanocorypha calandra	Calandra Lark	2070-99	B2	0.63	1.19	1	1	-2	0	-2	Moderate
PASSERIFORMES	Oenanthe leucura	Black Wheatear	2070-99	B2	0.06	0.49	1	1	-4	-4	-4	Very High
PASSERIFORMES	Oenanthe pleschanka	Pied Wheatear	2070-99	B2	0.17	0.60	0	0	-3	-2	-3	High
PASSERIFORMES	Pyrrhocorax pyrrhocorax	Red-billed Chough	2070-99	B2	0.20	0.62	1	1	-4	-3	-4	Very High
PASSERIFORMES	Sitta krueperi	Krueper's Nuthatch	2070-99	B2	0.00	1.63	2	1	-5	2	-5	Critical
PASSERIFORMES	Sylvia nisoria	Barred Warbler	2070-99	B2	0.47	0.96	0	0	-2	-1	-2	Moderate
PASSERIFORMES	Sylvia rueppelli	Rueppell's Warbler	2070-99	B2	0.00	1.07	1	1	-4	0	-4	Very High
PASSERIFORMES	Sylvia sarda	Marmora's Warbler	2070-99	B2	0.00	0.61	1	0	-4	-2	-4	Very High
PASSERIFORMES	Sylvia undata	Dartford Warbler	2070-99	B2	0.39	0.86	2	1	-4	-2	-4	Very High
PELECANIFORMES	Phalacrocorax pygmeus	Pygmy Cormorant	2070-99	B2	0.07	0.01	1	1	-4	-5	-5	Critical
PHOENICOPTERIFORMES	Phoenicopterus ruber	Greater Flamingo	2070-99	B2	0.00	0.06	2	1	-5	-5	-5	Critical
PICIFORMES	Dendrocopos leucotos	White-backed Woodpecker	2070-99	B2	0.21	0.83	1	1	-4	-2	-4	Very High
PICIFORMES	Dendrocopos medius	Middle Spotted Woodpecker	2070-99	B2	0.34	0.83	1	0	-3	-1	-3	High
PICIFORMES	Dendrocopos syriacus	Syrian Woodpecker	2070-99	B2	0.41	1.12	0	0	-2	1	-2	Moderate
PICIFORMES	Dryocopus martius	Black Woodpecker	2070-99	B2	0.62	0.73	0	0	-1	-1	-1	Low
PICIFORMES	Picoides tridactylus	Three-toed Woodpecker	2070-99	B2	0.61	0.68	1	1	-2	-3	-3	High
PICIFORMES	Picus canus	Grey-faced Woodpecker	2070-99	B2	0.41	0.84	1	0	-3	-1	-3	High
PODICIPEDIFORMES	Podiceps auritus	Slavonian Grebe	2070-99	B2	0.19	0.61	1	1	-4	-3	-4	Very High
PROCELLARIIFORMES	Calonectris diomedea	Cory's Shearwater	2070-99	B2	0.06	0.50	1	1	-4	-3	-4	Very High
PROCELLARIIFORMES	Hydrobates pelagicus	European Storm-petrel	2070-99	B2	0.10	1.18	1	1	-4	0	-4	Very High
PROCELLARIIFORMES	Oceanodroma leucorhoa	Leach's Storm-petrel	2070-99	B2	0.11	0.89	1	1	-4	-2	-4	Very High
PROCELLARIIFORMES	Puffinus yelkouan	Yelkouan Shearwater	2070-99	B2	0.00	0.36	1	1	-4	-4	-4	Very High
PTEROCLIFORMES	Pterocles alchata	Pin-tailed Sandgrouse	2070-99	B2	0.16	0.87	2	1	-5	-2	-5	Critical
PTEROCLIFORMES	Pterocles orientalis	Black-bellied Sandgrouse	2070-99	B2	0.14	0.81	2	1	-5	-2	-5	Critical
STRIGIFORMES	Aegolius funereus	Boreal Owl	2070-99	B2	0.52	0.59	0	0	-1	-2	-2	Moderate
STRIGIFORMES	Asio flammeus	Short-eared Owl	2070-99	B2	0.37	0.49	1	1	-3	-4	-4	Very High
STRIGIFORMES	Bubo bubo	Eurasian Eagle-owl	2070-99	B2	0.39	0.74	1	0	-3	-1	-3	High
STRIGIFORMES	Glaucidium passerinum	Eurasian Pygmy-owl	2070-99	B2	0.51	0.68	1	0	-2	-2	-2	Moderate
STRIGIFORMES	Nyctea scandiaca	Snowy Owl	2070-99	B2	0.22	0.22	1	1	-4	-5	-5	Critical
STRIGIFORMES	Strix nebulosa	Great Grey Owl	2070-99	B2	0.19	0.27	1	1	-4	-5	-5	Critical
STRIGIFORMES	Strix uralensis	Ural Owl	2070-99	B2	0.45	0.65	1	1	-3	-3	-3	High
STRIGIFORMES	Surnia ulula	Northern Hawk Owl	2070-99	B2	0.40	0.56	1	1	-3	-3	-3	High

Modelled breeding birds data are from Huntley *et al.*, 2007. Climate projections for 2070-99 based on the Hadley Centre HadCM3 coupled atmosphere–ocean general circulation model using the B2 emissions scenario.

Overlap: The number of squares within the intersection between the projected and simulated recent ranges divided by the number of squares in the simulated recent range.

Ratio (remaining): The number of UTM squares in the projected range divided by the number in the simulated recent range.

Impact score / categories: EC = Extremely Critical (-6), C = Critical (-5), VH = Very High (-4), H = High (-3), M = Moderate (-2), L = Low (-1); - = reduction in climate space, + = increase in climate space.

Appendix 2: Reptiles and amphibians

Model based vulnerability assessment for amphibians and reptiles listed as N2K species. The SRES Scenario “A1” in the table stands for “A1F1”.

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst Vulnerability category
Reptiles	Caretta caretta	Loggerhead turtle	2050	A1	0.971	1.931	1	1	-1	3	-1	Low
			2050	A2	0.975	1.749	1	1	-1	3	-1	Low
			2050	B1	0.980	1.965	1	1	-1	3	-1	Low
			2050	B2	0.993	1.889	1	1	-1	3	-1	Low
Reptiles	Emys orbicularis	European pond turtle	2050	A1	0.907	1.592	1	1	-1	2	-1	Low
			2050	A2	0.950	1.656	1	1	-1	2	-1	Low
			2050	B1	0.933	1.659	1	1	-1	2	-1	Low
			2050	B2	0.938	1.623	1	1	-1	2	-1	Low
Reptiles	Mauremys leprosa	Mediterranean pond turtle	2050	A1	0.738	1.010	1	1	-1	0	-1	Low
			2050	A2	0.788	1.242	1	1	-1	0	-1	Low
			2050	B1	0.685	0.914	1	1	-2	-2	-2	Moderate
			2050	B2	0.752	1.100	1	1	-1	0	-1	Low
Reptiles	Mauremys caspica	Caspian pond turtle	2050	A1	0.998	1.749	1	1	-1	3	-1	Low
			2050	A2	0.999	1.580	1	1	-1	2	-1	Low
			2050	B1	0.998	1.605	1	1	-1	2	-1	Low
			2050	B2	0.997	1.720	1	1	-1	3	-1	Low
Reptiles	Testudo graeca	Greek tortoise	2050	A1	0.987	2.247	1	1	-1	3	-1	Low
			2050	A2	0.985	2.090	1	1	-1	3	-1	Low
			2050	B1	0.991	2.076	1	1	-1	3	-1	Low
			2050	B2	0.990	2.148	1	1	-1	3	-1	Low
Reptiles	Testudo hermanni	Hermann's tortoise	2050	A1	0.999	1.969	1	1	-1	3	-1	Low
			2050	A2	0.999	1.941	1	1	-1	3	-1	Low
			2050	B1	0.999	1.850	1	1	-1	3	-1	Low
			2050	B2	0.999	1.987	1	1	-1	3	-1	Low
Reptiles	Testudo marginata	Marginated tortoise	2050	A1	0.986	1.668	1	1	-1	2	-1	Low
			2050	A2	0.985	1.649	1	1	-1	2	-1	Low
			2050	B1	0.989	1.533	1	1	-1	2	-1	Low
			2050	B2	0.996	1.782	1	1	-1	3	-1	Low
Reptiles	Phyllodactylus europaeus	European leaf-toed gecko	2050	A1	0.544	1.009	1	1	-2	0	-2	Moderate
			2050	A2	0.594	1.034	1	1	-2	0	-2	Moderate
			2050	B1	0.514	0.906	1	1	-2	-2	-2	Moderate
			2050	B2	0.530	0.883	1	1	-2	-2	-2	Moderate
Reptiles	Lacerta monticola	Iberian rock lizard	2050	A1	0.477	0.511	1	1	-3	-3	-3	High
			2050	A2	0.541	0.572	1	1	-2	-3	-3	High
			2050	B1	0.536	0.577	1	1	-2	-3	-3	High
			2050	B2	0.556	0.613	1	1	-2	-3	-3	High
Reptiles	Lacerta schrieberi	Schreiber's green lizard	2050	A1	0.449	0.556	1	1	-3	-3	-3	High
			2050	A2	0.508	0.628	1	1	-2	-3	-3	High
			2050	B1	0.475	0.583	1	1	-3	-3	-3	High
			2050	B2	0.517	0.645	1	1	-2	-3	-3	High
Reptiles	Elaphe situla	European ratsnake	2050	A1	0.997	2.679	0	0	0	4	0	Moderate positive
			2050	A2	0.996	2.507	0	0	0	4	0	Moderate positive
			2050	B1	0.998	2.441	0	0	0	4	0	Moderate positive
			2050	B2	0.998	2.670	0	0	0	4	0	Moderate positive
Reptiles	Vipera ursinii	Meadow viper	2050	A1	0.628	1.250	2	1	-3	0	-3	High
			2050	A2	0.762	1.640	1	1	-1	2	-1	Low
			2050	B1	0.626	1.252	2	1	-3	0	-3	High
			2050	B2	0.725	1.497	1	1	-1	1	-1	Low
Amphibians	Proteus anguinus	Olm	2050	A1	0.795	1.275	2	2	-2	-1	-2	Moderate
			2050	A2	0.862	1.560	2	2	-2	1	-2	Moderate
			2050	B1	0.719	1.045	2	2	-2	-1	-2	Moderate
			2050	B2	0.859	1.496	2	2	-2	0	-2	Moderate
Amphibians	Chioglossa lusitannica	Gold-striped salamander	2050	A1	0.526	0.593	1	1	-2	-3	-3	High
			2050	A2	0.526	0.593	1	1	-2	-3	-3	High
			2050	B1	0.551	0.657	1	1	-2	-3	-3	High
			2050	B2	0.550	0.646	1	1	-2	-3	-3	High
Amphibians	Salamandra atra	Alpine salamander	2050	A1	0.619	0.786	2	2	-3	-3	-3	High
			2050	A2	0.619	0.786	2	2	-3	-3	-3	High
			2050	B1	0.572	0.853	2	2	-3	-3	-3	High
			2050	B2	0.599	0.888	2	2	-3	-3	-3	High
Amphibians	Salamandrina terdigitata	Spectacled salamander	2050	A1	0.248	0.682	1	1	-4	-3	-4	Very High
			2050	A2	0.248	0.682	1	1	-4	-3	-4	Very High
			2050	B1	0.324	0.853	1	1	-3	-2	-3	High
			2050	B2	0.246	0.739	1	1	-4	-2	-4	Very High
Amphibians	Triturus vulgaris	Smooth newt	2050	A1	0.796	0.491	0	0	0	-3	-3	High
			2050	A2	0.796	0.491	0	0	0	-3	-3	High
			2050	B1	0.817	0.381	0	0	0	-3	-3	High
			2050	B2	0.804	0.569	0	0	0	-2	-2	Moderate
Amphibians	Triturus montandoni	Carpathian newt	2050	A1	0.491	1.329	1	1	-3	1	-3	High
			2050	A2	0.491	1.329	1	1	-3	1	-3	High
			2050	B1	0.381	2.438	1	1	-3	3	-3	High

Modelled reptile and amphibian data are from Araujo *et al.*, 2006. Climate projections for 2050 are based on the Hadley Centre HadCM3 coupled atmosphere–ocean general circulation model using the A1F1, A2, B2 and B1 emissions scenarios.

Overlap: The number of squares within the intersection between the projected and simulated recent ranges divided by the number of squares in the simulated recent range.

Ratio (remaining): The number of UTM squares in the projected range divided by the number in the simulated recent range.

Impact score / categories: EC = Extremely Critical (-6), C = Critical (-5), VH = Very High (-4), H = High (-3), M = Moderate (-2), L = Low (-1); - = reduction in climate space, + = increase in climate space

Appendix 3: Butterflies

Model based vulnerability assessment for butterflies listed as N2K species.

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
Butterflies	Coenonympha oedippus	False Ringlet	2050	B1	no data	0.97	0	0	1	-1	-1	Low
			2050	A2	no data	0.92	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.89	0	0	1	-1	-1	Low
			2080	B1	no data	1.69	0	0	1	3	1	Low positive
			2080	A2	no data	3.02	0	0	1	4	1	Low positive
			2080	A1FI	no data	3.12	0	0	1	4	1	Low positive
Butterflies	Colias myrmidone	Danube Clouded Yellow	2050	B1	no data	0.92	2	2	-1	-3	-3	High
			2050	A2	no data	0.49	2	2	-1	-5	-5	Critical
			2050	A1FI	no data	0.64	2	2	-1	-4	-4	Very High
			2080	B1	no data	0.55	2	2	-1	-4	-4	Very High
			2080	A2	no data	0.3	2	2	-1	-5	-5	Critical
			2080	A1FI	no data	0.37	2	2	-1	-5	-5	Critical
Butterflies	Erebia medusa polaris	Woodland Ringlet	2050	B1	no data	0.79	0	0	1	-1	-1	Low
			2050	A2	no data	0.84	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.73	0	0	1	-1	-1	Low
			2080	B1	no data	1.07	0	0	1	1	1	Low positive
			2080	A2	no data	1.03	0	0	1	1	1	Low positive
			2080	A1FI	no data	0.97	0	0	1	-1	-1	Low
Butterflies	Euphydryas aurinia	Marsh fritillary	2050	B1	no data	0.69	0	0	1	-2	-2	Moderate
			2050	A2	no data	0.82	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.84	0	0	1	-1	-1	Low
			2080	B1	no data	0.84	0	0	1	-1	-1	Low
			2080	A2	no data	0.83	0	0	1	-1	-1	Low
			2080	A1FI	no data	0.62	0	0	1	-2	-2	Moderate
Butterflies	Hesperia comma catena	Silver-spotted skipper	2050	B1	no data	0.83	0	0	1	-1	-1	Low
			2050	A2	no data	0.8	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.75	0	0	1	-1	-1	Low
			2080	B1	no data	0.61	0	0	1	-2	-2	Moderate
			2080	A2	no data	0.54	0	0	1	-2	-2	Moderate
			2080	A1FI	no data	0.4	0	0	1	-3	-3	High
Butterflies	Leptidea morsei	Fenton's Wood White	2050	B1	no data	0.88	2	2	-1	-3	-3	High
			2050	A2	no data	0.51	2	2	-1	-4	-4	Very High
			2050	A1FI	no data	0.76	2	2	-1	-3	-3	High
			2080	B1	no data	0.81	2	2	-1	-3	-3	High
			2080	A2	no data	0.87	2	2	-1	-3	-3	High
			2080	A1FI	no data	0.91	2	2	-1	-3	-3	High
Butterflies	Lycaena dispar	Large Copper Butterfly	2050	B1	no data	0.73	1	1	0	-2	-2	Moderate
			2050	A2	no data	0.55	1	1	0	-3	-3	High
			2050	A1FI	no data	0.63	1	1	0	-3	-3	High
			2080	B1	no data	0.55	1	1	0	-3	-3	High
			2080	A2	no data	0.38	1	1	0	-4	-4	Very High
			2080	A1FI	no data	0.46	1	1	0	-4	-4	Very High
Butterflies	Lycaena helle	Violet Copper	2050	B1	no data	0.93	1	1	0	-2	-2	Moderate
			2050	A2	no data	0.91	1	1	0	-2	-2	Moderate
			2050	A1FI	no data	0.98	1	1	0	-2	-2	Moderate
			2080	B1	no data	0.92	1	1	0	-2	-2	Moderate
			2080	A2	no data	0.99	1	1	0	-2	-2	Moderate
			2080	A1FI	no data	0.81	1	1	0	-2	-2	Moderate
Butterflies	Phengaris nausithous	Dusky Large Blue	2050	B1	no data	0.77	0	0	1	-1	-1	Low
			2050	A2	no data	0.81	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.6	0	0	1	-2	-2	Moderate
			2080	B1	no data	0.78	0	0	1	-1	-1	Low
			2080	A2	no data	0.53	0	0	1	-2	-2	Moderate
			2080	A1FI	no data	0.36	0	0	1	-3	-3	High
Butterflies	Phengaris teleius	N/A	2050	B1	no data	0.99	0	0	1	-1	-1	Low
			2050	A2	no data	0.91	0	0	1	-1	-1	Low
			2050	A1FI	no data	0.76	0	0	1	-1	-1	Low
			2080	B1	no data	0.84	0	0	1	-1	-1	Low
			2080	A2	no data	0.76	0	0	1	-1	-1	Low
			2080	A1FI	no data	0.62	0	0	1	-2	-2	Moderate
Butterflies	Melanargia arge	Italian Marbled White	2050	B1	no data	0.58	0	0	1	-2	-2	Moderate
			2050	A2	no data	0.41	0	0	1	-3	-3	High
			2050	A1FI	no data	0.41	0	0	1	-3	-3	High
			2080	B1	no data	2.26	0	0	1	4	1	Low positive
			2080	A2	no data	2.24	0	0	1	4	1	Low positive
			2080	A1FI	no data	2.06	0	0	1	4	1	Low positive
Butterflies	Plebejus glandon	Arctic Blue	2050	B1	no data	0.97	0	0	1	-1	-1	Low
			2050	A2	no data	0.78	0	0	1	-1	-1	Low
			2050	A1FI	no data	1	0	0	1	1	1	Low positive
			2080	B1	no data	0.48	0	0	1	-3	-3	High
			2080	A2	no data	0.78	0	0	1	-1	-1	Low

Modelled butterfly data are from Settele *et al.*, 2008. Climate projections are based on the Hadley Centre HadCM3 coupled atmosphere-ocean general circulation model for the A1F1, A2 and B1 scenarios.

Overlap: The number of squares within the intersection between the projected and simulated recent ranges divided by the number of squares in the simulated recent range.

Ratio (remaining): The number of UTM squares in the projected range divided by the number in the simulated recent range.

Impact score / categories: EC = Extremely Critical (-6), C = Critical (-5), VH = Very High (-4), H = High (-3), M = Moderate (-2), L = Low (-1); - = reduction in climate space, + = increase in climate space.

Appendix 4: Vascular plants

Model based vulnerability assessment for butterflies listed as N2K species. The SRES Scenario “A1” in the table stands for “A1F1”.

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
Plants	Aquilegia pyrenaica		2050	A1	0.589	0.820	0	0	-1	-1	-1	Low
			2050	A2	0.646	0.881	0	0	-1	-1	-1	Low
			2050	B1	0.650	0.873	0	0	-1	-1	-1	Low
			2050	B2	0.639	0.890	0	0	-1	-1	-1	Low
			2080	A1	0.296	0.639	0	0	-3	-2	-3	High
			2080	A2	0.460	0.714	0	0	-2	-1	-2	Moderate
			2080	B1	0.539	0.769	0	0	-1	-1	-1	Low
			2080	B2	0.539	0.761	0	0	-1	-1	-1	Low
Plants	Arabis scopoliana		2050	A1	0.561	1.010	1	1	-2	0	-2	Moderate
			2050	A2	0.675	1.090	1	1	-2	0	-2	Moderate
			2050	B1	0.696	1.146	1	1	-2	0	-2	Moderate
			2050	B2	0.645	1.113	1	1	-2	0	-2	Moderate
			2080	A1	0.349	1.163	1	1	-3	0	-3	High
			2080	A2	0.671	2.014	1	1	-2	3	-2	Moderate
			2080	B1	0.621	1.335	1	1	-2	1	-2	Moderate
			2080	B2	0.563	1.197	1	1	-2	0	-2	Moderate
Plants	Arenaria ciliata		2050	A1	0.599	0.881	0	0	-1	-1	-1	Low
			2050	A2	0.696	0.958	0	0	-1	-1	-1	Low
			2050	B1	0.645	0.872	0	0	-1	-1	-1	Low
			2050	B2	0.667	0.908	0	0	-1	-1	-1	Low
			2080	A1	0.301	0.674	0	0	-2	-2	-2	Moderate
			2080	A2	0.402	0.735	0	0	-2	-1	-2	Moderate
			2080	B1	0.490	0.741	0	0	-2	-1	-2	Moderate
			2080	B2	0.468	0.756	0	0	-2	-1	-2	Moderate
Plants	Asplenium adulterinum		2050	A1	0.697	0.844	1	0	-2	-1	-2	Moderate
			2050	A2	0.747	0.904	0	0	0	-1	-1	Low
			2050	B1	0.766	1.003	0	0	0	1	0	Moderate positive
			2050	B2	0.745	0.907	0	0	0	-1	-1	Low
			2080	A1	0.467	0.824	1	0	-3	-1	-3	High
			2080	A2	0.580	0.896	1	0	-2	-1	-2	Moderate
			2080	B1	0.676	1.007	1	0	-2	1	-2	Moderate
			2080	B2	0.650	0.916	1	0	-2	-1	-2	Moderate
Plants	Botrychium simplex		2050	A1	0.636	0.801	1	1	-2	-2	-2	Moderate
			2050	A2	0.666	0.821	1	1	-2	-2	-2	Moderate
			2050	B1	0.663	0.830	1	1	-2	-2	-2	Moderate
			2050	B2	0.652	0.814	1	1	-2	-2	-2	Moderate
			2080	A1	0.432	0.677	1	1	-3	-3	-3	High
			2080	A2	0.460	0.724	1	1	-3	-2	-3	High
			2080	B1	0.582	0.782	1	1	-2	-2	-2	Moderate
			2080	B2	0.513	0.762	1	1	-2	-2	-2	Moderate
Plants	Braya linearis		2050	A1	0.689	0.747	0	0	-1	-1	-1	Low
			2050	A2	0.706	0.761	0	0	0	-1	-1	Low
			2050	B1	0.719	0.779	0	0	0	-1	-1	Low
			2050	B2	0.694	0.753	0	0	-1	-1	-1	Low
			2080	A1	0.630	0.844	0	0	-1	-1	-1	Low
			2080	A2	0.684	0.782	0	0	-1	-1	-1	Low
			2080	B1	0.759	0.849	0	0	0	-1	-1	Low
			2080	B2	0.732	0.812	0	0	0	-1	-1	Low
Plants	Dianthus arenarius		2050	A1	0.698	1.085	1	1	-2	0	-2	Moderate
			2050	A2	0.786	1.094	1	1	-1	0	-1	Low
			2050	B1	0.763	1.089	1	1	-1	0	-1	Low
			2050	B2	0.772	1.107	1	1	-1	0	-1	Low
			2080	A1	0.366	1.004	1	1	-3	0	-3	High
			2080	A2	0.532	1.005	1	1	-2	0	-2	Moderate
			2080	B1	0.610	0.977	1	1	-2	-2	-2	Moderate
			2080	B2	0.434	0.835	1	1	-3	-2	-3	High
Plants	Dianthus cintranus		2050	A1	0.719	1.292	1	1	-1	0	-1	Low
			2050	A2	0.797	1.342	1	1	-1	1	-1	Low
			2050	B1	0.747	1.274	1	1	-1	0	-1	Low
			2050	B2	0.766	1.302	1	1	-1	1	-1	Low
			2080	A1	0.487	1.465	1	1	-3	1	-3	High
			2080	A2	0.643	1.554	1	1	-2	2	-2	Moderate
			2080	B1	0.600	1.106	1	1	-2	0	-2	Moderate
			2080	B2	0.511	0.977	1	1	-2	-2	-2	Moderate

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
Plants	Dianthus rupicola		2050	A1	0.905	1.555	0	0	0	3	0	Moderate positive
			2050	A2	0.926	1.490	0	0	0	2	0	Moderate positive
			2050	B1	0.908	1.495	0	0	0	2	0	Moderate positive
			2050	B2	0.922	1.514	0	0	0	3	0	Moderate positive
			2080	A1	0.677	2.254	1	0	-2	4	-2	Moderate
			2080	A2	0.811	1.743	0	0	0	4	0	Moderate positive
			2080	B1	0.824	1.559	0	0	0	3	0	Moderate positive
			2080	B2	0.838	1.664	0	0	0	3	0	Moderate positive
Plants	Diplazium sibiricum		2050	A1	0.591	0.697	0	0	-1	-2	-2	Moderate
			2050	A2	0.651	0.741	0	0	-1	-1	-1	Low
			2050	B1	0.657	0.743	0	0	-1	-1	-1	Low
			2050	B2	0.623	0.712	0	0	-1	-1	-1	Low
			2080	A1	0.357	0.515	0	0	-2	-2	-2	Moderate
			2080	A2	0.475	0.622	0	0	-2	-2	-2	Moderate
			2080	B1	0.579	0.718	0	0	-1	-1	-1	Low
			2080	B2	0.532	0.749	0	0	-1	-1	-1	Low
Plants	Herniaria latifolia		2050	A1	0.833	1.474	0	0	0	2	0	Moderate positive
			2050	A2	0.865	1.473	0	0	0	2	0	Moderate positive
			2050	B1	0.830	1.426	0	0	0	2	0	Moderate positive
			2050	B2	0.863	1.488	0	0	0	2	0	Moderate positive
			2080	A1	0.678	2.225	0	0	-1	4	-1	Low
			2080	A2	0.750	1.939	0	0	0	4	0	Moderate positive
			2080	B1	0.742	1.769	0	0	0	4	0	Moderate positive
			2080	B2	0.834	1.958	0	0	0	4	0	Moderate positive
Plants	Herniaria lusitanica		2050	A1	0.935	1.514	1	1	-1	2	-1	Low
			2050	A2	0.941	1.478	1	1	-1	1	-1	Low
			2050	B1	0.867	1.413	1	1	-1	1	-1	Low
			2050	B2	0.939	1.491	1	1	-1	1	-1	Low
			2080	A1	0.845	2.171	1	1	-1	3	-1	Low
			2080	A2	0.927	2.013	1	1	-1	3	-1	Low
			2080	B1	0.950	1.849	1	1	-1	3	-1	Low
			2080	B2	0.951	1.907	1	1	-1	3	-1	Low
Plants	Marsilea quadrifolia		2050	A1	0.824	1.231	1	1	-1	0	-1	Low
			2050	A2	0.845	1.188	1	1	-1	0	-1	Low
			2050	B1	0.842	1.304	1	1	-1	1	-1	Low
			2050	B2	0.838	1.179	1	1	-1	0	-1	Low
			2080	A1	0.643	1.990	1	1	-2	3	-2	Moderate
			2080	A2	0.826	1.794	1	1	-1	3	-1	Low
			2080	B1	0.844	1.634	1	1	-1	2	-1	Low
			2080	B2	0.872	1.631	1	1	-1	2	-1	Low
Plants	Moehringia lateriflora		2050	A1	0.753	0.861	0	0	0	-1	-1	Low
			2050	A2	0.781	0.896	0	0	0	-1	-1	Low
			2050	B1	0.736	0.834	0	0	0	-1	-1	Low
			2050	B2	0.663	0.725	0	0	-1	-1	-1	Low
			2080	A1	0.460	0.486	0	0	-2	-3	-3	High
			2080	A2	0.593	0.629	0	0	-1	-2	-2	Moderate
			2080	B1	0.639	0.704	0	0	-1	-1	-1	Low
			2080	B2	0.693	0.760	0	0	-1	-1	-1	Low
Plants	Paeonia officinalis		2050	A1	0.809	1.110	0	0	0	1	0	Moderate positive
			2050	A2	0.872	1.149	0	0	0	1	0	Moderate positive
			2050	B1	0.838	1.048	0	0	0	1	0	Moderate positive
			2050	B2	0.859	1.148	0	0	0	1	0	Moderate positive
			2080	A1	0.566	1.306	0	0	-1	2	-1	Low
			2080	A2	0.733	1.160	0	0	0	1	0	Moderate positive
			2080	B1	0.734	1.056	0	0	0	1	0	Moderate positive
			2080	B2	0.754	1.164	0	0	0	1	0	Moderate positive

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	**Species**	**English name**	**Time Horizon**	**SRES Scenario**	**Overlap**	**Ratio**	**General + colonisation**	**General**	**Overlap**	**Ratio**	**Worst vulnerability**	**Worst vulnerability category**
Plants	Papaver radicatum		2050	A1	0.609	0.862	2	1	-3	-2	-3	High
			2050	A2	0.684	1.028	2	1	-3	0	-3	High
			2050	B1	0.709	1.023	1	1	-1	0	-1	Low
			2050	B2	0.654	0.999	2	1	-3	-2	-3	High
			2080	A1	0.434	1.080	2	1	-4	0	-4	Very High
			2080	A2	0.527	1.066	2	1	-3	0	-3	High
			2080	B1	0.678	1.230	2	1	-3	0	-3	High
			2080	B2	0.553	1.049	2	1	-3	0	-3	High
Plants	Petrocoptis grandiflora		2050	A1	0.885	1.069	1	1	-1	0	-1	Low
			2050	A2	0.899	1.077	1	1	-1	0	-1	Low
			2050	B1	0.879	1.055	1	1	-1	0	-1	Low
			2050	B2	0.892	1.086	1	1	-1	0	-1	Low
			2080	A1	0.767	1.122	1	1	-1	0	-1	Low
			2080	A2	0.836	1.102	1	1	-1	0	-1	Low
			2080	B1	0.815	1.069	1	1	-1	0	-1	Low
			2080	B2	0.863	1.081	1	1	-1	0	-1	Low
Plants	Pulsatilla patens		2050	A1	0.669	1.076	1	1	-2	0	-2	Moderate
			2050	A2	0.729	1.085	1	1	-1	0	-1	Low
			2050	B1	0.718	1.097	1	1	-1	0	-1	Low
			2050	B2	0.724	1.101	1	1	-1	0	-1	Low
			2080	A1	0.375	0.790	1	1	-3	-2	-3	High
			2080	A2	0.515	0.954	1	1	-2	-2	-2	Moderate
			2080	B1	0.578	1.016	1	1	-2	0	-2	Moderate
			2080	B2	0.584	1.028	1	1	-2	0	-2	Moderate
Plants	Pulsatilla pratensis		2050	A1	0.581	0.975	2	1	-3	-2	-3	High
			2050	A2	0.682	1.023	2	1	-3	0	-3	High
			2050	B1	0.684	1.066	2	1	-3	0	-3	High
			2050	B2	0.659	1.025	2	1	-3	0	-3	High
			2080	A1	0.315	0.859	2	1	-4	-2	-4	Very High
			2080	A2	0.407	0.902	2	1	-4	-2	-4	Very High
			2080	B1	0.515	1.045	2	1	-3	0	-3	High
			2080	B2	0.474	0.966	2	1	-4	-2	-4	Very High
Plants	Pulsatilla vulgaris		2050	A1	0.812	1.452	1	1	-1	1	-1	Low
			2050	A2	0.848	1.409	1	1	-1	1	-1	Low
			2050	B1	0.859	1.460	1	1	-1	1	-1	Low
			2050	B2	0.847	1.423	1	1	-1	1	-1	Low
			2080	A1	0.572	1.516	1	1	-2	2	-2	Moderate
			2080	A2	0.728	1.652	1	1	-1	2	-1	Low
			2080	B1	0.767	1.639	1	1	-1	2	-1	Low
			2080	B2	0.756	1.518	1	1	-1	2	-1	Low
Plants	Ranunculus lapponicus		2050	A1	0.803	0.894	0	0	0	-1	-1	Low
			2050	A2	0.806	0.893	0	0	0	-1	-1	Low
			2050	B1	0.803	0.901	0	0	0	-1	-1	Low
			2050	B2	0.803	0.890	0	0	0	-1	-1	Low
			2080	A1	0.670	0.780	1	0	-2	-1	-2	Moderate
			2080	A2	0.709	0.819	0	0	0	-1	-1	Low
			2080	B1	0.770	0.885	0	0	0	-1	-1	Low
			2080	B2	0.745	0.842	0	0	0	-1	-1	Low
Plants	Rumex rupestris		2050	A1	0.814	1.233	1	1	-1	0	-1	Low
			2050	A2	0.834	1.220	1	1	-1	0	-1	Low
			2050	B1	0.835	1.210	1	1	-1	0	-1	Low
			2050	B2	0.822	1.205	1	1	-1	0	-1	Low
			2080	A1	0.546	1.371	2	1	-3	1	-3	High
			2080	A2	0.708	1.442	1	1	-1	1	-1	Low
			2080	B1	0.779	1.349	1	1	-1	1	-1	Low
			2080	B2	0.722	1.425	1	1	-1	1	-1	Low
Plants	Sisymbrium supinum		2050	A1	0.660	1.218	1	0	-2	1	-2	Moderate
			2050	A2	0.847	1.547	0	0	0	3	0	Moderate positive
			2050	B1	0.794	1.464	0	0	0	2	0	Moderate positive
			2050	B2	0.847	1.562	0	0	0	3	0	Moderate positive
			2080	A1	0.640	2.647	1	0	-2	4	-2	Moderate
			2080	A2	0.821	2.264	0	0	0	4	0	Moderate positive
			2080	B1	0.733	1.765	0	0	0	4	0	Moderate positive
			2080	B2	0.835	1.827	0	0	0	4	0	Moderate positive

			MODELLED IMPACT				ADAPTATION CONSTRAINTS		VULNERABILITY ASSESSMENT			
Order	Species	English name	Time Horizon	SRES Scenario	Overlap	Ratio	General + colonisation	General	Overlap	Ratio	Worst vulnerability	Worst vulnerability category
Plants	Spergularia azorica		2050	A1	1.000	1.000	1	1	-1	0	-1	Low
			2050	A2	1.000	1.000	1	1	-1	0	-1	Low
			2050	B1	1.000	1.000	1	1	-1	0	-1	Low
			2050	B2	0.857	1.160	1	1	-1	0	-1	Low
			2080	A1	0.585	1.256	2	1	-3	0	-3	High
			2080	A2	0.702	1.219	1	1	-1	0	-1	Low
			2080	B1	0.785	1.168	1	1	-1	0	-1	Low
			2080	B2	0.770	1.170	1	1	-1	0	-1	Low
Plants	Thesium ebracteatum		2050	A1	0.771	1.672	1	1	-1	2	-1	Low
			2050	A2	0.800	1.537	1	1	-1	2	-1	Low
			2050	B1	0.882	1.452	1	1	-1	1	-1	Low
			2050	B2	0.794	1.554	1	1	-1	2	-1	Low
			2080	A1	0.602	1.891	1	1	-2	3	-2	Moderate
			2080	A2	0.668	2.033	1	1	-2	3	-2	Moderate
			2080	B1	0.736	1.662	1	1	-1	2	-1	Low
			2080	B2	0.673	1.650	1	1	-2	2	-2	Moderate
Plants	Trichomanes speciosum		2050	A1	0.745	0.923	1	1	-1	-2	-2	Moderate
			2050	A2	0.759	0.938	1	1	-1	-2	-2	Moderate
			2050	B1	0.777	0.964	1	1	-1	-2	-2	Moderate
			2050	B2	0.752	0.937	1	1	-1	-2	-2	Moderate
			2080	A1	0.686	1.103	1	1	-2	0	-2	Moderate
			2080	A2	0.748	1.137	1	1	-1	0	-1	Low
			2080	B1	0.835	1.170	1	1	-1	0	-1	Low
			2080	B2	0.765	1.048	1	1	-1	0	-1	Low

Modelled plant data for 2050 are from Thuiller, 2004. Modelled plant data for 2080 are from Thuiller *et al.*, 2005. Climate projections for 2050 and 2080 are based on the Hadley Centre HadCM3 coupled atmosphere–ocean general circulation model using the A1F1, A2, B2 and B1 emissions scenarios.

Overlap: The number of squares within the intersection between the projected and simulated recent ranges divided by the number of squares in the simulated recent range.

Ratio (remaining): The number of UTM squares in the projected range divided by the number in the simulated recent range.

Impact score / categories: EC = Extremely Critical (-6), C = Critical (-5), VH = Very High (-4), H = High (-3), M = Moderate (-2), L = Low (-1); - = reduction in climate space, + = increase in climate space.

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