Supplement

Managing climate change for the Natura 2000 network

Assessment of the vulnerability of Natura 2000 species and habitats for climate change: species and habitat types most at risk

Overall approach and the result of the analyses.

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Contents

This supplement has been developed based on best available knowledge. Caution is advised in the use and interpretation of the results: for many species, no or little information is available on the impacts of climate change; for habitats, the majority of the assessment is based on expert knowledge.
The information regarding the EU conservation status is based on the Article 17 reporting and the assessment undertaken by Birdlife (Birdlife International, 2004). For many species and habitats, no conservation status has been determined. Therefore, the results presented in this report on the vulnerability to climate change of Natura 2000 species and habitats and their current conservation status is strongly influenced by those species and habitats for which good data is available.

1 Introduction to vulnerability of species and habitats to climate change

The aim of this assessment is to categorise species and habitats in groups based on their vulnerability and expected responses to climate change. Vulnerability, as defined by the IPCC (2007), is a combination of exposure, sensitivity and adaptive capacity (see also figure 1). The IPCC uses the following definitions:

- *Vulnerability* (Appendix 1, IPPC 2007): Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of character, magnitude and rate of climate change, and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
- *Adaptive capacity* (Appendix 1, IPPC 2007): Adaptive capacity is 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. (See ecosystem adaptive capacity in figure 1)
- Definition *Adaptation* (Glossary, IPPC, 2007): Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. (See adaptive capacity of society in figure 1).

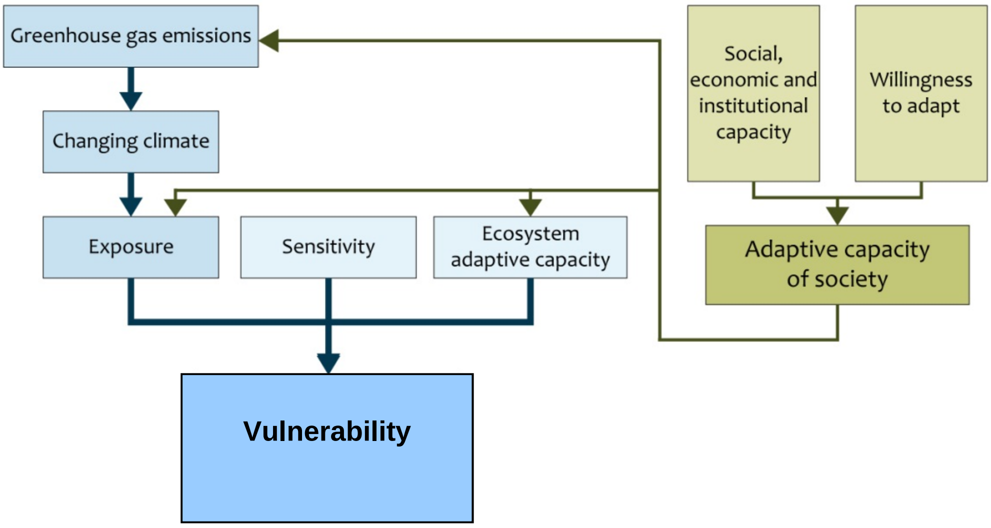

Figure 1. Schematic overview of the components that determine the vulnerability to climate change of species and habitats (blue parts) and the adaptation or mitigating response of society (shown in green).

As is illustrated in figure 1, vulnerability to climate change is a combination of exposure, sensitivity and the capacity of a ecosystems (composed of species / habitats) to adapt. An important aspect in determining vulnerability is whether or not species or habitats are able to adapt to the changes caused by climate change. Species or landscape characteristics might put constraints on autonomous adaptation responses, thus adding to the vulnerability. Species traits that might put constraints on adaptation are, for instance: limited dispersal capacity, which would reduce the ability of a species to adjust its distribution to its shifting suitable climate zone. Landscape characteristics, which may affect the success of adaptation, are, for instance: lack of opportunity for inland, altitudinal or pole ward migration.

The conservation status of species and habitats is often already not optimal as a result of human activities. Climate change vulnerability poses an additional threat for the conservation and might intensify existing anthropogenic pressures (figure 2). The complex, direct and indirect impacts of climate change are illustrated in Figure 2. For instance, habitat fragmentation might increase the impacts of climate change because it blocks the ability of species to expand their range as a response to shifting suitable climate zones: also, for example, eutrophication is an existing pressure that might be intensified by higher temperatures and fluctuating water tables, caused by climate change.

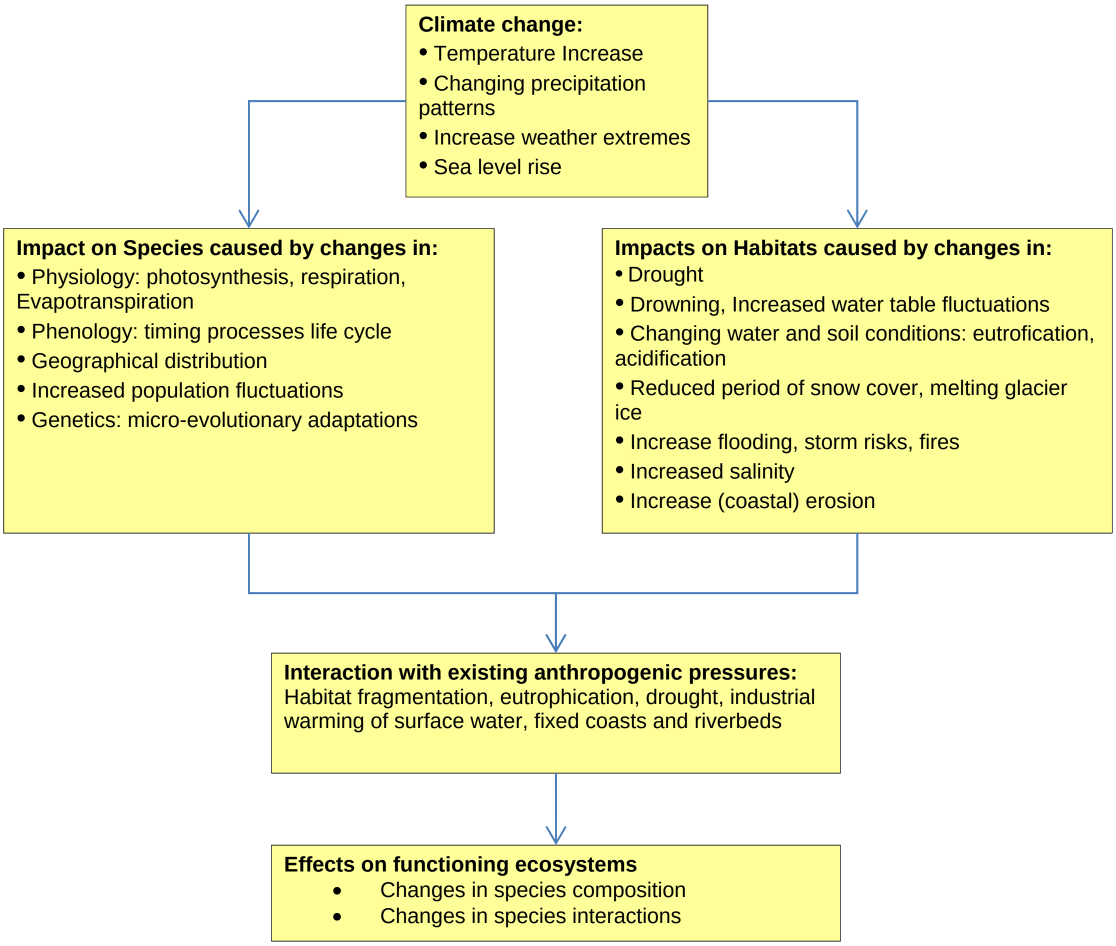

Figure 2. Overview of direct and indirect impacts of climate change

2 Scenario's

Many uncertainties exist in predicting the future climate. The IPCC (2007) have tackled this problem by developing different Scenarios that give an impression of the range of possible future climates (see figure 3). Figure 3 shows the large differences in predicted global temperature increase between the scenarios. The studies that were used as sources for the vulnerability assessment use a variety of different climate change scenarios and time horizons. As a general rule, we based our assessment for species on the reported impacts of the A2 scenario for 2080-2100 (except for Birds, as information is only available for one scenario B2). In the A2 scenario, the rate of global warming is relatively high and impacts on biodiversity are therefore relatively severe. There are several reasons to choose this scenario: temperature increase in Europe is relatively strong compared to the global increase; also, the observed rate of temperature increase in the last decades follows the higher scenarios and even exceeds them (Berry et al, 2009); in addition, as a vulnerability assessment is about identifying possible risks in future, the precautionary principle would justify choosing the scenario predicting the highest impact. When the A2 scenario is not available in the source data or a different time horizon is used, this is indicated in the matrix.

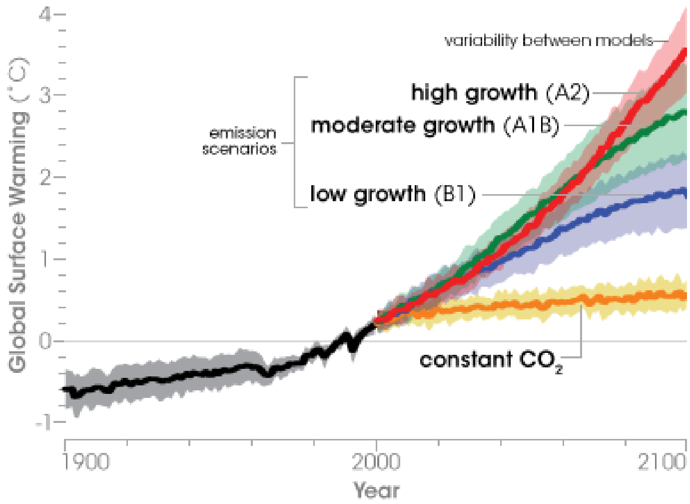

Figure 3. Temperature projections to the year 2100, based on a range of emission scenarios and global climate models. Scenarios that assume the highest growth in greenhouse gas emissions provide the estimates in the top end of the temperature range. The orange line ("constant CO2") projects global temperatures with greenhouse gas concentrations stabilized at year 2000 levels. Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007).

3 Overall approach and the development of the matrices

A large body of literature already exists on the impacts of climate change on biodiversity. We reviewed the recent scientific and applied literature on publications that categorise the vulnerability of species and/or habitats for the impacts of climate change. This information forms the basis for the development of vulnerability matrices for habitats and species. We used the following criteria to determine suitable approaches:

- The approach is applied on a sufficient number of species and/or habitats or can be applied on a sufficient number of species and or/ habitats.
- The methods used are explicitly described.
- The approach can be applied in the timescale and resources available for the development of the Guidelines 'Managing climate change for the Natura 2000 network'.

Large differences exist in the amount of available data between species groups and habitats. As a consequence, for some groups part of the assessment is based on expert judgement or impacts are classified as 'unknown'.
To improve the accessibility of the available information we developed four matrixes (figure 4):

- Habitat vulnerability (matrix A)
- Species vulnerability (matrix B)
- Conservation status per bio-geographical region (matrix C)
- Species and habitats most at risk per bio-geographical region (matrix D)

The habitat vulnerability matrix describes the main impacts of climate change on habitat functioning and indicates which habitat types are vulnerable for specific impacts. The species vulnerability matrix provides an overview of climate change vulnerability, based on available knowledge in literature and expert knowledge.
Next, the vulnerability for climate change impacts is linked to the current state of conservation, based on the Article 17 reporting data (except for Birds, as no Article 17 data are available). When the current status is already unfavourable, vulnerability for climate change will pose an additional threat for conservation. The assessment results in matrix D indicate which species and habitats are most at risk for the (additional) impacts of climate change per bio-geographical region. For Birds, matrix D only provides an estimation for the whole of the EU as no assessment per bio geographical region is available.

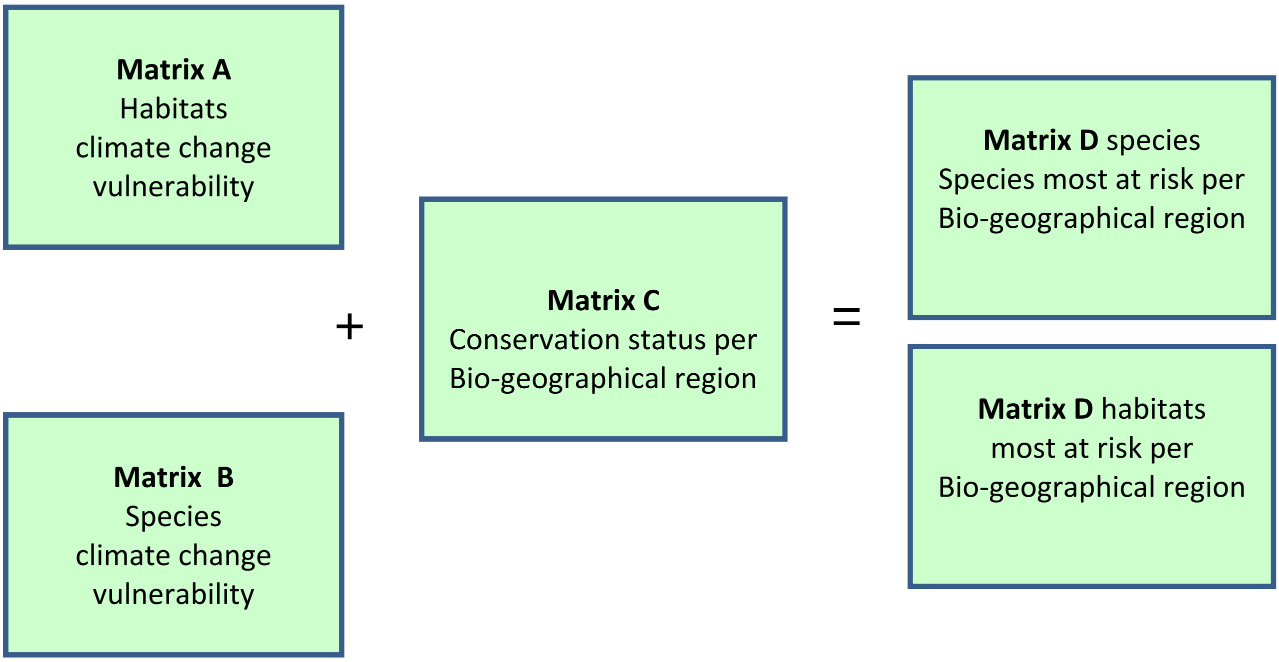

Figure 4. Overview of the assessment to identify species and habitats most at risk for the impacts of climate change.

4 Description of Matrix A: habitat vulnerability to climate change

4.1 Climate change impacts and indicators for habitat vulnerability

A habitat consists of a range of animal and plant species, which respond differently to changes in abiotic conditions and fire, floods and storms. As a result the interactions between species can change, leading to a change in vegetation structure, or species composition but, not necessarily, leading to a deterioration of the habitat or succession to a different habitat. The assessment of the impact of climate change on habitats is more complex than on a single species , amongst others because of these species interactions. Furthermore, evidence suggests that systems might be more resistant to change then single species. Therefore, in this study, a rather cautious approach was chosen – high vulnerability scores were only assigned if scientific studies were available which indicated recorded effects of climate change or modelled effects.

The habitats of Natura 2000 are of differing inherent variability, varying from single plant associations to habitats encompassing much variation, there are also variations in how the habitats have been interpreted between the Member States and sometimes between regions of the same country (Evans 2010).

Evans (in prep) proposed different options to model the response of Natura 2000 habitats to climate change:

- For habitats defined by a few species: a prediction of the future distribution of the species also gives a future distribution of the associated habitat. Hartley et al (2010) developed an approach to assess the vulnerability of Natura 2000 habitat types based on the response of characteristic species using climate envelope models.
- For complex habitats: Predict range shifts by developing an ecological characterisation of the habitat using current climatic parameters. This approach is currently still under development.

For habitats defined by their biogeographical region or vegetation zone they occur in the change will depend on expansion or decrease of the specific zone.

In this report, the approach is chosen to assess the vulnerability of the entire habitat to a given pressure that results from climate change and the likelihood that the habitat will be exposed to this pressure in its range of occurrence.

Main reason to choose this approach is:

- It can be applied to all habitats
- It does not require time consuming modelling in order to assess the ecological character of the habitat and an assessment of the change in habitat. The reasoning however is in line with this approach that assesses how climate parameters of habitats might change.
- And most important it enables site managers to link the climate change response of habitats to the pressures which they can address.

This approach however does not take into account the fact that for some habitat types the disappearance of characteristic species may have strong (partly indirect) effects on ecosystem functioning or that habitat types that are not very species rich the disappearance of characteristic species might lead to shifts to other habitat types that are not of conservation concern (ie. Non-N2000 habitat types). In the following section the different of climate change effects are described and the pressures they might cause. A total of 13 pressure indicators were identified (see figure 5).

Habitat												
Temperature increase\ CO_2 increase					Sea level rise		Changing precipitation patterns			Extreme events		
1.Increased availability of nutrients , eutrophication	2. Acidification	3. Reduced period of snow cover	4. Melting of glacier ice/loss of permafrost	5. Altitudinal migration	6. Submersion	7. Erosion	8. Drought	9.Submersion/higher water table	10.Increased salinity	11.Fires	12.Storm risks	13. Flooding

Figure 5. Indicators (1 to 13) used to determine habitat vulnerability to climate change.

Temperature increase

Combined effects of temperature rise and CO_2 primarily impact habitats by changing abiotic conditions (IPCC, 2001), resulting in processes that affect the quality of habitat and might eventually lead to loss of habitats: as examples, effects already reported are acidification of oceanic habitats, reduction of snow cover and melting of glaciers (IPPC, 2001;Hofmann & Schellnhuber, 2010; Keller et al, 2005). Modelling studies predict shifts in range for many species associated with alpine habitats (Dirnböck et al, 2003). This is further substantiated by field observations in which altitudinal migration of both grassland and forest species are recorded (Camarero & Gutiérrez, 2004; Kullman, 2002). The matrix developed is restricted to assessing the vulnerability of the following effects of climate change: acidification, eutrophication, reduced period of snow cover or melting of glacial ice and altitudinal migration of tree and shrub species invading Alpine habitats (indicator 1-5). The choice is based on the current effects mentioned in existing literature (Sajwaj et al, 2009; Berry, 2007; IPCC 2007) and the possibility to link them to the habitat types of the Directive.

Sea level rise

Sea-level rise, combined with higher frequency of storms, leads to the loss of coastal habitat through flooding and erosion. Low-lying coastal land and estuaries are impacted by inundation and salt water intrusion. Often, these areas are either cut off from the hinterland because of coastal defence structures or different types of land use – for example, a built environment, transport infrastructure, or agricultural land can constitute physical barriers, which prevent or stop dynamic processes. This phenomenon is known as coastal squeeze (Sutherland et al. 2008). For coastal habitats, national and European assessments have been undertaken on the possible influence of sea level rise on the habitats of the Directive. On habitat level, the effects reviewed are vulnerability to increased erosion and drowning (Berry et al, 2007; Chust et al, 2010; Kont, 2007; Richards, 2007).

Changes in precipitation patterns

Changes in precipitation patterns (IPPC 2007) can impact on habitats by increasing periods of drought, waterlogging or increasing salinity. Decreases in annual rainfall might lead to water levels dropping in rivers, streams and lakes and even periodical drying out. Suitable conditions for bogs decline because of prolonged periods of drought and dynamics in precipitation patterns (Casparie & Streefkerk 1992).

Increases in weather extremes

The occurrence of fire, storms and floods will increase IPPC, 2007). The assessment of these extreme events on habitats is rather complex. Often, the structure, species composition and dominance of species will temporarily change, but the system can recover and return to its former state. The vulnerability of habitat types to storms, floods and fires show remarkable differences depending on their geographical location. Based on existing publications and general knowledge of recovery time of habitat types, a vulnerability to these extreme events is assessed.

Landscape constraints on adaptive capacity

The landscape context might put a constraint on the adaptive capacity of habitats. As these constraints depend on the specific landscape context of a given Natura 2000 sites, it is not possible without a time consuming detailed analysis to indicate which habitat types are more prone to such constraints.

4.2 Scoring and input used for each indicator

Based on existing literature and expert knowledge, a score has been assigned for each field in the matrix for each habitat type. Values used are:

No risk foreseen due to climate change = 0
Low risk foreseen due to climate change= 1
Medium risk foreseen due to climate change= 2
High risk foreseen due to climate change = 3
U = unknown
NA = not applicable (for instance erosion due to sea level rise for alpine habitats)
NAS = not assessed.

For a few Natura 2000 habitats, scientific literature exists on the current or expected effects of climate change (e.g. 1120: Posidonia beds, 7320: Palsa mires, 7110-Raised bogs, 21A0: Machairs, 4030: European dry heaths, 1230: Vegetated sea cliffs of the Atlantic and Baltic coasts, 1140: Mudflats and sandflats not covered by sea water at low tide; 9570: Tetraclinis articulata forests, 9010-Western Taiga; 4070-Bushes with Pinus mugo and Rhododendron hirsutum; 9360-Macaronesian laurel forests). For other habitats, more generic knowledge is available on the expected impacts climate change impacts, for example, on coastal and alpine habitats (EEA, 2010, EEA, 2009). In general, the approach was to assign a score of 3 if specific literature indicated that the a given habitat was very vulnerable – if only generic information was available a score of 2 or lower was assigned, based on an expert assessment of the expected vulnerability of the system.

1. <u>Increased availability of nutrients , eutrophication (indicator 1)</u>
    - Bog, mires and fen habitats were assigned a score of 2 as literature indicates an increased risk of eutrophication due to climate change.
    - European dry heaths: a score of 2 was assigned based on available literature.
    - Grasslands: the risk of eutrophication for grasslands is related to the availability of water – only in cases were increased temperature coincides with an increase in rainfall eutrophication was found. As rainfall patterns are highly variable across Europe a score of 1 was assigned for most

grassland types. Some grassland types with a low productivity are probably more vulnerable (2). Relatively small changes in nitrogen availability might lead to colonisation / invasion by species with a relatively high growth rate. This might be reinforced by increases in atmospheric CO2 concentrations. These types were assigned a score of 2.

- Given the general susceptibility of aquatic habitats to climate change, a score of 2 was assigned (except for the nutrient rich coastal systems).

2. Acidification

Scores for acidification were assigned to oligotrophic and dystrophic aquatic habitats as they are most susceptible to change. In terrestrial ecosystems, no information was found on increased risk of acidification due to climate change. Modelling studies assessing the impact of forests already suffering from acidification due to air pollution indicate a small positive effect on recovery (Reinds et al, 2009).

3/4/5. Reduced period of snow cover (indicator 3), Melting of glacier ice/loss of permafrost (indicator 4) and altitudinal migration (indictor 5)

Natura 2000 mountain habitats were ordered along the alpine and subalpine gradient. Natura 2000 habitats restricted to the alpine zone were considered more vulnerable than those occurring in the alpine and subalpine zones or even at lower levels. A score of 2 was assigned for all grassland habitats restricted to alpine areas, a score of 1 was assigned to subalpine grassland habitats. Habitats with a wide range in occurrence or restricted to lowland were assigned a 0. For habitats related to river systems, where the dynamic of the river is strongly dependant on glacial ice or occurrence of snow, a score of 2 or 3 was assigned.

6/7/12. Effects of sea level rise (Indicators 6. Drowning; 7. Erosion; & 12. Storm risk)

Based on existing information about impacts of sea level rise on coastal habitats (Berry et al, 2007; Chust et al, 2010; Kont, 2007; Richards, 2007), the majority of the Natura 2000 coastal habitats were situated along the offshore-backshore gradient. Depending on their location along this gradient, a score for drowning and erosion and storm risk was assigned. For erosion, furthermore, the substrate of the habitat was taken into account.

8. Drought

The effect of drought was assessed based on the expert information on the effect of climate change in the FP 7 project ECOCHANGE (Mucher et al, 2009).

9. Waterlogging/higher water table

The effect for waterlogging/ higher water table were assessed based on expert judgement. Only a few aquatic habitats are expected to be influenced by increases in water table caused by increased rainfall.

10. Increased salinity

The effect for waterlogging/ higher water table were assessed based on expert judgement. Only a few aquatic habitats and estuaries are expected to be influenced by increased salinity.

11. Fires

- For heathlands in Europe, a score of 0 was assigned as fire is a standard, long-established management practice and the habitats are relatively well adapted to fire (Mitchell et al, 2009; Borghesio, 2009; Davies et al, 2010)
- For forests, the impacts of fires are also relatively well researched. However, the impact of increased fire occurrence caused by climate change for forest habitats largely depends on the frequency. As assessments regarding the increase in occurrence of fires vary in the regions forest were assigned a score 1. As it is predicted that especially in the Mediteranean region a sharp increase in both occurance and severity is expected resulting of climate change, forest habitat types occurring in the Mediterranean region and which are prone to fires a score of 2 was assigned.

12. Flooding

Overall, most aquatic systems are relatively well adapted to flooding. Detrimental impacts only occur where flooding leads to large-scale erosion of the habitat and increased sedimentation on other locations (for example, in estuaries). Long-term effects for the impacts of overall change in river dynamics are less well known. Only a few aquatic habitats and estuaries are expected to be influenced by increased occurrence and severity of floods.

In the matrices a distinction has been made between whether the assessment ('score') is based on literature, or an expert estimation (see column 'Source').

Further remarks to matrices

A total of 231 habitats are reviewed: for 64 habitats, no information on the conservation status is available (status unknown 'XX'); for 15 habitats, no conservation status was ever determined as they occur in Bulgaria and Romania.

5 Description of Matrix B: species vulnerability to climate change

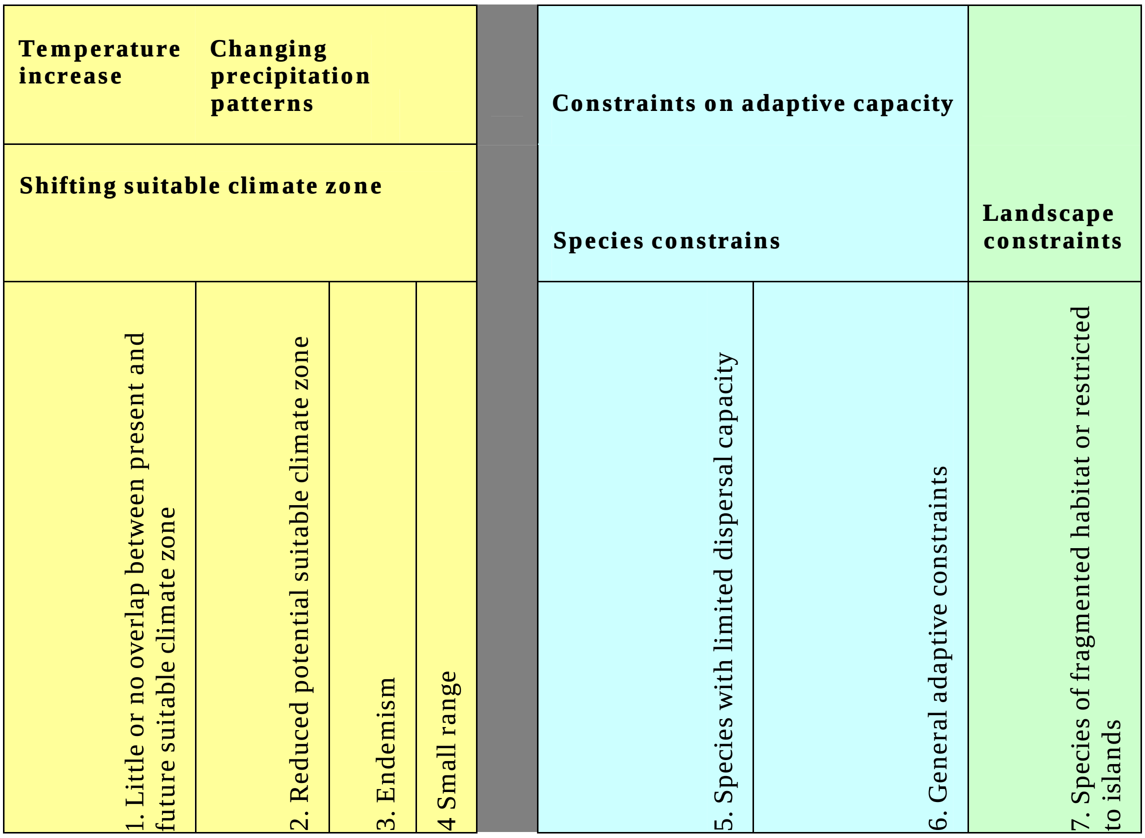

Figure 6. Indicators used to determine species vulnerability to climate change.

5.1 Climate change impacts and indicators for species vulnerability

5.1.1 Shifting of suitable climate zones

A well-documented impact of climate change is the shifting of suitable climate zones towards the north (or south in the southern hemisphere) and to higher altitudinal levels as a result of temperature increase and changing precipitation patterns. Changes in species distributions have already been reported for many species from various taxa (e.g. Parmesan and Yohe 2003; Root et al 2003). Projections based on bio-climate envelope modelling (e.g. Harrison et al. 2006) under different climate change scenarios (IPPC 2007) predict further shifts of at least several hundreds of kilometres for many species in the 21st century (Huntley et al. 2007).

As a response, species are changing their geographical distributions (Hickling et al 2007). Species might not be able to keep pace with the rate of their shifting suitable climatic conditions, for instance because they are insufficiently capable of colonizing their new climate space: in general, the smaller the overlap between the present and the future range, the higher the risk that species might not be able to keep pace (Indicator 1, figure 6).

A second aspect of shifting suitable climate zones is that the future range might be smaller than the present range. Even if species would be able to colonize their future range, this would lead to an overall range decline (Indicator 2, figure 6).

For some species groups, no climate envelope models are available (for instance, for many invertebrates, fish, bryophytes); equally, for plant species, information is available for only part of the species of the Habitat Directive. For these species, it is possible to indicate potential vulnerability based on their characteristics, as the species is endemic (Indicator 3, figure 6) or the species has a small range size (Indicator 4, figure 6). Species with a limited distribution have a relative high risk that they will not be able to keep pace with the rate of their shifting climate envelope: either, there is only a small overlap between present and future suitable zone, or these species have little buffer when range expansion is slower than range contraction.

5.1.2 Weather extremes

Climate change is also likely to result in changes in the variance and frequency of climate extremes. Increases in mean temperature and variance together will lead to increases in frequency of heat waves. The amplitude and frequency of extreme precipitation events are expected to increase over many areas and the return period for extreme precipitation events are projected to decrease (IPCC 2001, 2007). In several regions of the world, indications of changes in heat waves, droughts and floods have been observed (IPCC 2001). Secondary effects of extreme weather events include altered fire and flooding regimes. It is not possible to relate risks of flooding and fire, for instance, directly to individual species, as impacts will to a large extent depend on the context, the type of habitat and the location of that habitat where these species occur.

5.1.3 Species constraints on adaptive capacity

Species traits might limit autonomous adaptation responses, thus adding to vulnerability. A relatively well studied trait that might put a constraint on adaptation is a limited dispersal capacity, as it would reduce the ability of a species to adjust its distribution to its shifting suitable climate zone (Indicator 5).

Several other traits might put constraints on the ability of species to adapt to climate change or the ability to recover from population declines caused by weather extremes. Sajwaj et al. (2009) listed eight general traits that might constrain the autonomous ability of species to adapt to climate change impacts: among others, low survival and/or reproductive rates, long generation times and low genetic diversity (Indicator 6).

5.1.4 Landscape constraints on adaptive capacity

The landscape context might put a constraint on the adaptive capacity of species. For instance, species that are restricted to islands or depend on highly fragmented habitat will have difficulty to adjust their distribution or recover after weather extremes. As these constraints depend on the specific landscape context of Natura 2000 sites, it is not possible to give an indicator value per species.

5.2 Score and input used for each indicator

1. Little or no overlap between present and future suitable climate zone

Overlap between present and future potential suitable climate zone	Impact	Score
Overlap > 70%	Low risk	1
Overlap 50-70%	Moderate risk	2
Overlap 50- 30%	High risk	3
Overlap < 30%	Very high risk	4

The following sources were available:

- AEA Report Task 2a An assessment framework for climate change vulnerability: methodology and results (Sajwaj et al. 2009)

- A climatic atlas of European breeding birds (Huntley et al. 2007; remaining bird species).
- Climate Risk Atlas of European Butterflies (Settele et al. 2008; remaining butterfly species).
- Climate Response Database (van der Veen et al. 2010).

2. Reduced potential suitable climate zone

Ratio between present and future potential suitable climate zone	Impact	Score
Ratio > 100%	No risk	0
Ratio 70-100%	Low risk	1
Ratio 50-70%	Moderate risk	2
Ratio 50- 30%	High risk	3
Ratio < 30%	Very high risk	4

The following sources were available:

- AEA Report Task 2a An assessment framework for climate change vulnerability: methodology and results (Sajwaj et al. 2009)
- A climatic atlas of European breeding birds (Huntley et al. 2007).
- Climate Risk Atlas of European Butterflies (Settele et al. 2008).
- Climate change threatens European conservation areas (Araujo et al. 2011; potential range in protected areas increase (no risk) or decrease (high risk).

3. Endemism

Only for species where no projection of future range under climate change scenarios are available this indicator is used.

Endemic species	Impact	Score
No endemic species	No known risk	-1
Endemic species	High risk	3

Available sources: IUCN website for Red List Species (http://www.iucnredlist.org/), the European site on Habitat and Bird Directive (http://www.eea.eionet.europa.eu).

Fishbase (http://www.marinespecies.org) Handbook of European freshwater fishes. Kottelat, M. and J. Freyhof (2007).

4. Small range

Only for species where no projections of future range under climate change scenarios were available, an assessment was made whether they had a small range. When the distribution of a species is restricted to a small part of Europe the score 2 was assigned, otherwise the score 0 was assigned.
Available sources: IUCN website for Red List Species (http://www.iucnredlist.org/), http://www.eea.eionet.europa.eu, for plants (Atlas Flora Europea), Fishes (Fishbase (http://www.marinespecies.org); Handbook of European freshwater fishes) and invertebrate groups (diverse sources) and expert judgement.

Range size	Impact	Score
Medium to large range	No known risk	-1
Small Range	Moderate risk	2

5. Species with limited dispersal capacity

Dispersal capacity constraint	Impact	Score
Dispersal > 30 km	No constraint	0
Dispersal between 10 and 30 km	Low constraint	1
Range between 3 and 10 km	Moderate constraint	2
Range < 3 km	High constraint	3

Sources: AEA study (Sajwaj et al. 2009), Bouwma et al. (2004), Fishes (Fishbase (http://www.marinespecies.org); Kottelat, M. and J. Freyhof 2007 Handbook of European freshwater fishes) and invertebrate groups (diverse sources) and expert judgement.

6. General adaptive constraints

General adaptive capacity	Impact	Score
Score for less than 2 of the 8 criteria	Low constraint	1
Score for 2-4 of the 8 criteria	Moderate constraint	2
Score for more than 4 criteria score negative	High constraint	3

The AEA study (Sajwaj et al. 2009) has scored general adaptive constraints based on 8 criteria: small population in Europe, low survival and/or productivity rates, long generation time, declining populations in Europe, low genetic diversity, specialized and uncommon habitat requirements, narrow niche and critical association with another vulnerable species. As some of these traits are not known for all species or not available in databases, species were considered to have high constraints when 4 of the 8 criteria were met.

The overall constraints on adaptive capacity are based on the Dispersal constraint (indicator 5) and the General constraints (indicator 6), resulting in: low constraints on adaptive capacity (less than 2 criteria, score negative), moderate constraints on adaptive capacity (2-4 criteria, score negative) or high constraints on adaptive capacity (more than 4 criteria, score negative). The dispersal indicator is only taken into account for species with a predicted overlap between present and future distribution (Indicator 1) smaller than 70%.

For the remaining species a similar approach was chosen mainly based on the following sources: IUCN website for Red List Species (http://www.iucnredlist.org/), the European site on Habitat and Bird Directive (http://eea.eionet.europa.eu, http://ec.europa.eu/environment/nature/conservation/wildbirds/

Fishes (Fishbase (http://www.marinespecies.org); Kottelat, M. and J. Freyhof 2007 Handbook of European freshwater fishes), invertebrate groups (diverse sources) and expert judgement.

7. Landscape constraints on adaptive capacity

Species of fragmented habitats or islands are landscape constraints that depend on the specific landscape context of Natura 2000 sites. It is therefore not possible to give an indicator value per species.

Calculating vulnerability

To determine species vulnerability, the calculation method of the AEA study was followed (see Sajwaj et al 2009 for details, for the scores see table 1 & 2). This method takes the highest sensitivity for climate change into account, based on either overlap (indicator 1), or on ratio (indicator 2), together with the expected constraints on adaptive capacity.

Table 1. Vulnerability based on overlap

adaptive capacity constraint	**Sensitivity based on overlap**			
	low (1)	moderate (2)	high (3)	very high (4)
high (3)	moderate	high	very high	critical
moderate (2)	low	moderate	high	very high
low (1)	none	low	moderate	high

Table 2. Vulnerability based on ratio

Adaptive capacity constraint	**Sensitivity based on ratio**				
	no risk (0)	low (1)	moderate (2)	high (3)	very high (4)
high (3)	none	high	very high	critical	extremely critical
moderate (2)	none	moderate	high	very high	critical
low (1)	non e	low	moderate	high	very high

For species for which the indicators Overlap and Ratio were not known, we estimated sensitivity based on indicator 3 Endemic, or indicator 4 Small range (taking the highest value). The vulnerability calculation was similar to the vulnerability based on overlap (table 1).

6 Results

6.1 Habitats

6.1.1 Results of vulnerability of Natura 2000 habitats to climate change

Based on the vulnerability scores of the different pressures, which might occur due to climate change, the maximum scores for a given habitat were calculated. It is based on the maximum value assigned to a given habitat (for example, the habitat type ‘Temperate Atlantic wet heaths with Erica ciliaris and Erica tetralix’ has received a score of 2 for vulnerability to drought and a score 1 for the effects of eutrophication. The resulting ScoreMax is 2). The results of the analysis for vulnerability of habitats based on ScoreMax show that almost 11 % of the habitats have a high vulnerability to climate change, the majority of habitats has a medium (39%) to low (44%) vulnerability to climate change (table 3). Figure 7 outlines the number of habitats, which are vulnerable to different types of pressures. For each habitat, the calculation takes into account the amount of different pressures to which it is susceptible (value > 0). The results are summarized for each major habitat group. Figure 8 provides more detail on the types of pressures that are relevant for each habitat group. Figure 9 depicts the scores for the different biogeographical regions. It shows that all regions have habitats that are highly vulnerable to climate change.

Table 3. Scores for habitat vulnerability of major ecosystem type based on highest score of the assessed indicators (ScoreMax)

Habitatgroup	Not vulnerable	Low vulnerability	Medium vulnerability	High vulnerability	Unknown	**Grand Total**
bogs, mires & fens		3	7	2		12
coastal habitats		3	14	9	2	28
dunes habitats	2	10	6	2	1	21
forests		55	23	3		81
freshwater habitats	1		13	5		19
grasslands		17	14			31
heath & scrub		6	5	1		12
rocky habitats	3		1	4	6	14
sclerophyllous scrub		7	6			13
Grand Total	**6**	**101**	**90**	**25**	**9**	**231**
%	2.6%	43.7%	38.5%	11.3%	3.9%	

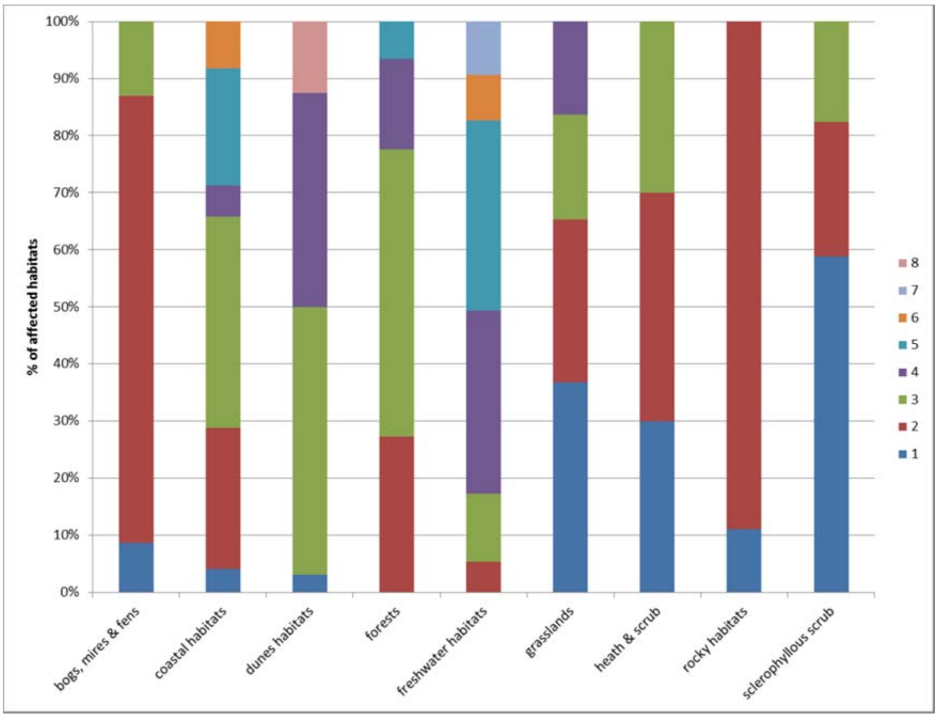

Figure 7. Numbers of different pressures relevant for a habitat type by major habitat group

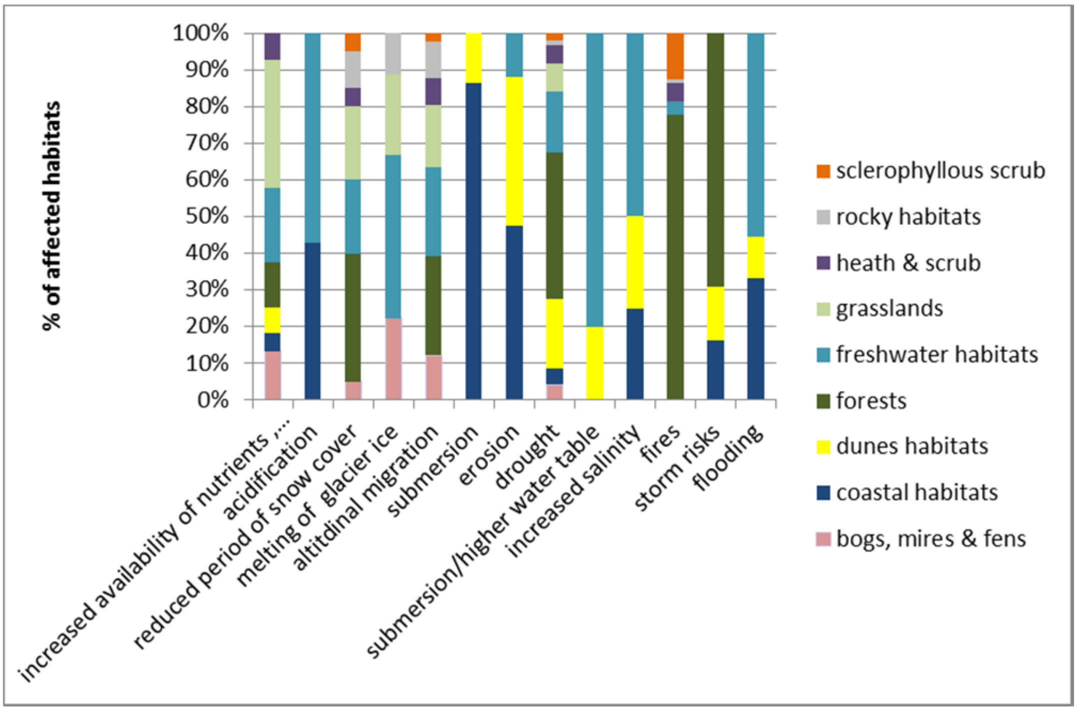

Figure 8. Different types of pressures per major habitat group

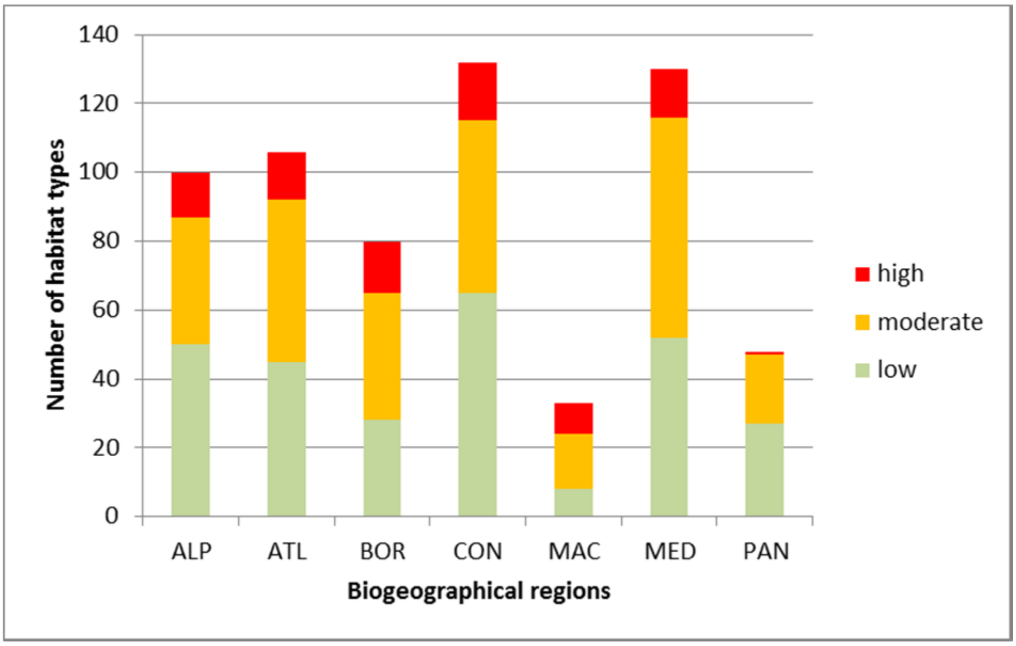

Figure 9. Impact of climate change for specific regions based on the maximum value for habitat vulnerability

Conclusions

Coastal habitats, fresh water habitats, rocky habitats and bogs, mires and fens are the habitat clusters with the highest vulnerability to climate change (Figure 7). In these habitat clusters, more than 75 % of the habitat types have a medium to high vulnerability.

Habitats with the largest amount of pressures are within the group of dunes habitats (maximum of 8 pressures for habitat type), and fresh water habitats (maximum of 7 pressures for habitat type) (Figure 8). The biogeographical regions Continental and Mediterranean show the largest numbers of highly vulnerable and moderately vulnerable habitat types.

6.1.2 Additional risks posed by climate change to the conservation status of Natura 2000 habitats

Figure 10 outlines the additional risks posed to climate change given the current conservation status of the habitats. Table 4 provides the information for habitats in an unfavorable conservation status. A total of 241 habitats currently is considered to be in an unfavorable-bad (U2) conservation status in one of the regions of the EU. Of the habitats for which vulnerability for climate change was reviewed, of those that currently have an unfavorable-bad conservations status in one of bio geographical regions in the EU, 12% have a high vulnerability for climate change, 46% a medium vulnerability and 41% a low vulnerability.

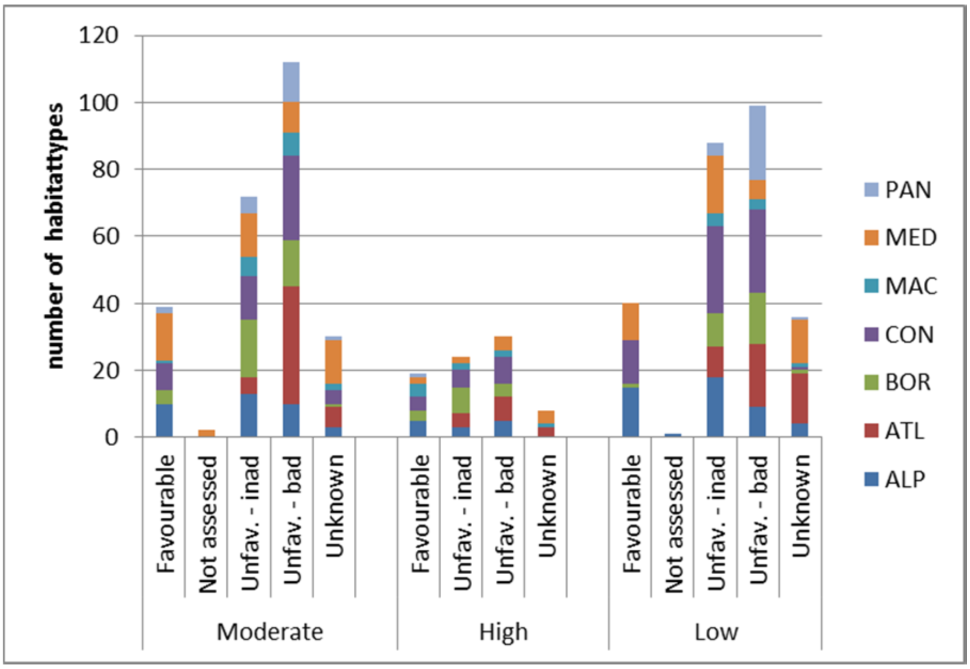

Figure 10. Additional risks posed by climate change. Note: As habitats might have different conservations statuses in the different regions, habitat types occur more than once in the below table.

Table 4. Vulnerability for climate change for habitats that currently have an unfavorable – bad conservation status in a given biogeographical region.

	low vulnerability	moderate vulnerability	high vulnerability	
bogs, mires & fens	8	18	5	31
coastal habitats		15	9	24
dunes habitats	8	14	3	25
forests	52	7	5	64
freshwater habitats		20	5	25
grasslands	24	28		52
heath & scrub	5	8	1	14
rocky habitats		1	2	3
sclerophyllous scrub	2	1		3
	99 (41 %)	112 (46%)	30 (12 %)	241

6.2 Species

6.2.1 Results of vulnerability of Natura 2000 species to climate change

For Natura 2000 species, scores for sensitivity and adaptive capacity were calculated. Based on these two scores an overall vulnerability score was calculated. Table 5 and figure 11 show for each species group the amount of species falling into one of the sensitivity classes (not vulnerable, low, medium, high vulnerability or unknown). Figure 12 outlines the impact for the different biogeographical regions.

Table 5. Vulnerability score for climate change for the different species groups

	not vulnerable	low vulnerability	moderate vulnerability	high vulnerability	very high vulnerability	critical vulnerability	extremely critical vulnerability	unknown	Total
Amphibian/Reptile	3	8	3	16	10	5		6	51
Bird	1	12	26	43	49	23	4	41	199
Fish		3	7	11	5			66	92
Invertebrate	3	3	3	9	5	1		112	136
Mammal	1			5	1			47	54
Plant	4	10	19	8	5			541	587
Grand Total	12	36	58	92	75	29	4	815	1121

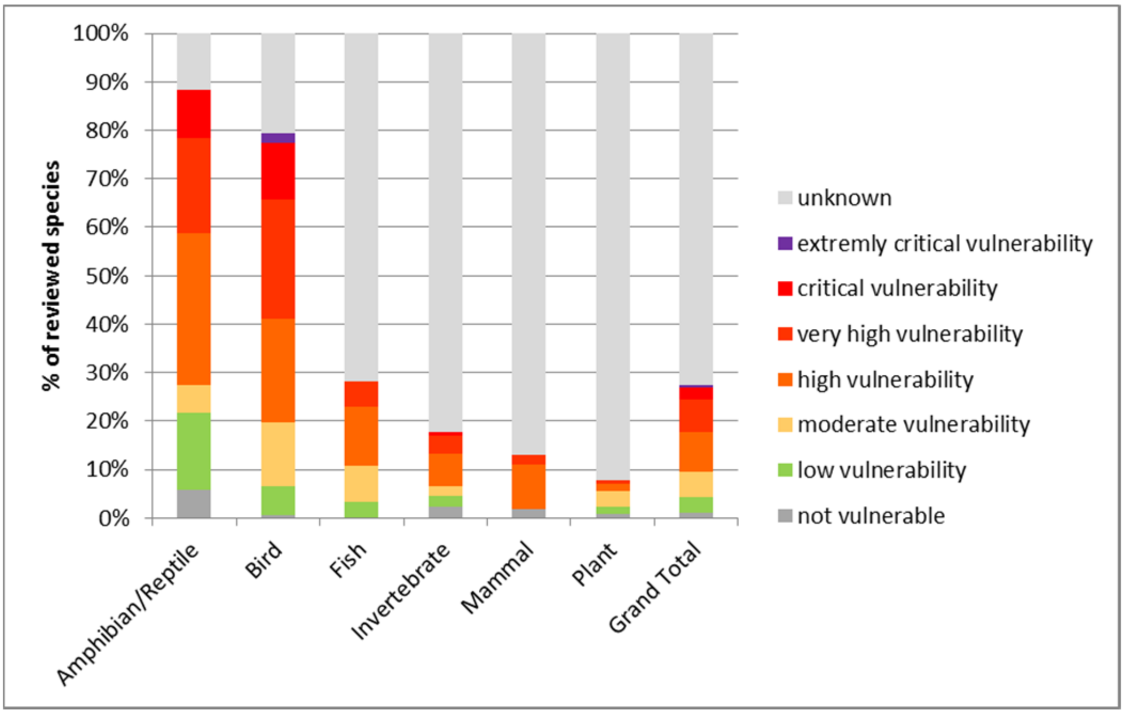

Figure 11. Vulnerability to climate change for the various species groups.

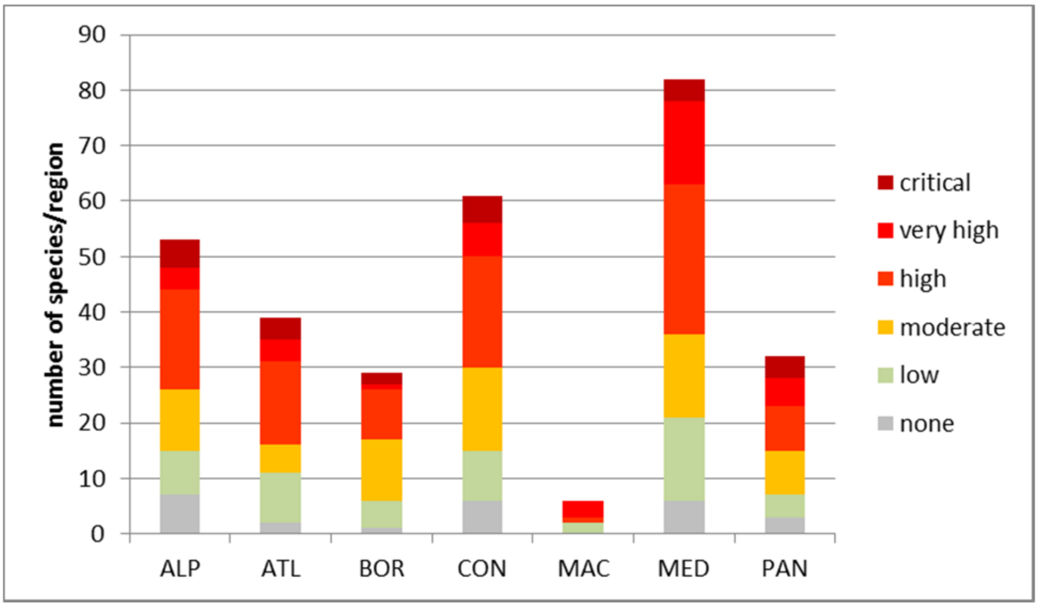

Figure 12. Impact of climate change for specific regions based on species' vulnerability.

Conclusions

Of the reviewed 306 Natura 2000 species, 35% are very high to extremely vulnerable to climate change. The most sensitive groups are amphibians and reptiles and breeding birds. For the majority of species (72%), no information was found during the review to determine their vulnerability to climate change. The Mediterranean biogeographical region shows the highest numbers of vulnerable species.

6.2.2 Additional risks posed by climate change to the conservation status of Natura 2000 species

Figure 13 outlines the additional risks posed by climate change given the current conservation status of the species. Table 6 outlines the risk for those species already in an unfavorable – bad conservation status. Of the assessed species with an unfavorable-bad conservations status in one of biogeographical region in the EU, 60% have a high to critical vulnerability for climate change, 20% moderate vulnerability and 20% no to low vulnerability.

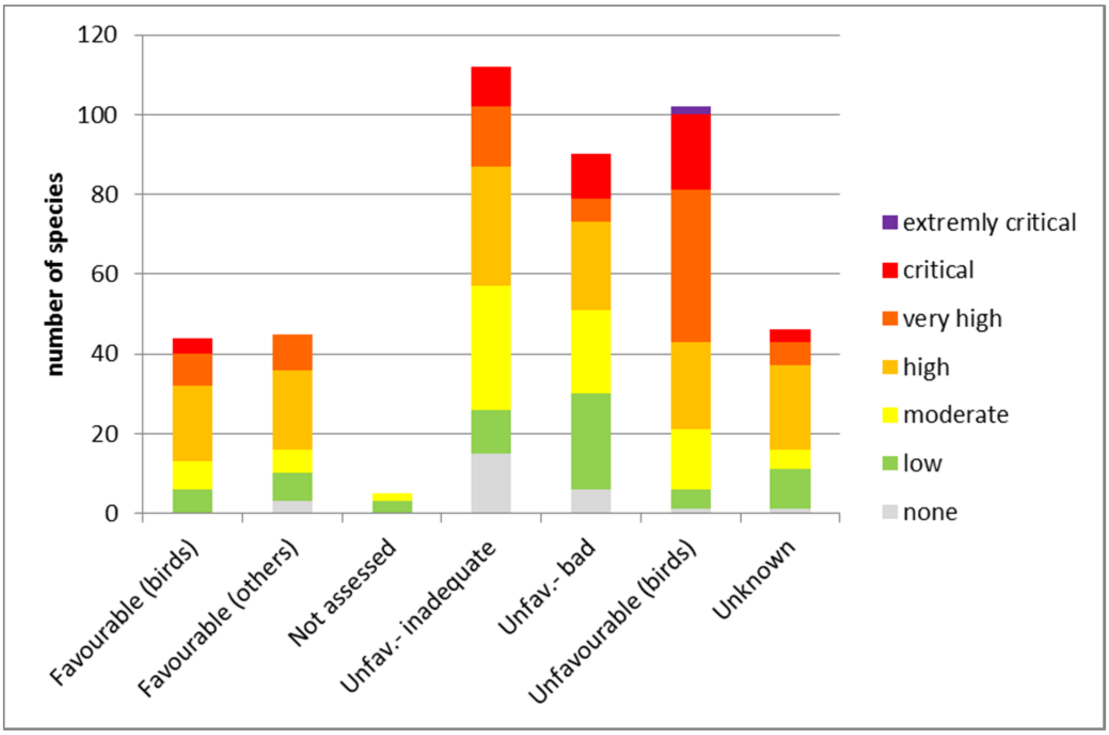

Figure 13. Additional risks posed to climate change given the current conservation status of species.

Table 6. Vulnerability for climate change for species that currently have an unfavorable – bad conservation status in a given biogeographical region.

	low	moderate	high	very high	critical	ex. critical	none	Unknown
Amphibian/Reptile	7	2	2	1	9			5
Fish	6	2	2	1				45
Invertebrate	6	7	9	2	2		2	72
Mammal			3				2	50
Plant	5	10	6	2			2	119
Total	29	36	43	43	29	2	7	313

References

Araújo M.B., D. Alagador, M. Cabeza, D. Nogués-Bravo. Climate change threatens European conservation areas. Ecology Letters, Volume 14, Issue 5.

Berry, P.M., Jones, A.P., Nicholls, R.J. and Vos, C.C. (eds.). 2007. Assessment of the vulnerability of terrestrial and coastal habitats and species in Europe to climate change, Annex 2 of Planning for biodiversity in a changing climate – BRANCH project Final Report, Natural England, UK. Borghesio, 2009

Borghesio L., 2009. Effects of fire on the vegetation of a lowland heathland in North-western Italy. Plant ecology vol:201 iss:2 pg:723 -731 .

Bouwma, I.M.; Foppen, R.P.B.; Opstal, A.J.F.M. van (2004). Ecological corridors on a European scale: a typology and identification of target species *In: Ecological networks and greenways; concept, desing, implementation / Jongman, Dr R.H.G., Pungetti, G., . - Cambridge : Cambridge University Press, (Studies in landscape ecology).*

BirdLife International (2004) Birds in the European Union: a status assessment. Wageningen, The Netherlands: BirdLife

International Bray et al, 1997. Prediction of soft-cliff retreat with accelerating sea-level rise. Journal of coastal research. Vol:13 iss:2 pg:453 -467

Camarero, J. J. and E. Gutiérrez. 2004. Pace and pattern of recent treeline dynamics response of ecotones to climatic variability in the Spanish Pyrenees. Climatic Change 63:181-200

Casparie W.A., J G Streefkerk & J T A Verhoeven. Climatological, stratigraphic and palaeo-ecological aspects of mire development.

Chust et al, 2010. Regional scenarios of sea level rise and impacts on Basque (Bay of Biscay) coastal habitats, throughout the 21st century. Estuarine, coastal and shelf science vol:87 iss:1 pg:113 -124 .

Davies G.M. , A. A. Smith, A, J. MacDonald, J. D. Bakker and C.J. Legg, 2010. Fire intensity, fire severity and ecosystem response in heathlands: factors affecting the regeneration of Calluna vulgaris. Journal of Applied Ecology 2010, 47, 356–365. Dirnböck, T., S. Dullinger and G. Grabherr. 2003. A regional impact assessment of climate and land-use change on alpine vegetation. Journal of Biogeography 30:401-417 .

EEA, 2009. Progress towards the European 2010 biodiversity target. EEA, Copenhagen.

EEA, 2010. Impacts of Europe's changing climate. 2008 indicator based assessment, Stockholm: European Environment Agency.

Evans, D. (2010): Interpreting the habitats of Annex I – Past, present and future. – Acta Botanica Gallica 157 (4): 677-686.

Evans in prep. The Habitats of Annex I and Climate Change. Naturschutz und Biologische Vielfalt, Bundesambt für Naturschutz.

Harley M., T. Chambers, N. Hodgson, J.van Minnen & M. Pooley, 2010. A methodology for assessing the vulnerability to climate change of habitats in the Natura 2000 network. ETC/ACC Technical Paper 2010/14.

Harrison P.A., P.M. Berry, N. Butt & M. New, 2006. Modelling climate change impacts on species distributions at the European scale: implications for conservation policy. Environmental Science & Policy 9:116-128.

Hickling, R., D.B. Roy J. K Hill R. Fox & C.D. Thomas, 2006 The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology 12, 450-455. (DOI: 10.1111/j.1365-2486.2006.01116.x)

Hofmann M. and H. J. Schellnhuber. Ocean acidification: a millennial challenge.Energy Environ. Sci., 2010, 3, 1883-1896

Huntley, B. , R.E. Green, Y.C. Collingham, & S.G. Willis, 2007. A climatic atlas of european breeding birds. Durham University, The RSPB and Lynx Edicions, Barcelona.

IPPC 2001. IPCC Third Assessment Report - Climate Change 2001.

IPPC. 2007 Climate change 2007: synthesis report, pp. 73.

Keller, F., S. Goyette and M. Beniston. 2005. Sensitivity analysis of snow cover to climate change scenarios and their impact on plant habitats in alpine terrain. Climatic Change. 72:299-319.

Kont, 2007. Impact of climate change on Estonian coastal and inland wetlands - a summary with new results. Boreal environment research. vol:12 iss:6 pg:653 -671

Kullman, L., 2002: Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. Journal of Ecology 90: 68-77.

Kottelat, M. and J. Freyhof 2007. Handbook of European freshwater fishes. Publications Kottelat, Cornol, Switzerland.

Mitchell, Ruth J. , Simonson, Will , Flegg, Laura A. , Santos, Patricia and Hall, Jeanette(2009) 'A comparison of the resilience of four habitats to fire, and the implications of changes in community composition for conservation: a case study from the Serra de Monchique, Portugal', Plant Ecology & Diversity, 2: 1, 45 — 56"

Mücher C.A., F. Kienast, G. Hazeu, J. Bolliger, S.M.Hennekens, R.G.H. Bunce, J.H.J. Schaminée, J.A.M.,Janssen, C. Schuiling, A.J.W. de Wit and N.E. Zimmerman, 2009 Deliverable D01.02.02 Fragmentation and other landscape metrics at European Scales. KP 6 ECOCHANGE project - Challenges in assessing and forecasting biodiversity and ecosystem.

Parmesan, C. & G. Yohe, 2003. A globally coherent fingerprint of climate change impacts across natural systems" Nature 421: 37-42.

Richards et al, 2008. Regional assessment of climate change impacts on coastal and fluvial ecosystems and the scope for adaptation. Climatic change. vol:90 iss:1-2 pg:141 -167.

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, & J.A. Pounds, 2003. Fingerprints of global warming on wild animals and plants, Nature,421, 57-60.

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. AEA.

Settele et al. 2008. Climatic risk atlas of European butterflies. Pensoft.

Sutherland W.J, Bailey J. M, Bainsbridge I. P, Brereton T., Dick J. T. A., Drewitt J., Dulvy N.K., Dasic N. R., Freckleton R. P., Gaston K. J., Gilder P. M., Green R. E., Osborn D., Owen R. P., Pretty J., prior S. V., Prosser H., Pullin A. S., Rose P., Stott A., Tew T., Thomas C. D., Thompson D. B. A., Vickery J. A., Walker M., Walmsley C., Warrington S., Watkinson A. R., Williams R. J., Woodroffe R and Woodroof H. J (2008) Future novel threats and opportunities facing UK biodiversity identified by horizon scanning, Journal of Applied Ecology.

Reinds et al, 2007. Modelling recovery from soil acidification in European forests under climate change. Science of the total environment volume 407 iss:21 pg:5663 -5673.

Van der Veen, M., Wiesenekker, E., Nijhoff, B.S.J. & Vos, C.C. (2010). Climate Response Databas, version 2.0. [In Dutch].