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

Summary Report

Monika Bertzky[4], Barney Dickson[4], Russell Galt[1,5], Eleanor Glen[2], Mike Harley[2], Nikki Hodgson[2], Guus Keder[5], Igor Lysenko[4], Maria Pooley[2], Corinna Ravilious[4], Todd Sajwaj[2], Roxi Schiopu[2], Yves de Soye[1] and Graham Tucker[3].

[1]: IUCN. [2]: AEA. [3]: IEEP. [4]: WCMC. [5]: AXIOM

February 2011

Final Report to the European Commission under Contract ENV.B.2/SER/2007/0076 "Natura 2000 Preparatory Actions – Lot 5: Climate Change and Biodiversity in relation to the Natura 2000 Network"

Citation and disclaimer

This document should be quoted as follows:

Bertzky, M., B. Dickson, R. Galt, E. Glen, M. Harley, N. Hodgson, G. Keder, I. Lysenko, M. Pooley, C. Ravilious, T. Sajwaj, R. Schiopu, Y. de Soye & G. Tucker (2010). Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network: Summary Report. European Commission and International Union for Conservation of Nature, Brussels.

The present Summary Report is based on the following five individual task reports:

*Hodgson, N., E. Glen, M. Harley, M. Pooley, T. Sajwaj, R. Schiopu & Y. de Soye (2009). Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network: **Task 1** – Impacts of climate change on EU biodiversity: evidence and modelling results. European Commission and International Union for Conservation of Nature, Brussels.*

*Sajwaj, T., G. Tucker, M. Harley & Y. de Soye (2009). 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. European Commission and International Union for Conservation of Nature, Brussels.*

*Bertzky, M., I. Lysenko, C. Ravilious, B. Dickson & Y. de Soye (2009). Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network: **Task 3a** - Applying the vulnerability assessment framework: impacts of climate change on the Natura 2000 network. European Commission and International Union for Conservation of Nature, Brussels.*

*Tucker, T. & Y. de Soye (2009). Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network: **Tasks 2b & 3b** - Impacts of climate change on EU biodiversity policy, and recommendations for policies and measures to maintain and restore biodiversity in the EU in the face of climate change. European Commission and International Union for Conservation of Nature, Brussels.*

*Keder, G. & R. McIntyre Galt (2009). Impacts of climate change and selected renewable energy infrastructures on EU biodiversity and the Natura 2000 network: **Task 4** – Wind, hydro and marine renewable energy infrastructures in the EU: biodiversity impacts, mitigation and policy recommendations. European Commission and International Union for Conservation of Nature, Brussels.*

Contract objectives, contributors and main responsibilities for tasks

The general purpose of the service contract underlying the present Summary Report, as well as the aforementioned individual task reports, were "to provide the [European] Commission with an overview of the likely impact of climate change on biodiversity in the European Union and indications as to how the design and implementation of current policy might need to be adapted in order to ensure that the EU respects its commitment to reduce biodiversity loss by 2010 and beyond. The contract will also provide support to the Commission with regard to biodiversity impacts associated with specific climate change mitigation measures."

The service contract tender identified four tasks which, during the execution of the project, were regrouped into five tasks. The following were the leading and supporting contributors to the respective task reports:

Task	Title	AEA	IEEP	UNEP-WCMC	IUCN	AXIOM
1	Impacts of climate change on EU biodiversity: evidence and modelling results	! (Leading)			Supporting	
2a	An assessment framework for climate change vulnerability: methodology and results	! (Leading)	Strongly supporting	Supporting	Supporting	
3a	Applying the vulnerability assessment framework: impacts of climate change on the Natura 2000 species and network	Supporting	Supporting	! (Leading)	Supporting	
2b & 3b	Impacts of climate change on EU biodiversity policy, and recommendations for policies and measures to maintain and restore biodiversity in the face of climate change	Supporting	! (Leading)	Supporting	! (Leading)	
4	Impacts of wind, marine and hydro renewable energy infrastructures on biodiversity in the EU	Supporting	Supporting		Strongly supporting	! (Leading)

!	Leading contributor
	Strongly supporting contributor
	Supporting contributor

Acknowledgements

The authors and project team wish to first and foremost express their gratitude to the European Commission for the opportunity to work on this subject, and thank in particular Karin Zaunberger for her patient and knowledgeable management of the underlying service contract. We are grateful for the provision of the necessary spatial and site specific information on the Natura 2000 network. We equally thank François Wakenhut, Stefan Leiner and Patrick Murphy for their supporting roles during the project.

The team furthermore acknowledges the contributions to Task Report 3a from: Jörn Scharlemann (UNEP-WCMC) for scientific advice on analyses conducted; Lera Miles (UNEP-WCMC) for expert input on method and presentation of results; and Wendy Foden (IUCN) for expert input on data sourcing and method.

We lastly wish to express our gratitude to the following people for their support and cooperation to Task Report 4: Michaël Pierrot of The Windpower (www.thewindpower.net), Patrick Bradley of Platts Inc. (www.platts), John Coleman of LaTene Maps (www.latene.com), Morten Holmager of Offshore Center Danmark (www.offshorecenter.dk), Martin McCarthy of Sustainable Energy Ireland (www.sei.ie), José Carlos Matos of Instituto de Engenharia Mecânica e Gestão Industrial (www.inegi.pt), Hannele Holttinen of VTT Finland (www.vtt.fi), Carsten Ender of DEWI (www.dewi.de), Glória Rodrigues and Nicolas Fichaux of the European Wind Energy Association (www.ewea.org) as well as Matthew Finn of the European Marine Energy Centre (www.emec.org.uk).

Table of contents

1. Introduction

a. Direct impacts of climate change on biodiversity

The 4th Assessment Report of the IPCC, the Millennium Ecosystem Assessment, the UNEP-World Conservation Monitoring Centre and similar authorities concur that climate change is likely to become the greatest threat to global biodiversity in the course of the 21st century. As global mean annual temperature rises towards a critical threshold of 2 degrees Celsius above pre-industrial levels, the structure and function of both terrestrial and marine ecosystems will experience substantial changes, and plant and animal species will be exposed to increasing extinction risks.

Looking at Europe in particular, Alcamo *et al.* (2007)[1] concluded that climate related hazards and water stress will mostly increase, and that regional differences of Europe's natural resources and assets will get magnified. They also considered the effects of climate change on the physiology, phenology and distribution of plant and animal species, and concluded that natural ecosystems and biodiversity will be substantially affected, with many species expected to have difficulties in adapting. Climate change has the potential, over a period of a few decades, to undermine our efforts relating to the conservation and sustainable use of biodiversity.

The centrepieces of the European Union's biodiversity and nature conservation policy framework are the **Birds Directive[2]** and **Habitats Directive[3]**. Member States are legally bound to designate Special Protection Areas (SPAs) under the former and Special Areas of Conservation (SCAs) under the latter. These sites together form the **Natura 2000 protected area network**, which currently consists of more than 26,000 sites and covers an area of around 850,000 km^2 (terrestrial and marine), corresponding to about 20% of the EU's territory. One of the specific aims of the Natura 2000 network is to protect species and habitats of Community Interest; the two Directives altogether list more than 869 species[4] of flora and fauna, as well as 218 terrestrial and marine habitats of which around 70 have been given priority status.

In May 2006, the European Commission adopted a **Communication on "Halting the loss of Biodiversity by 2010 – and Beyond: Sustaining ecosystem services for human well-being"**[5]. The Communication underlined the importance of biodiversity conservation and included a detailed **EU Biodiversity Action Plan (BAP)** with ten overarching objectives, one of which is to "support biodiversity adaptation to climate change".

In 2008 the Biodiversity Action Plan underwent a **mid-term assessment**, the report[6] of which provides essential reflections on the achievements of biodiversity and nature policy in the EU. It is now clear that, for a number of reasons, the 2010 target will not be met. The role played by climate change in this failure is not yet understood since the impacts of climate change on species and habitats have only recently started to become visible.

It is obvious that future climate change impacts will not spare Natura 2000 sites or the species and habitats that they and surrounding landscapes contain. Climate change will affect species distribution ranges, reproductive cycles, growing seasons and interactions with their biophysical environment. However, species and habitats react differently to climatic changes - while some European species may benefit, others will suffer considerably. A range of projects and studies has therefore started to shed light on the more precise nature and

[1] Alcamo, J. *et al*. 2007: Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. 4th IPCC Assessment Report.
[2] Council of the European Communities 1979 http://ec.europa.eu/environment/nature/legislation/index_en.htm
[3] Council of the European Communities 1992 http://ec.europa.eu/environment/nature/legislation/index_en.htm
[4] Some sources refer to up to 1150 species.
[5] COM 2006/216, http://ec.europa.eu/environment/nature/biodiversity/comm2006/bap_2006.htm
[6] http://ec.europa.eu/environment/nature/biodiversity/comm2006/bap_2008.htm

extent of the consequences of climate change (see Table 1 for a non-exclusive list), such as to help determine the vulnerability of Europe's species and habitats.

Table 1: A selection of studies looking at the impacts of and response measures to climate change in Europe.

- **MACIS** www.macis-project.net Minimisation of and adaptation to climate change impacts on biodiversity
- **ALARM** www.alarmproject.net Assessing large scale environmental risks for biodiversity with tested methods
- **ECOCHANGE** www.ecochange-project.eu Biodiversity and ecosystem changes in Europe
- **BRANCH** www.branchproject.org Biodiversity Requires Adaptation in Northwest Europe under a CHanging climate
- **ACCELERATES** Assessing climate change effects on land use and ecosystems: from regional analysis to the European scale
- **SESAME** www.sesame-ip.eu Southern European Seas: Assessing and Modelling Ecosystem changes
- **ATEAM** www.pik-potsdam.de/ateam Advanced Terrestrial Ecosystem Analysis and Modelling
- **ENSEMBLE** http://ensembles-eu.metoffice.com Develop a prediction system for climate change based on high resolution, global and regional Earth System models developed in Europe
- **CECILIA** www.cecilia-eu.org Central and Eastern Europe Climate Change Impact and Vulnerability Assessment
- **PRUDENCE** http://prudence.dmi.dk Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects
- **PESETA** http://peseta.jrc.ec.europa.eu Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis
- **ESPACE** www.espace-project.org European Spatial Planning: Adapting to Climate Events
- **ADAM** www.adamproject.eu Adaptation and Mitigation Strategies: supporting European climate policy
- **MONARCH** www.eci.ox.ac.uk/research/biodiversity/monarch.php Modelling natural resource responses to climate change in the UK
- **REGIS** www.eci.ox.ac.uk/research/biodiversity/regis.php Simulating the effects of future climate and socio-economic change in East Anglia and North West England
- **ASTRA** www.astra-project.org Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region
- **FINADAPT** www.ymparisto.fi/default.asp?contentid=165496&lan=en Assessing the adaptive capacity of the Finnish environment and society under a changing climate
- **Potsdam Institute** www.pik-potsdam.de/research/research-domains/earth-system-analysis/projects/biodiversity/copy_of_schutzgebiete Protected Areas in Germany under Global Change - Risks and Policy Options
- **EEA** Impacts of Europe's changing climate: indicator based assessment, 2008 http://www.eea.europa.eu/publications/eea_report_2008_4/
- **EEA** Vulnerability and adaptation to climate change in Europe, 2005 http://reports.eea.europa.eu/technical_report_2005_1207_144937/en
- **EU Biodiversity Action Plan Review 2008** with ETC/BD data assessment, http://ec.europa.eu/environment/nature/biodiversity/comm2006/bap_2008.htm
- **EC Discussion Paper "Towards a Strategy on Climate Change, Ecosystem Services and Biodiversity"** http://circa.europa.eu/Public/irc/env/biodiversity_climate/home
- **Council of Europe Contracts** (CC & Biodiversity, CC & Protected Areas, CC & Invertebrates, CC & Plants)

The assessment of vulnerability of species to climate change underpins many strategies for biodiversity adaptation, as it will be necessary to identify and prioritise species and habitats that require supporting measures. Setting priorities for biodiversity adaptation appears particularly important in light of the BAP mid-term assessment, which revealed that 50% of species and possibly up to 80% of habitat types of Community Interest have an unfavourable conservation status.

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)[7] 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]".

Following the terminology of the IPCC's 4th Assessment Report, a full assessment of **vulnerability** 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 (their **adaptive capacity**) must be considered to establish a robust indication of vulnerability. This can be expressed by the following simplified conceptual equation:

[7] http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/bio_brochure_en.pdf

Vulnerability = Exposure x Sensitivity / Adaptive Capacity = Impact / Adaptive Capacity

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.

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** (aka climatic space) 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 range of species. Climate envelope models use various emissions scenarios to capture the range of possible climate futures.

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)[8] 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). It implicitly blends the assessments of exposure, impact and adaptive capacity in its methods. The amount of climate space lost was then compared to IUCN threat categories to assign threat category labels. Settele *et al.* (2008)[9] used the World Organisation for Animal Health's risk assessment process for butterflies to identify hazards and assess risks from climate change. Neither of these two studies separated the assessment of impacts from that of adaptive capacity.

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. However, in the longer-term species vulnerability traits could provide a good framework for assessing species' vulnerability to climate change and provide a globally applicable, consistent approach[10].

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 and/or European biogeographical regions** has been qualitatively assessed using expert knowledge by a few studies[11].

[8] Thuiller, W. *et al*. (2005): Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences.
[9] Settele, J. *et al*. (2008): Climatic risk atlas of European butterflies. Pensoft, Sofia.
[10] Berry, P. (2008): Climate change and the vulnerability of Bern Convention species and habitats. Council of Europe.
[11] Berry. P. (2008): as above. Berry P. (2004): Plant vulnerability to climate change. In Yearbook of Science and Technology, McGraw-Hill, NY, pp. 259-261. WGBU (2003): Climate Protection Strategies for the 21st Century: Kyoto and beyond. EEA (2004): Impacts of Europe's changing climate - an indicator-based assessment.

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**. The MONARCH Project 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. 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; this is one of the few quantitative approaches used for habitat vulnerability, but is unfortunately restricted to coastal habitats.

In an attempt to provide further guidance to the European Commission and EU member states, the aims of the first four Task Reports (1, 2a, 3a, 2b&3b) of the present study were to

- Review the evidence and projections of the direct impacts of climate change on biodiversity in the EU;
- Develop a semi-quantitative assessment methodology for establishing the vulnerability of species and habitats;
- Apply the vulnerability assessment methodology such as to identify species and habitats of Community Interest that are vulnerable to climate change in the EU;
- Evaluate the consequences of climate change for the overall Natura 2000 network;
- Review the likely impact of climate change on the EU biodiversity target and Action Plan, i.e. on the EU's ability to halt biodiversity loss by 2010 and beyond; and
- Provide recommendations for policies and measures protecting the integrity of the Natura 2000 network and promoting the adaptation of EU biodiversity to climate change.

b. <u>Assessing and mitigating impacts from marine, wind and hydro energy infrastructures</u>

Renewable energies are expected to become an ever increasing component of the energy mix in the European Union. They contribute to energy security and at the same time are essential for the EU to meet its commitment to reduce greenhouse gas emissions by 20% by 2020.

In order to promote the development and deployment of renewable energy generating capacity, the EU therefore adopted a new **Renewable Energy Sources Directive** (2009/28/EC) in 2009 as part of the overall EU Energy and Climate Package. The Directive requires that, by the year 2020, 20% of the final total energy consumption in the EU's come from renewable sources (up from 8.5% by 2008). This effectively means that **renewable energy production will grow almost 2.5 fold by 2020**.

While in a few European countries hydroelectric dams already provide a considerable portion of electricity, it is unavoidable that new infrastructures will need to be deployed across the EU member states for them to comply with the new mandatory targets. The renewable energy sources that will contribute to meeting the 20% target are, in particular, onshore wind, offshore wind, marine energy, photovoltaics, solar thermal, small and large hydro, geothermal and biomass.

Unfortunately, the environmental benefits of renewable energy come with a price: **some if not many of the necessary infrastructures may pose an immediate risk to biodiversity**; and conflicts with the objectives and management of individual Natura 2000 sites can be expected. For example, the risks of intensification and expansion of agriculture associated with an increasing use of biomass (wood, feedstock crops) for providing electricity, heat and transport fuels have been well documented and discussed in many recent assessments.

The present project **reviewed impacts on biodiversity and the Natura 2000 network of onshore and offshore wind farms, large hydro dams and infrastructures harnessing tidal and wave marine energy**, including through a geospatial analysis. It also provided **guidelines** on how best to develop and implement a given project in order to minimise these impacts during the construction, operation and decommissioning of either of these infrastructures. Finally, it **compared the environmental benefits and risks associated with the different technologies**, which may guide further policies and investment.

2. Impacts of climate change on EU biodiversity: evidence and modelling results

Task 1 of this project took the form of a systematic review, synthesis and analysis of published reports, information and data relating to the **observed and projected impacts of climate change in Europe**, with a particular focus on the species, habitats and ecosystems in the EU 27 member states. The starting point was the IPCC's 4^{th} Assessment Report, which provided a sound contextual setting and extensive reference lists. Additionally and significantly, members of the Project Team used wide-ranging knowledge and experience of other relevant research programmes across Europe to feed into the study. Of particular note in this context was the EC-funded MACIS Project.

The review considered the impacts of climate change across the EU's terrestrial, freshwater, coastal and marine environments, focusing particularly on the nine biogeographic regions and 23 'broad' habitat classes that characterise the Natura 2000 network.

Table 2 provides an overview of the consequences of climate change recorded in the review. Evidence and modelled projections were found for the following key impacts on EU biodiversity and the physical environment:

- Species and ecosystem composition changes;
- Range contraction and expansion;
- Phenological changes;
- Decoupling of events;
- Land use constraints;
- Sea-level rise;
- Climate related stress and changes to disturbance regimes;
- Hydrological and carbon sequestration changes.

Importantly, the quantity, quality and diversity of relevant data from across Europe were found to be highly variable. A considerable amount of published material is available at a range of spatial and temporal scales and on a range of specific issues for some biogeographic regions (e.g. Atlantic, Alpine, Boreal, and parts of the Continental region).

In contrast, comparatively little research and modelling results were available on climate impacts from the Macaronesian and Mediterranean regions, and in particular from the eastern EU (esp. Black Sea, Pannonian and Steppic, but also Continental region).

Moreover, information was available only for a subset of the EU's species and habitats. For the majority, no data could be found on climate change impacts – notably for a significant proportion of species of Community Interest, which tend to be rarer and harder to study.

Table 2: Overview of the observed and projected impacts of climate change in the EU's nine biogeographic regions

Biogeographic region									
Impact category	**Alpine**	**Atlantic**	**Black Sea**	**Boreal**	**Continental**	**Macaronesian**	**Mediterranean**	**Pannonian**	**Steppic**
Physical effects									
Increase in sea level and coastal flooding	N/A	**OE MP**		**CM**		**OE**			
Increase in annual average temperature	**OE MP**	**OE MP**	**OE**	**OE MP**	**OE**	**OE MP**	**OE MP**	**OE MP**	
Increase in extreme weather events		**OE MP**		**MP**	**OE**			**MP**	
Increased drought	**OE MP**	**OE**	**OE**		**OE**	**OE MP**	**C MP**	**OE MP**	
Increased precipitation, run-off and flooding	**OE MP**		**OE**	**OE MP**	**OE**				
Change in snowlines and duration	**OE MP**	**MP**							**OE**
Increased carbon dioxide		**OE MP**		**OE MP**		**OE**			
Increased forest fire	**OE MP**			**OE**	**CO**				
Increased disease and infestation	**OE MP**			**OE MP**					
Increased rate of change in temperature	**OE**								
Shifts in water quantity and quality			**OE**		**OE**				**OE**
Decreased river discharge			**OE MP**						
Increased biomass and carbon sequestration				**OE MP**	**OE MP**				
Decreased plant productivity						**OE**			
Increased humidity						**OE MP**			
Increased ocean acidification						**OE**			
Effects on biodiversity and ecosystems									
Altitudinal movement of plants/animals/habitats	**OE MP**	**MP**			**OE MP**	**OE**			
Latitudinal movement of plants/animals/habitats		**OE MP**		**MP**	**OE MP**				
Seasonal changes in plants		**OE**							
Changes in limiting resources							**OE**		
Increase in species richness	**OE MP**			**OE MP**			**OE**		
Earlier life cycle events		**OE**	**OE**	**CO**				**CO**	
Decreased life cycle events						**OE**	**OE**		
Longer growing season		**OE**	**OE**	**OE**	**OE**				
Range contraction and extinction	**OE MP**				**OE MP**	**OE**	**OE**		
Gain in climate space	**OE MP**	**OE MP**		**MP**	**OE MP**	**OE**			
Loss in climate space	**OE MP**	**OE MP**			**OE MP**	**OE**			
Loss of glacial extent	**OE**								
Land use constraints		**OE**							
Breeding decline and sea level rise		**OE**							
Increase in species competitive advantage					**OE**		**OE**		
Increased invasive species						**OE**			
Loss of wetlands						**OE**	**OE**		
Decoupling of species interactions		**OE**						**MP**	
Increased species mixing									
Vulnerability									
Identification of vulnerable species and/or habitats	**OE**	**OE MP**	**MP**	**OE MP**	**OE**	**OE**	**MP**	**OE**	
Identification of resilient species and/or habitats								**OE MP**	
KEY Observed evidence exists and showing impact - **OE** Model prediction exists and showing impact – **MP** Contradiction in observed literature **CO** Contradiction in modelled literature **CM** Not applicable N/A									

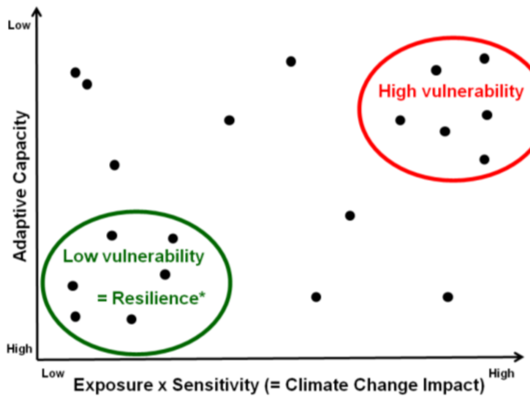
3. A framework for assessing the climate change vulnerability of European species of fauna and flora: Methodology

One of the main objectives of the present project was to determine the vulnerability of the EU species and habitats of Community Interest. The concurrent methodology was developed and described in Tasks 2a and 3a.

a. Background

The semi-quantitative methodology developed to assess the vulnerability of species to climate change comprises a two-part process (see Figure 1). 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**.

Figure 1: The two main components of the vulnerability assessment framework: climate change impact and adaptive capacity.



While the project team's initial intention had been to use evidence-based data to underpin the vulnerability assessment, the literature review in Task 1 revealed that the evidence was too scarce and too qualitative for almost every species and that virtually no suitable information existed on the impacts on different EU habitats.

The project therefore capitalised on the existence of modelled climate space projections for 212 individual Natura 2000 species within several taxonomic groups and from across the EU27. Climate space modelling identifies bioclimatic envelopes for species and predicts changes to their potential distribution 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.

The model outputs used here include those by Huntley *et al.* (2007)[12] on breeding birds, Araujo *et al.* (2006)[13] on reptiles and amphibians, Settele *et al.* (2008)[14] on butterflies, and Thuiller (2004)[15] and Thuiller *et al.* (2005)[16] on vascular plants. This choice simplifies the

[12] Huntley, B. *et al.* (2007): A climatic atlas of European breeding birds. Lynx Edicions, Barcelona.
[13] Araujo, M. *et al.* (2006): Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33: 1712-1728.
[14] Settele, J. et al. (2008): Climatic risk atlas of European butterflies. Pensoft, Sofia.
[15] Thuiller, W. (2004): Patterns and uncertainties of species' range shifts under climate change. Global Change Biology 10: 2020-2027.
[16] Thuiller, W. *et al.* (2005): Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences.

impact and vulnerability assessment dramatically: all are modelling studies applying the standard greenhouse gas emission scenarios from the IPCC Special Report on Emissions Scenarios[17] (i.e. SRES, incl. A1F1, A2, B1, B2) to the Hadley Centre HadCM3 coupled atmosphere–ocean general circulation model. However, the projects employed different modelling algorithms, emission scenarios and time horizons (see Table 4). For this reason, and the obvious ecological differences between the taxonomic groups, the analyses were carried out for each taxonomic group separately.

Table 3: Number of assessed species per taxon and biogeographic region

Biogeographic region	Number of assessed species					
	Amphibians	Reptiles	Butterflies	Plants	Birds	Total
Alpine	10	6	12	10	117	**155**
Atlantic	6	4	5	6	100	**121**
Black Sea	2	5	3	-	107	**117**
Boreal	2	1	3	11	76	**93**
Continental	9	7	10	10	125	**161**
Macaronesian	-	1	-	2	33	**36**
Mediterranean	6	12	6	9	142	**175**
Pannonian	4	2	8	4	90	**108**
Steppic	2	4	2	1	94	**103**

Table 4: SRES greenhouse gas emission scenarios and time horizons used in the different impact and vulnerability assessments of different taxonomic 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

Similar modelling data are unfortunately not yet available for habitats, mainly due to the considerable computational challenges involved in building models to integrate the complex interactions between species and ecosystem processes. Moreover, many problems remain in interpreting the EU habitat types. The hope was to use indicator species as surrogates in habitat assessments and assign each of the species to one or more habitats. For reasons linked to the suitability of potential databases, this proved impossible within the scope of this project. **For these reasons, this study eventually focused only on species**.

b. Determining surrogates for climate change impact

In this study, the time horizons and SRES used to drive global climate models (GCMs) were used as the **surrogate for climate change exposure** (see Table 4; the A1F1, A2, B2 and B1 SRES scenarios can be viewed in a descending order of climate exposure). With the

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

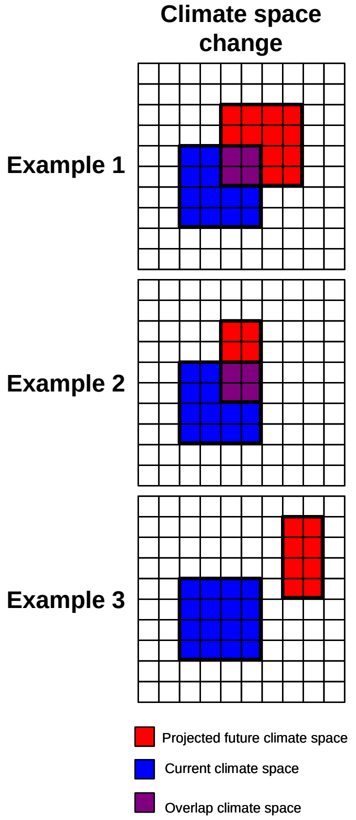
modelling algorithms implicitly contributing the climate sensitivity component, the resulting **surrogate for climate change impact** consisted of the changes in potential suitable climate space from current predicted distribution to projected future distribution. This surrogate is described by two metrics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

2. "**Ratio**" is calculated as the number of grid cells in the projected future range divided by the number in the simulated recent range. This metric describes the relative change in total suitable climatic space and is 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.

The impact scores for climate ratio and climate overlap, and the respective threshold values, are defined in Table 5. These impact scores are the basis for the next step in the vulnerability assessment - the integration of adaptive capacity.

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



	Overlap	Ratio
Example 1	(no. cells overlap) / (no. cells current) = 4 / 16 **25%**	(no. cells projected) / (no. cells current) = 16 / 16 **100%**
Example 2	(no. cells overlap) / (no. cells current) = 4 / 16 **25%**	(no. cells projected) / (no. cells current) = 8 / 16 **50%**
Example 3	(no. cells overlap) / (no. cells current) = 0 / 16 **0%**	(no. cells projected) / (no. cells current) = 8 / 16 **50%**

Table 5: Categories and threshold values for the two metrics of climate impact: overlap and ratio. 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

c. Determining and adding a surrogate for adaptive capacity

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

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, certain life history traits can be identified that might constrain the autonomous ability of species to adapt to climate change impacts; these are here called **general restrictions**. For species with <70% overlap in projected climate space (i.e. a moderate, high or very high climate overlap impact), additional factors are considered, here called **colonisation restrictions**. These adaptive capacity restrictions are then scored 0 (no constraint), 1 (moderate constraint) or 2 (severe constraint), using quantitative data or expert judgement. For example, many of the breeding bird species had either low to moderate constraints to colonisation, while those of reptiles and amphibians were routinely moderate to high. Table 6 lists the general and colonisation restrictions and illustrates how the sum of the individual traits scores produces the **total adaptive capacity constraint score** - which then feeds back into the vulnerability assessment.

Table 6: The scoring of general and colonisation restrictions to adaptive capacity producing the total adaptive capacity constraint score.

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

Adaptive Capacity Restriction	Ecological Trait	Adaptive Capacity Constraint
General restrictions	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	
	Subtotal	
If **Climate Overlap Impact Score** is Moderate, High or Very High, add scores for: **Colonisation restrictions**	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	
	Subtotal	

Total Adaptive Capacity Constraint Score: < 2 = Low 2-4 = Moderate >4 = High

d. Combining impact and adaptive capacity scores to determine the vulnerability category

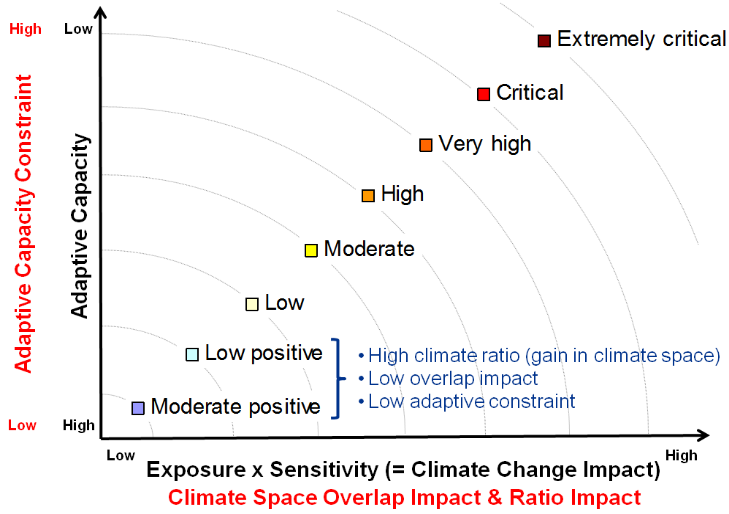
The overall vulnerability of each species is calculated using the scores resulting from the assessments of impact (climate space ratio, climate space overlap) and adaptive capacity (total adaptive capacity constraint score).

In a first step, **preliminary vulnerability categories are determined separately for both climate space ratio space and climate space overlap**. The underlying assumption 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.

Finally **the higher of the two preliminary categories is chosen as the final vulnerability category** for the given species.

Figure 3 illustrates the grading of the different vulnerability categories. The lowermost categories "low positive" and "moderate positive" (bottom left) identify species that may potentially benefit from climate change, because they gain in climate space (have a high climate space impact ratio), have a low overlap impact ratio, and only low constraints to adaptive capacity.

Figure 3: The final vulnerability categories/scores resulting from the assessment methodology developed in this study. The red labels represent the surrogates used for adaptive capacity and climate change impact.



4. Results from the species vulnerability assessment and impacts of climate change on the Natura 2000 network

The vulnerability assessment framework developed in Task 2a was applied to the entire subset of 212 species of Community Interest for which model data was available. 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 (see Tables 3 & 4).

The outcome was presented and reviewed in Tasks 2a and 3a. Task 3a furthermore assessed the direct impacts of climate change on the Natura 2000 network and also related the results of the species vulnerability assessments to the Natura 2000 network. In this context, analyses were made of: the distribution of assessed species across member states by taxon; distribution of assessed species across biogeographic regions by taxon; the number of assessed species that were considered of at least high vulnerability by taxon and by biogeographic region; and the number of Natura 2000 sites and biogeographic regions in which each assessed species occurs.

It is beyond the scope of this Summary Report to list or review the results for each of the species or for all the SRES scenarios and time horizons considered in the project. However, the following highlights some of the summary analyses as well as the most important findings. It is worth noting that the value of the study lies in the detail of the individual assessments, particularly where they provide guidance for conservation planning and species management.

a. Vulnerability assessment for species with analysis of geographic distribution

Assessment data for breeding birds were only available for 2070-2099 and for the medium-low (B2) SRES scenario. One of the 149 species was assessed as reacting positively to climate change. Eight species were assessed as being of low vulnerability, 22 species as moderately vulnerable, 41 species as highly vulnerable, 51 species as very highly vulnerable, 24 species as critically vulnerable and two species as extremely critically vulnerable. 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.

A significant portion of highly vulnerable bird species are reported to occur in the Alpine, Continental and, particularly, the Mediterranean biogeographic regions. Moreover, more than 72% of the assessed bird species occurring in Macaronesian Natura 2000 sites fall into the top four vulnerability categories. In the Mediterranean biogeographic region, about 78% of species fall into these top four categories.

Assessment data for reptile and amphibian species were only available for 2050. 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. This is important as these species have special habitat requirements, but do not have large dispersal capabilities and therefore cannot easily colonise new areas of habitat. Still others have restricted geographic distributions and limited ability to take advantage of potential expansions of suitable climate space.

Seven of the 12 amphibian and two of the 12 reptile species were ranked to be of more than moderate vulnerability under the A2 2050 scenario. This is not surprising given that amphibian species are strongly associated with and depend on water and wetland habitats and react more strongly to climate change than other taxa.

The largest number of assessed amphibian species occurs in the Natura 2000 sites of Italy. Those considered of high or very high vulnerability occur in Natura 2000 sites of the Alpine, Atlantic, Continental and Mediterranean biogeographic regions; five of the 10 species assessed for the Alpine biogeographic region belong to these two categories.

The largest number of assessed reptile species occurs in the Natura 2000 sites of Greece and Italy. All of the 12 assessed reptile species occur in the Natura 2000 sites of the Mediterranean biogeographic region, while only one occurs in the Boreal and Macaronesian regions.

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. 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.

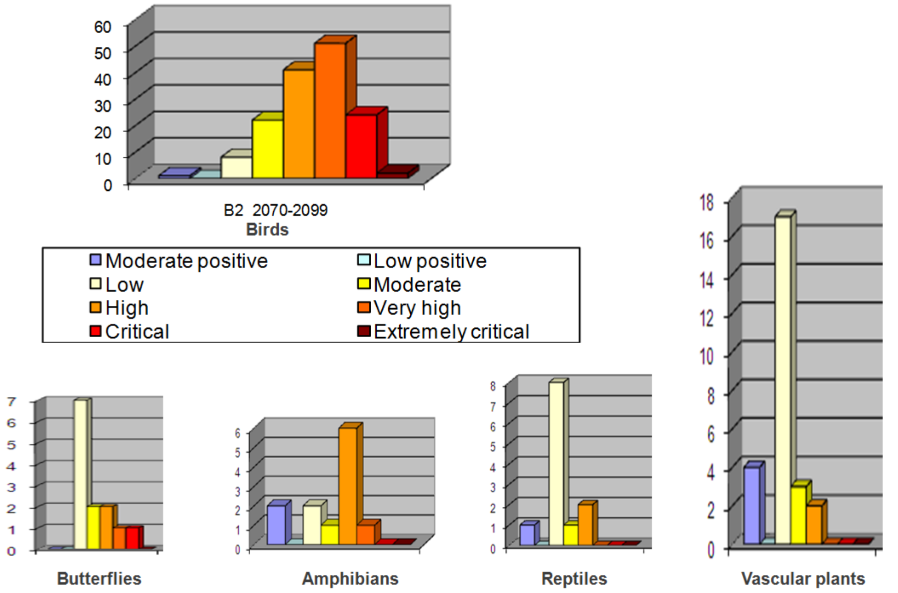
Of the 13 assessed butterfly species, 12 occur in Natura 2000 sites of the Alpine biogeographic region, 10 in the Continental region and eight in the Pannonian region. The three biogeographic regions also host the largest number of species assessed as of high vulnerability, very high vulnerability or critical vulnerability.

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. Again, these trends were similar to other taxa modelled to 2050, with the majority showing low vulnerability to climate change; however, trends by 2080 shift towards moderate to high vulnerability. At the same time, 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. Notably, the vulnerability assessments for plants did not show a large number of highly vulnerable species.

The largest number of assessed plant species were from Natura 2000 sites in Sweden (Boreal biogeographic region, 11 species), followed by Spain, Italy and France with six species each. Species assessed as more than moderately vulnerable in the period to 2050 occur only in Hungary, Romania, Slovakia and Sweden.

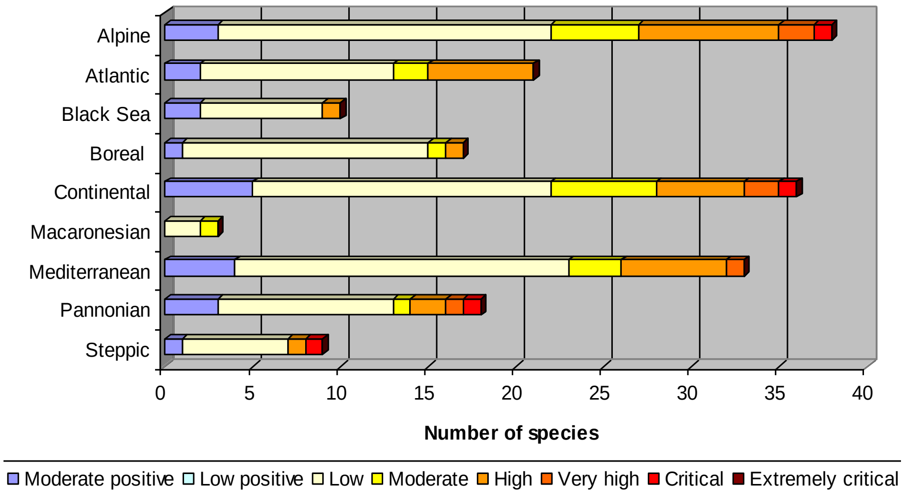
To provide an **exemplary overview**, Figure 4 brings together the respective vulnerability assessments for the A2 2050 scenario, which was shared by all taxonomic groups with the exception of birds (B2 2070-2099). Figure 5 gives a regional analysis for the pool of amphibian, reptile, butterfly and plant species assessed under the A2 2050 scenario. It shows that Natura 2000 sites in the Alpine, Continental, Mediterranean and Pannonian biogeographic regions host the greatest proportion of species considered to be more than moderately vulnerable – they are also the biogeographic regions in which the largest numbers of assessed species are reported to occur (Macaronesia is notably under-represented).

Figure 4: Vulnerability of assessed species by taxonomic groups, for the A2 scenario and 2050 time horizon (butterflies, amphibians, reptiles, plants); and for the B2 scenario and 2099 time horizon (birds).



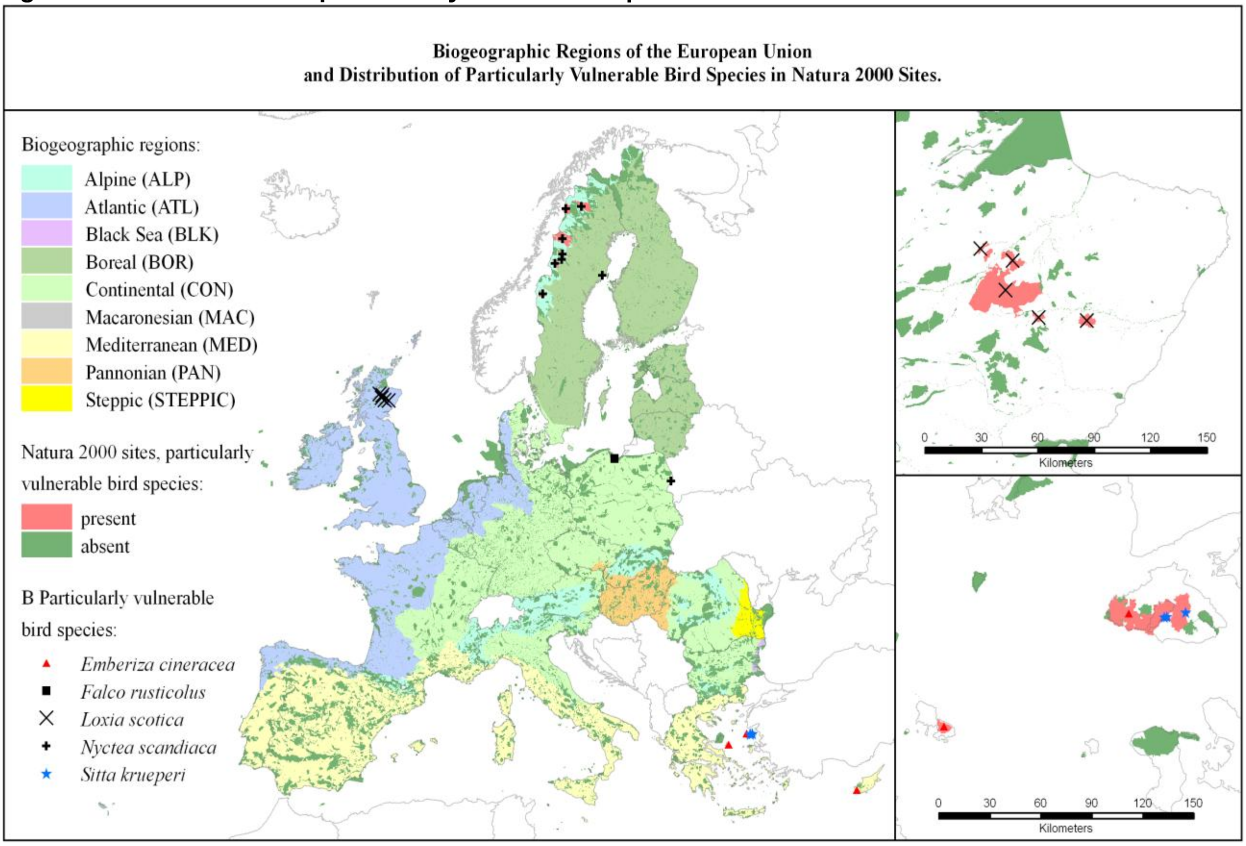
*: the results cannot be fully and directly compared between taxa, given some differences in the underlying models, but this still offer some guidance

Figure 5: Vulnerability of assessed amphibian, reptile, butterfly and plant species by biogeographic region for the SRES A2 2050 scenario.



The study applied an additional filter to the analysis in order to identify species "particularly vulnerable" to climate change, defined as species assessed as being more than moderately vulnerable (i.e. of high, very high, critical, and extremely critical vulnerability) and, in addition, occurring in 20 or less Natura 2000 sites. This applied to 11 (5%) of the 212 assessed taxa. Figure 6 shows the occurrence in Natura 2000 sites of the five species of birds that fell into this category.

Figure 6: Distribution of "particularly vulnerable species" of birds in Natura 2000 sites.



Whilst the purpose of the 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). This equally applied to 11 (5%) of the taxa assessed.

The study's vulnerability assessments go beyond the estimation of potential impacts (i.e. the combined effects of exposure and sensitivity), by additionally considering each species' adaptive capacity. 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** - 135 (64%) of the 212 species were ranked as of high, very high, critical, or extremely critical vulnerability under at least one scenario and time horizon. 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**.

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.

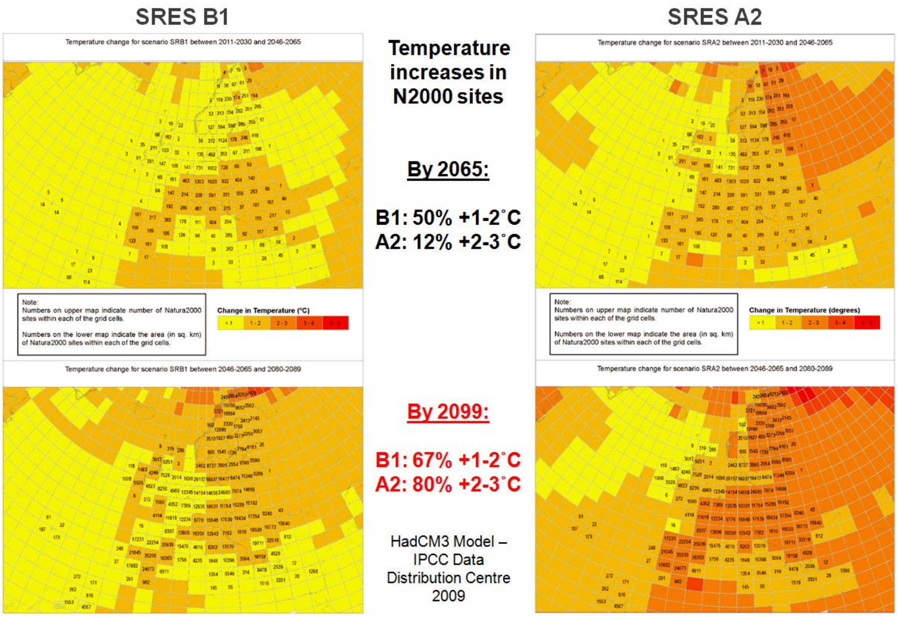
The results of the study's vulnerability assessments should, nevertheless, be treated with some caution. This is firstly because there are many uncertainties and limitations concerning the use of climate models in projecting impacts on biodiversity. Given that ecological constraints and limiting factors 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, the vulnerability assessments are of a preliminary nature as they essentially relied on an expert-based subjective assessment of adaptation constraints.

b. Temperature increases due to climate change in Natura 2000 sites and network

To evaluate the impact of climate change on the network of Natura 2000 sites, the project ran model simulations for annual average surface temperature in the EU under different scenarios and for different time horizons, which were then overlaid with spatial data for the Natura 2000 network.

Figure 7 summarises the relative increases in surface temperature across the EU for the severe A2 and the less severe B1 scenarios, for the time horizons 2065 and 2099. Under the B1 scenario, 67% of all sites and 65% of surface area experience a temperature increase of 1-2˚C by 2099. Under the more severe A2 scenario, almost 80 percent of the EU's Natura 2000 sites and surface area face temperatures increases of 2-3˚C towards the end of the century. The greatest increases are projected to occur in northernmost Europe.

Figure 7: Temperature increase across the Natura 2000 network across the EU for the B1 and A2 scenarios, for 2065 and 2099.



5. Wind, hydro and marine renewable energy infrastructures in the EU: an assessment of biodiversity impacts and suggestions for impact mitigation

Task 4 of the study conducted a biodiversity impact assessment for various existing and prospective new renewable energy infrastructure types in the EU, focusing on onshore and offshore wind farms, large hydro-energy dams, and marine energy – especially tidal barrages. It reviewed the impacts of the construction, operation and decommissioning phases, and provided guidance as to how best avoid or mitigate the effects identified in both the technical and the policy sense. The study also conducted a spatially explicit analysis of the placement of these renewable energy infrastructures in relation to the Natura 2000 network. The study concluded with a summary expert comparison of the degree of impacts by infrastructure type and the mitigation options.

The biodiversity impacts of **onshore and offshore wind farms** can be summarised as follows:

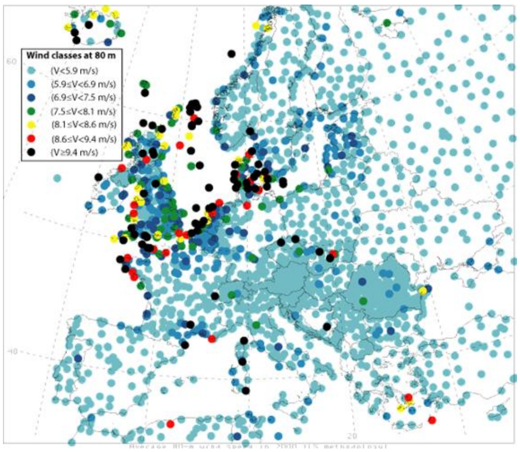
- Footprint of turbines, cabling, roads and infrastructure – impacts on natural habitats;
- Noise of construction and decommissioning and disturbance by human presence – leading to avoidance behaviour and direct damage (e.g. on marine mammal auditory systems) potentially leading to displacement and death;
- Collision with operating infrastructure – found to occur in birds and bats;
- Disturbance from operating infrastructure – barrier effects leading to avoidance behaviour during foraging bouts and migration (e.g. birds, bats), up to full displacement (e.g. offshore wind farms may have above and below water effects (including electromagnetic effects), affecting the breeding and foraging of seabirds, fish, marine mammals, etc.);
- Operating infrastructures, especially in offshore settings, may also offer new substrates to establish new communities, including invasive alien species, leading to artificial reef effects with unknown consequences for recruitment, harvesting and predation.

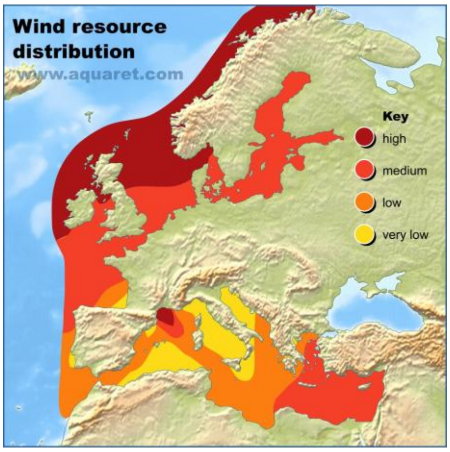
Opportunities to mitigate the negative impacts of onshore and offshore wind farms largely arise during the planning and design stages. The correct choice of turbine location is paramount, wherefore biodiversity should be given full consideration in Environmental Impact and Strategic Environmental Assessments. The exact design of turbines (turbine size, height, spacing, lighting and visibility) can be equally important. The timing of construction, maintenance and decommissioning activities also provides opportunities to reduce negative impacts on biodiversity.

While important local impacts on birds and bats have been demonstrated in a number of ill-placed wind farms, the study concludes that the overall impact of wind energy infrastructures on EU species and habitats has been rather limited, especially if one considers the huge generating capacity already installed.

Figures 8 and 9 show the distribution of wind energy resources across EU land and sea areas. The greatest wind energy potential lies in north-western Europe. In some of these countries (e.g. Germany) locations suitable for onshore wind farms have already been largely exploited. The biggest opportunities for additional wind power are located in the United Kingdom, Belgium and parts of Italy and Greece (onshore), along the coasts of the English Channel, the Atlantic, the Baltic region and southern France, particularly around the Rhone delta, and in large areas in the North Sea (offshore). Offshore locations offer not only greater expansion opportunities, but also greater and more stable wind speeds (and hence energy generation per turbine).

Figure 8 (left): Wind speeds across Europe. Figure 9 (right): Wind resource distribution across Europe





An interesting debate relates to whether offshore wind farms could provide positive biodiversity benefits (e.g. safe havens for marine resources from fishing activities) and whether they should be permitted in Natura 2000 sites (not current practice) where co-benefits prevail. This is a complex issue, which will differ from case to case, and one which should take account of alternative uses and the resources available for Natura 2000 management.

The significant biological impacts of **large hydropower dams** can be summarised as follows:

- Fragmentation of river ecosystems due to permanent barrier effects, with concurrent disruption of natural hydrology and sediment flows, and increased accumulation of methyl mercury;

- Water discharges from dams that, dictated by energy or cleansing needs, can be sudden and ecologically disruptive (water depth and velocity, oxygen levels, temperature, suspended particles, chemical composition, deposition and erosion);

- Impacts on freshwater species and habitats, such as changes from running water to still water habitats, including cave systems where groundwater is affected;

- Reduced floodplain inundation and impacts on other riparian biodiversity;

- Shrinking and drying deltas/estuaries, losses of related habitats, fishery nurseries, etc.

Opportunities to effectively mitigate the negative impacts of hydropower dams are limited, and relate to the location and design of the dam and its reservoir (e.g. avoiding pristine rivers and protected areas, and using tributaries instead of main rivers). A key further element is the maintenance of environmental flows throughout the year to reduce detrimental disruptive effects. Restoring degraded riparian ecosystems after construction, and compensating for unavoidable residual impacts, are additional ways to improve the net biodiversity impacts of dams.

The far-advanced exploitation of hydropower along rivers in the EU implies that, in many countries, few opportunities for important new dams remain. However, a range of countries, especially in eastern and south-eastern Europe, have plans to increase their hydropower capacity, putting in jeopardy some of the most pristine rivers. In addition, numerous sites across the EU may be suitable for the development of additional small hydropower, the cumulative impacts of which should undergo careful scrutiny (outside the scope of this study).

In the context of hydropower dams, aspects that require further study and consideration are:

- The degree to which methane emissions from the reservoir surface and, especially, through anaerobic deepwater discharges in the turbines undermine the achievement of greenhouse targets – one of the key drivers behind the continuing promotion of hydropower dams (recent research has shown this factor could have been ignored or significantly underestimated);

- The degree to which the plethora of out-dated smaller-scale hydropower infrastructures, with often very limited energy returns, could be decommissioned to improve the ecological status of the EU's rivers;

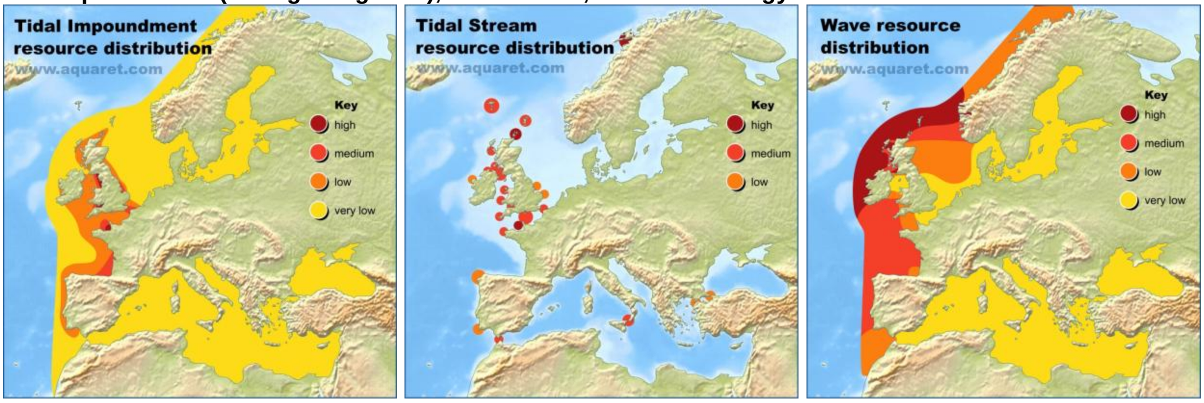
- The degree to which hydropower dams fulfil additional roles, such as flood control and water storage for agricultural purposes (the majority of river dams in the EU are not built to generate electricity). It therefore appears sensible to widen the debate to include non-electricity producing dams, particularly as climate change will lead many southern states to increase their water storage capacity. Are there opportunities for synergies, for retro-fitting, and for decommissioning inefficient structures?

The marine energy infrastructures that were assessed in the study comprised **tidal impoundment (barrage/lagoon; aka as tidal range), tidal stream and wave energy**. For some of these infrastructures, this study represents the first-ever in-depth compilation of the demonstrated and expected impacts.

Tidal barrages are typically very large installations that use existing geography to create an enclosure in which water is trapped. Tidal barrages may work both ways: the turbines can produce electricity when the pool fills and when the pool empties; the pressure differentials arising from tidal movements force water through the turbines. *Tidal lagoons* are like tidal barrages, but where the enclosure is a man-made self-contained enclosure that does not stretch fully across an estuary. *Tidal stream technology* captures the tidal motion without the use of a barrage or lagoon by placing water turbines in the tidal stream. These turbines are located under water and have a lot of similarity with wind turbines. Compared to wind turbines, the power that can be harvested through a tidal stream turbine is greater and more predictable. *Wave energy* is harvested in the open sea, using devices specifically designed for the purpose. Different designs are currently being tested. In order to capture large amounts of energy, wave energy collectors need to be large and need to be organised in farms, conceptually not unlike wind farms. There are currently no commercial wave farms in operation, but a number of single-machine wave energy collectors are being tested in EU waters.

Figures 10 to 12 show the distribution of tidal and wave energy resources in the EU. The greatest potential for development lies along the western and north-western European coast, especially around the British Isles. It should be noted that the number of suitable sites for tidal barrages/lagoons is limited – the Rance Estuary near Saint-Malo on the northern French coast is home to the only operational large-scale tidal barrage globally. The controversial Cardiff-Weston Tidal Barrage in the Severn Estuary in the United Kingdom is one of the few other projects currently under consideration in the EU.

Figures 10, 11 and 12: Geographical distribution of marine energy resources along the coasts of Europe: tidal impoundment (barrages/lagoons), tidal stream, and wave energy.



The biodiversity impacts resulting from the construction and operation of **tidal barrages** can be summarised as follows:

- During the lengthy construction phase (nine years are foreseen for the possible Severn Barrage), large scale and extended impacts are likely on species and natural habitats from dredging, drilling, sediment mobilisation, dam construction, and disturbance due to noise, machinery and human presence;

- During the operational phase (expected life spans of more than 100 years), the confinement of the area behind the barrage will lead to fundamental changes to currents and sediment regimes (affecting estuarine salinity, pollution and turbidity), reductions in tidal range (to about half), and extensions of inter-tidal habitats such as mudflats, salt marshes, rocky shores and sand dunes – with knock-on effects on benthic communities, as well as on breeding, resting and foraging grounds for birds (including migratory species);

- The structure will represent a barrier for some species, while other species (diving birds, fish and sea mammals) are at risk of being swept into barrage turbines;

- Indirect biodiversity impacts can furthermore result from the development of human and industrial infrastructures, including harbours around the energy-generating dam.

The options for mitigating the negative impacts of tidal barrages are theoretically linked to selecting more favourable dam locations and designs, but the availability of suitable sites is severely limited. Another objective is to reduce the degree of confinement and disruption of environmental flows resulting from the barrage. However, both types of impact mitigation will entail a reduction in the scale and power output of a proposed scheme.

The impacts of tidal stream farms on biodiversity will be rather limited until 2020, partly because the technology is still emerging, and partly because the technologies themselves are expected to impose relatively low impacts on biodiversity – except in cases where they create barriers in important locations, such as estuaries or channels used by migrating species. The potential to mitigate the impacts of tidal stream farms on biodiversity is high and increasing as the various technologies emerge onto the market.

There is higher potential to mitigate the impacts of modular technologies such as wind farms and tidal stream turbines than of tidal barrages and hydropower schemes. There is little evidence of the cumulative impacts of energy-generating infrastructures, of impacts resulting from species interactions, and of impacts on less charismatic species.

The study made a comparative summary assessment of the range of renewable energy infrastructures, which is summarised in Table 7. Of all the assessed infrastructures, large hydropower dams and tidal range barrages are ranked as having the highest impacts on biodiversity, whereas appropriately sited infrastructures harnessing offshore wind and wave energy are ranked as having the lowest biodiversity impacts. The greatest growth potential in terms of available energy potential lies in the wind energy sector, especially offshore wind.

Table 7: Summary evaluation of the biodiversity impacts and relative impact mitigation potentials for the different renewable energy infrastructures put in relation with energy generating potentials.

	Hydro dams	Tidal barrage/lagoon	Tidal stream	Onshore wind	Offshore wind	Wave
Potential biodiversity impacts	High	High	Low	Medium	Low	Low
Impact mitigation potential	Low	Medium	Medium	High	High	High
Residual biodiversity impacts	High	Medium-High	Medium-Low	Medium-Low	Low	Low
Installed Capacity in EU	99 GW = 40 GW corrected for capacity (1,362 dams)	240 MW	1 MW	65 GW = 20 GW corrected for capacity (60,667 turbines, mainly onshore)		Test phase, units of 2-4 MW each
Projected Capacity in EU	?	No additional yet by 2020	?	230 GW by 2020 = 70 GW corrected for capacity (added capacity mainly offshore)		?
Realistic energy potential in EU	?	20 GW?		?	?	10 GW (88 TWh)

Furthermore the study conducted an **in-depth spatial analysis (ArcGIS) of existing and planned wind and marine renewable energy projects** across the EU. It showed that currently only a small fraction of the Natura 2000 area is occupied by wind and marine energy infrastructure and that most impacts will be of a more localised scale. Moreover, vast opportunities remain to establish such energy infrastructures outside of Natura 2000 sites and many of these opportunities will prevail until and beyond 2020. As such, there are no reasons of overriding public interest to establish any such infrastructure within Natura 2000 areas, at least until 2020. Offshore renewable energy developments that may yield co-benefits for biodiversity management, as discussed above, may constitute an exception to this rule.

No suitable spatial data could be found for the location of hydropower infrastructures across Europe. It can, however, be assumed that the far-reaching ecological impacts of hydropower dams will be seen also in numerous upstream and downstream Natura 2000 sites.

The study concluded with an analysis of the expected new technological developments in the renewable and clean energy sector and how these relate to biodiversity, and with recommendations for policy and further research in the field of renewable energies and their link with biodiversity.

6. Impacts of climate change on EU biodiversity policy and recommendations for policy and research

The study's Task Report 2b & 3b reviewed existing principles and guidelines devised to help biodiversity adapt to climate change; summarised the sectoral policies affected; evaluated the impacts of climate change on the EU's biodiversity policy framework - most importantly the 2006 EU Biodiversity Communication and related Biodiversity Action Plan (BAP); and outlined a series of recommendations for actions and policies including on research.

The **assessment of the impacts on the 2006 EU Biodiversity Communication and related Biodiversity Action Plan (BAP)** came to the following conclusions:

1. *Direct* impacts of climate change on biodiversity and the EU BAP already exist and will become stronger. However, currently the effects of the *indirect* impacts of climate change, most notably the financial implications and those associated with mitigation measures and (mal-)adaptation in other sectors require more attention and response measures.

2. Funding for the conservation of biodiversity and ecosystem services, as well as for biodiversity adaption to climate change, is prone to reduction as decision-makers and stakeholders at all levels (e.g. WTO, EU, EU member states, ODA-recipient countries, regional and local authorities, businesses, land owners, farmers, fishermen) will need to allocate significant resources to climate change mitigation and adaptation across all sectors.

3. The EU Overseas Entities (Outermost Regions and Overseas Countries and Territories) harbour the EU's greatest biodiversity and will experience severe climate change impacts; they are especially vulnerable to reduced conservation funding, given that their economies are dependent on very few sectors (e.g. tourism).

4. The implementation of a wide range of actions may be delayed, weakened or impeded, as the direct and indirect impacts of climate change complicate scientific research and related policy procedures (e.g. the establishment of fisheries management plans where the evolution of fish stocks under climate change is uncertain).

5. Climate change is seen as an overriding environmental and political concern; there is a risk that the implementation and enforcement of existing biodiversity-friendly policies and measures may therefore be reduced, particularly where responsibility is devolved to national, regional or local authorities.

6. Various climate change adaptation and mitigation measures may have significant negative impacts on biodiversity and ecosystem services. The mandatory targets under the Renewable Energy Sources Directive are a particular concern, as they may lead to significant impacts through the production of bioenergy feedstock within and outside the EU, the installation of new small and large hydro power infrastructures along EU rivers, and the installation of other high impact renewable energy infrastructures (e.g. tidal barrages).

7. Despite this largely negative summary assessment, the rise of climate change to the top of the political agenda may provide an opportunity for biodiversity, if the critically important biodiversity-climate change interface is further exploited and recognised. Properly planned ecosystem-based adaptation and mitigation measures offer significant opportunities for biodiversity to benefit indirectly from climate change action and funding.

To **help the EU's biodiversity adapt to climate change, measures to increase the resilience and facilitate the movement of species are paramount**. In the first instance, the principal actions for increasing the resilience of existing populations of species and habitats should be those that reduce existing threats and constraints, including: habitat change and fragmentation; pollution; disturbance; predation and over-exploitation; as well as alien species and pathogens.

Where measures are necessary to facilitate the movement of species, these may include: increasing productivity and emigration rates (i.e. improve the condition of the population); improving the condition of individuals (to increase the likelihood of survival and colonisation during dispersal); reducing habitat fragmentation (to facilitate long-distance dispersal); and removing barriers to dispersal.

It is also apparent that, in practice, adaptation measures need to focus on existing conservation actions, such as: maintaining and increasing the area of core habitats (Natura 2000 sites and other protected areas); reducing external impacts (e.g. by establishing buffer zones and controlling pollutant emissions); managing/enhancing the ecological quality of habitats, especially in protected areas; managing species populations (e.g. controlling exploitation, and impacts of invasive alien species); and increasing/restoring connectivity through landscape-scale conservation measures (e.g. restoring habitat patches, enhancing the wider habitat matrix, and where well-justified creating habitat corridors).

In essence therefore, **biodiversity adaptation requires the redoubling and speeding up of current conservation efforts to protect and manage habitats and species populations**.

Further actions to increase the resilience of biodiversity and ecosystems, taken from the 2009 EC White Paper on Adapting to Climate Change, the 2009 Message from Athens[18], and the 2009 discussion paper "*Towards a strategy on climate change, ecosystem services and biodiversity*" of the EU Ad Hoc Expert Working Group on Biodiversity and Climate Change, include:

- Explore the possibilities to improve policies and develop measures which address biodiversity loss and climate change in an integrated manner to fully exploit co-benefits and avoid ecosystem feedbacks that accelerate global warming;
- Explore the potential for policies and measures to boost ecosystem storage capacity for water in Europe;
- Draft guidelines by 2010 on dealing with the impact of climate change on the management of Natura 2000 sites;
- Ensure that climate mitigation and adaptation measures are fully compatible with the objective of conserving biodiversity;
- Promote the implementation of "triple win" measures that conserve biodiversity while actively contributing to climate mitigation and adaptation;
- Develop and implement adaptation measures for nature conservation;
- Use ecosystem-based approaches to address climate change and biodiversity loss and ecosystem service degradation in an integrated manner and develop strategies that achieve mutually supportive outcomes. This implies addressing the wider ecosystem challenges and potential in the climate change negotiations (e.g. by

[18] http://ec.europa.eu/environment/nature/biodiversity/conference/pdf/message_final.pdf

establishing a REDD+ like mechanism, promoting a similar approach for other land use and ecosystems and, by including ecosystem-based approaches as an integral part in the UNFCCC Framework for Adaptation Action).

- Take immediate action to conserve and restore terrestrial and marine biodiversity and ecosystem services as these are the basis for cost-effective climate change adaptation and mitigation and can provide multiple economic, social and environmental benefits;

- Engage other sectors (e.g. agriculture, finance, transport, energy, regional planning, water management, fisheries, forestry, tourism, development policy, health, built environment) to maintain and increase ecosystem resilience and to ensure that their activities do not further damage biodiversity and ecosystem services;

- Raise awareness of the linkages between climate change, biodiversity and ecosystem services through communication and education initiatives, make use of local knowledge and build institutional capacity and partnerships to facilitate integration;

- Strengthen the knowledge base on the climate change-biodiversity linkage through increased research efforts, long-term monitoring, and valuation;

- Appropriately address the issue of biodiversity, ecosystem services and climate change in upcoming financial reviews.

Building on these, the study's Task Report 2b & 3b concludes with detailed **sector-specific policy recommendations** for the EU aimed at avoiding or reducing the negative impacts of climate change on biodiversity, and in particular the integrity of the Natura 2000 network. These are summarised below.

1. **Rapid and effective and implementation of the EU Biodiversity Action Plan**, to require and include:
    - Explicitly ring-fenced funding for biodiversity conservation and adaptation under all the funding mechanisms covered in the BAP (EU and EU member state allocations, European Social Fund (ESF), cohesion/structural funds, CFP and CAP/RDPs, etc.), and proper attention in the upcoming EC Budget Review;
    - Appropriate specific funding for biodiversity conservation, biodiversity adaptation and ecosystem-based adaptation and mitigation measures in the EU Overseas Entities (Outermost Regions and Overseas Countries and Territories);
    - Subject sectoral climate change adaptation and mitigation measures that may have negative impacts on biodiversity and ecosystem services to strict Environmental Impact and Strategic Environmental Assessments that fully integrate and respect biodiversity and ecosystem aspects, and closely and regularly monitor these measures;
    - Update and strengthen existing environmental legislation, where necessary and appropriate, and enhance implementation and enforcement;
    - Reach out to sectors responsible for the planning and implementation of adaptation and mitigation measures, in order to maximise the use of opportunities for biodiversity co-benefits and ensure that ecosystem-based measures are given priority;
    - Conduct new modelling, field research and review studies, as well as monitoring programmes and capacity-building on the climate change and biodiversity interface, to better inform measures and policy-making;

- Fast-track the implementation of no-regret measures that do not risk being maladaptive, such as conservation activities enhancing the resilience of existing species populations and habitats.

2. **Development by EU member states of national climate change adaptation strategies and action plans** (where still required), extending these with biodiversity adaptation action plans that identify responsibilities for implementation. Such action plans should be integrated with the requirements of the EU biodiversity policy framework and other sectoral strategies for climate change mitigation and adaptation, to take advantage of the potential co-benefits of combined actions with other sectors.

3. **Designation of Natura 2000 sites and other protected areas and revision in the light of climate change**. The protection and management of a robust and coherent protected area network, as is the aim of the Natura 2000 network, should continue to form the cornerstone of habitat and species protection and management in the EU. However, the Natura 2000 network, even when fully established, will not be sufficient to protect biodiversity in Europe according to all reasonable projections of climate change. In most parts of Europe, protected areas are too small to accommodate changes, and the matrix around them is too modified and intensively used. With the exception of some eastern EU member states in which suitable areas for protected area network expansion may be more easily found, the options for redesigning and extending the EU protected areas network are therefore limited. Instead, it is likely to be more feasible to support the Natura 2000 network by improving functional connectivity, establishing ‘buffer zones’ to increase the effective size of reserves, linking habitats in new suitable climate zones with existing relatively ‘climate-proof’ *refugia*, and including diverse protected area management strategies. Furthermore, although there is a strong case for retaining the vast majority of existing Natura 2000 sites for the foreseeable future, there is also a case for re-examining their objectives with respect to their focus on specific species and habitats (i.e. their “designated features”). It is therefore recommended that guidance should be provided for member states on objective setting for, and monitoring of, designated habitats and species that are being impacted by climate change. In the longer-term, the objectives for the Natura 2000 network may need to be more flexible, to accommodate change whilst maximising the ecological value of each site and the network as a whole.

4. **Increasing connectivity through corridors and ecological networks**, by:
   - Assessing the need for, and planning measures on the basis of, functional (not structural) connectivity;
   - Focusing on species that are most at risk from fragmentation and climate change;
   - Building network designs based on ecological science and evidence;
   - Protecting existing connectivity - following the precautionary principle when there is doubt over its value;
   - Only increasing connectivity where it is necessary and carefully consider the possible risks from such actions;
   - Considering all options for increasing functional connectivity and taking their cost-effectiveness into account;
   - Linking ecological networks to ecosystem-based adaptation and mitigation measures (e.g. the management of upland catchments for water resources and flood attenuation, of peatlands and natural forests for carbon storage and sequestration, of flood plains for flood alleviation, or of coastal wetlands for coastal protection).

5. **Control of invasive alien species (IAS)**. The EU should develop, implement and effectively enforce a strong and comprehensive over-arching IAS strategy, which aims to prevent the arrival of new IAS, control the spread and impacts of existing IAS, and where necessary eradicate existing IAS. The strategy should lead to increased

co-ordination between EU institutions, member states and regions on IAS prevention and response measures. It should moreover take into account the likely effects of climate change on the spread of IAS and the possible need for special and targeted measures for Natura 2000 sites, as well as for species and habitats of Community Interest in general. In the context of climate change, clarification will be necessary on distinguishing unwanted IAS from species that extend their natural ranges while adapting to climatic changes (which should therefore be considered benign immigrants).

6. **Delivery of conservation management**, especially by enhanced implementation of agri-environment and cross-compliance measures in agricultural landscapes and by strengthening the role of forest management in the context of biodiversity-friendly climate change adaptation and mitigation.

7. **Impact assessment and planning policy**. There is a need to better address biodiversity conservation needs in Strategic Environmental Assessments and Environmental Impact Assessments, both inside and outside Natura 2000 areas, and to ensure that they properly consider climate change related issues. Strategic Environmental Assessments may also be able to play an important role in identifying strategic opportunities for enhancing biodiversity resilience and allowing for biodiversity adaptation. The possible benefits of the introduction of a no-net-loss policy for biodiversity should also be considered. Such a policy would require practical measures to deliver, such as the promotion of offsets (e.g. through market-based habitat banking schemes). This could provide a useful mechanism for delivering habitat enhancement and restoration measures, which could help reverse habitat fragmentation. However, the introduction of such compensation measures would have to be introduced carefully with appropriate regulatory safeguards.

8. **Research and monitoring**. Further research and monitoring urgently needs to be conducted in order to provide reliable species-specific, habitat-specific and site-specific guidance. Although, the information that is currently available can give an indication of the broad strategies that are likely to help with climate change adaptation, the actual delivery of effective long-term actions will require much more detailed ecological knowledge. It is therefore recommended that the following biodiversity related climate change research actions be given a high priority:

    - Carry out fundamental ecological research to improve our understanding of the effects of climate change on biodiversity and interactions with other environmental changes and pressures. A particularly high priority should be given to examining the factors that affect resilience and the ability for species to move to and colonise new areas. The research should be combined with long-term monitoring of the impacts of climate and other abiotic factors on biodiversity at an appropriate range of spatial scales.
    - Undertake necessary field surveys and analyses to map the full spatial distribution of EU species and habitats of Community Interest, especially those likely to be vulnerable to climate change, to provide the necessary baseline for studies on climate change vulnerability, on potential climate-related distributional changes, and on specific biodiversity adaptation measures.
    - Extend climate envelope mapping to all taxa groups and habitat types (especially Habitats of Community Interest listed in Appendix 1 of the Habitats Directive) with suitable spatial distribution data. Link resulting climate envelope projection models to dispersal models and dynamic models of existing and potential habitat availability. The aim should be to quantitatively and objectively extend the analysis carried out in Task 2 of the present study, and provide clearer and more reliable assessments of vulnerability (i.e. that consider adaptation constraints) and projected changes in distribution of species and habitats.

- Further develop the spatial analysis of the impacts of climate change on the Natura 2000 network, by analysing the distribution of species of Community Interest that are vulnerable to the impacts of climate change in relation to modelled projections of their suitable climate space. This analysis should be supported by the development of reliable spatial maps of the distribution of species and habitats of Community Interest and the completion of inventories of the presence and relative abundance of habitats and species of Community Interest in all Natura 2000 sites. The studies should aim to identify Natura 2000 sites that are likely to lose species and habitats of Community Interest, and sites that might gain species and habitats of Community Interest, taking into account adaptation constraints. An integrated assessment should then be carried out to assess the potential coherence of the overall Natura network (and its biogeographic regions) in relation to projected losses and gains of species (taking into account adaptation constraints) according to various climate scenarios and timelines. This should consider the adequacy of representation of species and habitats of Community Interest and requirements for functional connectivity amongst sites.
- Develop and test methods for assessing functional connectivity requirements for species that are vulnerable to climate change. These should aim to reliably establish existing functional networks, assess their viability under various climate change scenarios, and identify needs for increasing connectivity to increase resilience and, where necessary, re-distribution to suitable habitats in areas projected to have suitable climate space.
- Carry out research and monitoring to improve our understanding of the potential impacts of extreme weather events on the viability of species populations and habitats, and how such events may drive changes in their distribution. Incorporate these findings into climate based models of species and habitat distribution.
- Conduct detailed monitoring of appropriate sample species and habitats that are considered to be vulnerable to climate change to validate and calibrate model based projections. Use the findings to identify indicators (species and otherwise) that will provide an early warning of climate change impacts in Natura 2000 sites.
- Carry out controlled experiments to assess the risks and benefits of assisted migration, learning from advances in IAS science.
- Monitor the impacts and cost-benefit relationships of biodiversity adaptation measures that aim to support species and habitats of Community Interest in Natura 2000 sites and the wider environment (e.g. the effectiveness of habitat management measures, increasing Natura 2000 site areas, buffer zones and connectivity measures).
- Conduct further research to identify practical, robust and cost-effective ecosystem management measures that can significantly support biodiversity conservation and/or climate change mitigation and/or climate change adaptation for other sectors. Develop policy instruments to support such ecosystem-based adaptation and mitigation measures, in particular where they offer multiple benefits.
- Model and monitor the impacts of land-use and biodiversity relevant climate change adaptation and mitigation measures, such as flood control infrastructures, new agricultural crops, renewable energy infrastructures, and most importantly the production of bioenergy feedstocks, including forest resources.