Bird’s eye view of European biodiversity policy under climate change

LAURA MELLER

LUOVA
Finnish School of Wildlife Biology, Conservation and Management

Department of Biosciences
Faculty of Biological and Environmental Sciences

University of Helsinki

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SUPERVISED BY: Dr. Mar Cabeza, Global Change and Conservation Group, Metapopulation Research Centre, Department of Biosciences, University of Helsinki, Finland

REVIEWED BY: Prof. Mikael Hildén, Finnish Environment Institute SYKE, Finland

Dr. Aleksi Lehikoinen, Finnish Museum of Natural History, Finland

EXAMINED BY: Dr. Pam Berry, Environmental Change Institute, University of Oxford, The United Kingdom

CUSTOS: Prof. Jouni Laakso, Department of Biosciences, University of Helsinki, Finland

MEMBERS OF THE THESIS ADVISORY COMMITTEE:

Prof. Mikael Hildén, Finnish Environment Institute SYKE, Finland

Dr. Hannu Pietiäinen, Department of Biosciences, University of Helsinki, Finland

Dr. Hanna Tuomisto, Department of Biology, University of Turku, Finland


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AH: Andries Hof
AvT: Astrid van T ee ffelen
DG: Damien Georges
JvM: Jelle van Minnen
JV: Jan Vermaat
LM: Laura Meller
MC: Mar Cabeza
MLa: Luigi Maiorano
MBM: Morgane Barbet-Massin
SP: Samuel Pironon
TL: Tobias Lung
WT: Wilfried Thuiller

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Anthropogenic pressures have pushed both climate and ecosystems to the point that their stability and functioning is at risk. Halting the loss of biodiversity by 2020 is one of the goals of the European Union. Climate change has been identified as one of the key challenges for biodiversity conservation in the EU.

Empirical observations of climate change impacts, predictive tools and approaches, and appropriate policy responses are developed in separate fields of research with different methodologies and cultures. My thesis aims at bringing these three aspects together to explore responses to climate change from the perspective of biodiversity in the European Union.

The thesis consists of a summary and five chapters. Chapter I looks into EU biodiversity policy in light of needs arising from climate change, with a focus on bridges between climate change impacts to appropriate conservation responses and further to policy. Chapter II evaluates approaches to reducing uncertainty in conservation prioritization based on ensemble modelling of species distributions. Chapter III builds methodologically on the findings of chapter II to explore the balance between various aims of biodiversity funding in the EU and how allocations of the funds reflect those aims. Chapters IV and V explore the balance between mitigation benefits and adaptation drawbacks of bioenergy as regards biodiversity conservation.

The existing EU biodiversity policy has more potential to support effective adaptation than what its current interpretation and practice allows, although there seem to be gaps that cannot be addressed with the existing policies. The numerous scientific recommendations for conservation responses to climate change mainly address species range shifts. There is a mismatch between future conservation needs and the current practice of allocating funds for biodiversity conservation in the EU. For birds of European conservation concern, climate change drives larger changes in range size than land use for short-rotation woody bioenergy. However, bioenergy was predicted to have a negative impact on a larger proportion of the species than climate.

Three policy recommendations arise from my thesis. First, compliance with strategic environmental assessment and green infrastructure guidance should be ensured for biodiversity projects receiving funds from the EU Structural and Cohesion funds. Second, biodiversity project funding from the SCF funds needs to be explicitly linked to the biodiversity strategy goals and assessed from the perspective of biodiversity needs. Indicators of project success should include an indicator relevant for biodiversity. Third, mitigation of climate change is a key strategy for biodiversity conservation, as it makes effective adaptation more feasible.
TIIVISTELMÄ


Empirisiä havaintoja ilmastonmuutoksen vaikutuksista, tulevaisuuden ennustamisen työkaluja ja sopivia politiikkoja toimia kehitetään ja tarkastellaan erillisillä tieteenaloilla, joilla on omat menetelmänsä ja kulttuurinsa. Pyrin tuomaan nämä kolme lähestymistapaa yhteen väitöskirjassani tarkastellaan ilmastonmuutosta suhteessa luonnon monimuotoisuuden suojeluun Euroopan Unionissa.


Ilmastonmuutos aiheuttaa suurempia levissäysysyysmuutoksia eurooppalaisiille lintulajeille kuin nopean kierron puuperäisen bioenergian viljely. Bioenergian vaikutukset ovat kuitenkin kielteisiä suuremmalle osalle lajeista kuin ilmastonmuutoksen.

SUMMARY

Laura Meller
Global Change and Conservation Group, Metapopulation Research Centre, Department of Biosciences, P.O.Box 65 (Viikinkaari 1), 00014 University of Helsinki, Finland

I. INTRODUCTION

1.1. CLIMATE CHANGE PUTS BIODIVERSITY UNDER PRESSURE

Civilization, as we understand it, is dependent on ecosystems and a relatively stable climate. These two features allow agriculture to provide yields and cities to persist everywhere in the world. Now anthropogenic pressures have pushed both to the point that their stability and functioning is at risk (Rockstrom, 2009; Barnosky et al., 2011).

The biodiversity crisis and climate change both arise from factors deeply woven into the working of modern human societies. Habitat loss and fragmentation, due to anthropogenic land use for agriculture, forestry and settlements, is the single most important driver of biodiversity loss (Millennium Ecosystem Assessment, 2005), and the single most important driver of anthropogenic climate change is the use of fossil energy (IPCC, 2014). Furthermore, the consequences of climate change will affect both societies and ecosystems, and adaptation to these effects needs to take place in all aspects of human life.

Global conventions and conservation efforts have not been able to reverse the rapid decline in biological diversity (Butchart et al., 2010). Climate change is expected to exacerbate the pressure on biodiversity (Millennium Ecosystem Assessment, 2005). Changes in the climate system already affect species, habitats and ecosystems across the globe (Parmesan, 2006; Chen et al., 2011; Bellard et al., 2012). The extinction risk of species is predicted to increase markedly in the future (Thuiller et al. 2005; Fischlin et al. 2007; Gregory et al. 2009). Local extinctions occur most often not due to temperature rise directly, but indirectly through physiological and ecological effects, such as changes in predation, food availability, competition and diseases (Cahill et al., 2012).

Biodiversity responses to climate change include changes in species distributions, phenological responses and physiological responses, and they may ultimately result in changes in community and ecosystem level (Hughes, 2000; Bellard et al., 2012). In recent years, changes in species distributions have gained most attention in the scientific literature related to climate change and biodiversity. A general pattern in European studies is that the suitable climate spaces shift from south-west to north-east in the order of tens of kilometres per decade (Harrison et al., 2006; Devictor et al., 2012). For many species, suitable climate space appears outside their current distribution, and this balances losses to some extent. However, certain species are more vulnerable: for example, the ranges of alpine species tend to contract rather than shift (Berry, 2008; Engler et al., 2011). Observations of butterfly species in Finland suggest that threatened species have not shifted their range like common species have (Pöyry et al., 2009). Overall, the observed range shifts seem to lag behind shifts in the respective climatic spaces, or climate envelopes, of bird and butterfly communities in Europe (Devictor et al., 2012). Changes in timing of ecologically important processes, i.e. changes in phenology, are evident across a range of taxa. In Europe, leafing, flowering and fruiting events of plants occurred earlier in the season during 1971–2000 in 78% of cases (Menzel et al., 2006). Insect phenology has advanced more rapidly than plants in the Mediterranean (Gordo & Sanz, 2005, 2010), which may bear implications for pollination. As warm seasons are extended, fungi species have been able to fruit multiple times in a growing season (Gange et al., 2007). Physiological responses may allow species to persist in changing climatic conditions. When a population is not able to adapt or adjust to changed conditions, the population declines and eventually goes extinct. This is the mechanism that causes the ‘trailing edge’ of a species
distribution to shift (Cahill et al., 2012) and has been observed repeatedly, for example, in butterflies (Wilson et al., 2005; Franco et al., 2006; WallisDeVries et al., 2011). Changes in communities and ecosystems result from the responses of individual species. Changes in species interactions have been observed with respect to species competition, predator-prey dynamics, host-parasite interactions, pollination and herbivory (Berg et al., 2010). Species compositions in communities are changing, as distributions shift. Species richness has increased in Alpine plant communities (Walther et al., 2005; Pauli et al., 2012) as well as butterfly and bird assemblages in the Great Britain (Menéndez et al., 2006; Davey et al., 2012). Cold-adapted plants and bird species of the north are becoming fewer (Lemoine et al., 2007; Pauli et al., 2012) while annual plants (Matesanz et al., 2009) and generalist butterflies (Menéndez et al., 2006) and birds (Davey et al., 2012) are increasing in abundance. Changes in community composition may, in turn, induce additional range shifts (Hughes, 2000).

1.2. IDENTIFYING PRIORITY AREAS FOR CONSERVATION UNDER CLIMATE CHANGE

Protected areas have promoted recent species’ range expansions (Beale et al., 2013). Better connected, more numerous and expanded protected areas have been the most often suggested strategies to address the climate challenge in conservation (Hannah et al., 2007; Heller & Zavaleta, 2009; Hodgson et al., 2009; Mawdsley et al., 2009). Management practices outside protected areas, in the so-called matrix, should also allow for persistence and dispersal of species (Hannah et al. 2002; Noss, 2001). Adaptive management, restoration and habitat creation are among the most often cited recommendations.

Historically, protected areas have been designated in unproductive regions, or places that have aesthetic, recreational or cultural value (Pressey, 1994; Mendel & Kirkpatrick, 2002; Joppa & Pfaff, 2009). Such ad hoc conservation does not lead to representative protected area networks (Rodrigues et al., 2004) and therefore a systematic approach to identifying conservation priority areas (Margules & Pressey, 2000) is gaining attraction and has been increasingly applied in conservation planning. Margules and Pressey (2000) describe a systematic conservation planning approach with six basic steps: 1) collecting data about species distributions (or other features) in a given region; 2) defining conservation targets for those species; 3) assessing the existing protected area network and the degree to which the targets are achieved there; 4) identifying areas that complement the existing network to achieve the conservation targets; 5) implementing conservation action; and 6) management and monitoring the protected areas to maintain their conservation value.

As virtually any country or region would already have some protected areas to start with, identifying priority areas to complement the existing network is key. Cost-efficient priorities are complementary (they add conservation value by increasing the representation of species or habitats that are currently underrepresented), irreplaceable (unique) and under pressure of being converted to other types of land use.

Spatial conservation prioritization tools are increasingly used to identify priority areas for conservation action. Available systematic conservation planning algorithms and software include Zonation (Moilanen et al., 2009, 2012), Marxan (Ball et al., 2009), C-Plan (Pressey et al., 2009) and ConsNet (Sarkar et al., 2009). Such computational tools use spatial biodiversity data to identify networks of areas that represent as much biodiversity, typically species occurrences, as possible while minimizing the costs or the total area of the network (Ball et al., 2009; Moilanen et al., 2009).

Spatial conservation prioritization requires good knowledge of the distributions of species. Availability of such basic ecological data – where species are and what protection they need – is often a bottleneck (Smith et al., 2007). Statistical modelling of species distributions (Franklin, 2009; Peterson et al., 2011) is increasingly used to fill in the information gaps. Observations about species occurrence and sometimes absence or abundance are related to variables that describe the environment (Guisan & Thuiller, 2005). Then the distribution is predicted to the whole area with that relationship. From the conservation planning perspective, species distribution models (SDMs) provide a balanced compromise between two other types of species distribution datasets: extent of occurrence data, grossly overestimating the area of occurrence, and point locality records, grossly underestimating the area of occurrence of a species (Rondinini et al., 2006).
Yet, conservation planning requires a lot from the predictive performance of SDMs. As the outcome of reserve selection exercises are completely dependent on the input data, the process is obviously sensitive to errors in the inputs (e.g. Langford et al., 2009). False positive predictions of species occurrence may indeed lead to misguided allocation of conservation resources or falsely optimistic estimates of the current conservation status of species (Loiselle et al., 2003; Rondinini et al., 2006). False negative predictions, on the other hand, reduce flexibility in reserve selection and hamper the efficiency of the resulting reserve networks (Carvalho et al., 2010; Graham et al., 2004; Rondinini et al., 2006).

Predictions of species distributions are sensitive to the choice of modelling technique, as techniques differ in ways which they associate environmental variables to species occurrences (Franklin, 2009). In general, the novel, more complex techniques perform better than old and more simplistic ones, but knowing which technique would perform best in a given situation is not straightforward (Elith et al., 2006). In several global change studies, the choice of modelling technique explained the most variation among model predictions, even when different climate change scenarios were considered (Thuiller, 2004; Pearson et al., 2006; Buisson et al., 2010; Garcia et al., 2011).

Ensemble modelling or ensemble forecasting (Araújo & New, 2007) combine the predictions from different models and allow calculating and visualizing where different models agree or disagree in their predictions of species occurrence or absence. They have been suggested to improve predictions of the current range of a species (Thuiller, 2004; Araújo et al., 2005; Marmion et al., 2009b) as well as patterns in species richness (Parviainen et al., 2009) and diversity (Mateo et al., 2012) as compared to predictions with any single statistical model. For example, the modelling platform BIOMOD2 (Thuiller, 2003; Thuiller et al., 2009) allows combining predictions of different models and calculating average probabilities as well as degree of model agreement for a given species in a given cell to form consensus predictions across models. The usefulness of ensemble techniques is pronounced in studies that seek to predict species distributions under climate change. In the climate change context, uncertainty arises from (i) the data of species distributions, (ii) emission scenarios predicting different developments in greenhouse emissions, (iii) circulation models predicting how different greenhouse gas concentrations are reflected in global or regional climate, and (iv) the choice of modelling method to predict species distributions in these future scenarios (Buisson et al., 2010; Garcia et al., 2011).

Ensemble modelling has been applied in assessments of climate change impacts on current areas of conservation priority (Coetzee et al., 2009; Araújo et al., 2011; Kujala et al., 2011; Thuiller et al., 2014) as well as in identifying climate-resilient protected area networks (Carroll et al., 2010) and networks that are robust against prediction uncertainty (Carvalho et al., 2011).

The ensemble of predictions can be summarized into one, or a few, predictive map(s) of species distribution in several different ways (Araújo & New, 2007; Marmion et al., 2009b). The current practice has been to summarize the ensemble into a consensus prediction that is then used as input in spatial conservation prioritization. Alternatively, multiple sets of conservation priorities could be identified using the full ensemble as input. The multiple priorities could be summarized to produce a consensus priority map. The latter approach is expected to retain more information about the model prediction variability throughout the conservation prioritization.

1.3. BIODIVERSITY POLICY IN THE EUROPEAN UNION

Halting the loss of biodiversity by 2020 is one of the goals of the European Union. To reach this ambitious target, the EU has established a biodiversity strategy (European Commission, 2011a).

The main legal conservation instruments in the EU are the Birds and Habitats Directives (European Council, 1992; European Parliament, 2010). The overarching goal of the Birds and Habitats Directives is to maintain a favourable conservation status (FCS) for all target species and habitats. While a variety of measures should be used in combination to achieve a FCS, implementation of the Directives seems currently focused mainly on establishing protected areas (Dodd et al., 2010).

The EU-wide Natura 2000 network of protected areas has been established through these directives, as EU Member States have designated Special Areas of Conservation (SAC) as mandated by the Habitats Directive, and Special Protection Areas as mandated by
the Birds Directive. The network aims at representing and safeguarding the most precious bird species and habitats in the EU.

The protection status of a Natura 2000 area depends on the criteria by which the areas were assigned. While some of the areas are strict nature reserves, others allow other forms of use. For example, 38% of the areas are located within agro-ecosystems (Condé et al., 2010), which means that developments in agricultural policy and spatial development and planning play an important role in maintaining the biodiversity values of the Natura 2000 network.

Large-scale spatial planning and programmes are subject to Strategic Environmental Assessment (SEA), and an Environmental Impact Assessment (EIA) is required for significant projects. These assessments explicitly require evaluation of the plans’ impacts on biodiversity and the broader environment, and to minimise those impacts (European Environment Agency, 2009).

The primary aim of the European cohesion policy is to achieve social, economic and territorial cohesion across the EU. The main means to this are the Structural and Cohesion Funds (SCF) which are allocated to projects in the seven-year budget cycle of the EU. The projects are classified under 86 priority themes (European Commission, 2012) which include three themes directly relevant for biodiversity (“Promotion of biodiversity and nature protection (including Natura 2000 areas)”, “Promotion of natural assets”, and “Protection and development of natural heritage”). These three themes were allocated around 5 billion euros over the 2007–2013 budget period. The SCF is the largest tangible source of biodiversity funding in the EU. Another key source of funding is the LIFE fund, with its objective to facilitate the implementation of EU environmental policy through pilot projects with a particular focus to the Habitats and Birds Directives. Since 1992, approximately 1.2 billion euros have been allocated to such projects through the Nature strand of LIFE.

As the 5 billion euros allocated to biodiversity under the SCF only represent 1.4% of the total SCF (348 billion euros during 2007–2013), ensuring that the rest of the spending does not have negative impacts on biodiversity is an area that requires attention. Although the potential of biodiversity conservation to benefit human well-being (European Commission, 2011a) and the synergies between biodiversity and societal vulnerability reduction (Munang et al., 2013) have been recognized, a lack of appropriate indicators to link SCF allocations to their biodiversity impacts has been identified with concern (European Environment Agency, 2009).

The EU Birds and Habitats Directives have been considered to be advanced tools in intergovernmental conservation policy (Trouwborst, 2009). While the status of European bird populations is better in areas designated under the Birds Directive (Donald et al., 2007) and the latest EU-wide assessment assigns an unfavourable conservation status to 72% of the species of key conservation interest (BirdLife International 2004). Similarly, an assessment of the species and habitats protected under the Habitats Directive assigned a favourable conservation status only to 17% of them (Condé et al., 2010).

In an assessment of current policy, the European Commission identified the following shortcomings (European Commission, 2010): implementation gaps in the Natura 2000 network; policy gaps with respect to biodiversity and soil policy, invasive species, Common Agricultural Policy, ecosystem services, environmental impacts from economic developments and ‘green infrastructure’; knowledge and data gaps at various levels; insufficient integration of biodiversity concerns into other policies; lack of proper assessment of funding needs for biodiversity; and consideration of equity issues.

Climate change has been identified as one of the key challenges for biodiversity conservation in the EU, and the current biodiversity strategy acknowledges adequate adaptation measures as essential in this regard, even though this recognition has not been further linked to the targets or actions in the strategy.

Availability of financial resources and their optimal distribution and uptake is vital for effective management of the Natura 2000 network and complementary measures so that the network functions as a buffer to help species and habitats adapt to climate change (Kettunen et al., 2009; European Commission, 2011a). Analyses of climate change impacts on the effectiveness of the current Natura 2000 network suggests that current locations of species become unsuitable, and complementation of the network is therefore necessary (Araújo et al., 2011;
Maintaining or increasing the biodiversity value of the matrix around protected areas as suggested by research (Noss, 2001; Hannah et al., 2002) also requires that climate adaptation needs of biodiversity are embedded in energy policy and spatial planning. The European Commission has provided guidance for enhancing connectivity of the Natura 2000 network with so-called ‘green infrastructure’ (European Commission, 2013a), a concept that aims at incorporating regional development with sustainability goals. Green, as opposed to grey, infrastructure, constitutes of networks of natural and semi-natural areas which are present in both rural, urban and aquatic settings, and are expected to deliver a broad range of ecosystem services, such as temperature regulation in cities (Benedict & McMahon, 2002). Tools in the current EIA and SEA allow taking biodiversity and climate aspects effectively into account in spatial planning but current practice does not systematically take advantage of them (Wilson & Piper, 2008).

1.4. CLIMATE CHANGE ACTION AND BIODIVERSITY CONSERVATION CROSS SECTORAL POLICY BOUNDARIES

While climate change is a global issue, its impacts have a localized nature, and both mitigation and adaptation measures take a physical and localized form. Similarly, biodiversity loss proximately results from local population extinctions, and conservation is profoundly spatial. Policy planning therefore needs to be based on sound understanding of these local events and their interactions. This balance between local and global should also be reflected in the tools used in predicting trends and developments into the future.

Climate change mitigation has been identified as a primary strategy to reduce its future impact on biodiversity (Heller & Zavaleta, 2009; Dawson et al., 2011; Warren et al., 2013). However, some mitigation actions can have negative impacts on biodiversity (Paterson et al., 2008). For example, hydropower dams that are supposed to decarbonize the energy sector can severely affect local biodiversity (Nilsson and Berggren, 2000). Afforestation, if based on tree plantations, may result in low-biodiversity ecosystems with high water uptake replacing naturally open habitats and lead to habitat loss for native flora and fauna (Jackson et al., 2005; Cabeza et al., 2009). Many key climate change adaptation strategies in conservation focus on assigning more land to biodiversity, either through designation of protected areas or by adjusting management practices and spatial planning. Such strategies may be in conflict with mitigation actions via competition for land. Where possible, climate change mitigation should make use of win-win strategies, which benefit both climate change mitigation and biodiversity conservation. Conservation of primary forests along with their carbon stores and sinks as well as their high biodiversity value is an example of such strategy (Righelato & Spracklen, 2007).

Limiting climate change to below 2 degrees Celsius above pre-industrial times is the agreed aim of the global community under the United Nations Framework Convention on Climate Change (UNFCCC, 2010). Current commitments to reduce greenhouse emissions fall far short from reaching this target (UNEP 2012), to the extent that the feasibility of the 2 degrees target has been questioned (Geden & Beck, 2014). A range of scenarios have demonstrated that the target is still economically, technically and politically within reach although political inertia is a considerable challenge which is often not explicitly addressed (Bertram et al., 2015; Loftus et al., 2015). At the same time, these scenarios demonstrate that reaching the target strains the technical potential to an extreme, and win-win strategies alone will not be sufficient.

Bioenergy lies in the heart of this mitigation-conservation paradox. Scenarios that reach the 2 degrees target are particularly dependent on rapid increase in bioenergy as to replace fossil fuels (van Vuuren et al. 2010) as they need to reach negative emissions using bio-energy-and-carbon-capture-and-storage (BECCS) in the latter half of the century.

Increased use of bioenergy means that land needs to be allocated to biomass production. This may lead to conflicts with food security, water availability and biodiversity conservation (Dornburg et al., 2012). After accounting for these basic needs, estimates of global sustainable bioenergy potentials range between 130 and 500 EJ/year (Beringer et al., 2011; Dornburg et al., 2012).

The impact of bioenergy-related land use on biodiversity most often takes the form of replacing other habitats (or, in the case of forest residues, changing the habitat
Box 1: Designing and assessing responses to climate change in two contrasting worlds

Climate change mitigation refers to actions which aim at reducing emissions of greenhouse gases, thus limiting the magnitude of climate change caused by those emissions. Mitigation is often contrasted with adaptation actions which aim at reducing the vulnerability of a system – society or biodiversity, for example – to climate change.

My thesis was written in context of a large research project European RESPONSES to climate change, a part of the European Commission’s Seventh Framework Programme. The aims of the project was to identify options for climate change mitigation in order to limit global warming to 2 degrees Celsius; to identify strategies and options for mainstreaming climate mitigation and adaptation in EU policy (chapter I); and to identify linkages between sectors that can complicate or facilitate such developments (chapters III, V).

A common theme for the project was the idea of two alternative futures. One scenario, dubbed the ‘2 degrees world’, is strongly focused on climate change mitigation: it is characterised by deep emission reductions by which the global community is able to limit global warming under 2 degrees Celsius compared to pre-industrial times. In the other scenario, ‘4 degrees world’, climate change mitigation continues as countries have pledged under the United Nations Convention on Climate Change, the global mean temperature is expected to increase by 4 degrees by the end of the century, and the focus is on climate adaptation (Table 1). The year 2050 was used as a common reference point in the future. While this was pragmatic for thought experiments, it is important to note that the division between mitigation and adaptation is not as simplistic in reality: adaptation is required also in the 2 degrees world, given that the impacts of climate change are already felt today. Likewise, giving up mitigation altogether would lead to temperature increases much more than 4 degrees by the end of the century.

Many analyses of the EU project were built on the integrated assessment modelling framework IMAGE 2.4 (MNP, 2006) that simultaneously accounts for changes in emissions and land use. In chapter V, previously published scenario outputs (OECD, 2012) from IMAGE were used to quantify and compare bioenergy-related land use in the two worlds by the year 2050. These scenarios are based on the recent representative concentration pathways (RCP) that consider strong and concerted global effort to climate change mitigation (van Vuuren et al., 2011) and were therefore better suited for such analyses than the IPCC Special report on emission scenarios (SRES; IPCC, 2000) which project societal developments in the absence of specific climate-related policies.

In chapters III and V the focus was on priority areas for conservation in the future, based on where relevant species are projected to occur in 2050. For modelling biodiversity responses to climate change, however, scenarios were needed for which regional climatic circulation models were available, given that regional variation and extremes are key for biodiversity responses rather than global averages. As such circulation models were not yet available for the RCP scenarios, the future bird distributions were projected based on the SRES scenarios (chapters III, V). Although none of the SRES scenarios reaches the 2 degrees target, the B1 SRES scenario reasonably represents a “2 degrees world” up to 2050 (climatic conditions start to diverge more strongly between the B1 and a 2 degrees trajectory after 2050). The A2 scenario is comparable to a scenario where the global average temperature increases by 4 degrees by the year 2100 compared to pre-industrial time (IPCC, 2007).

In terms of global averages, the climatic scenarios B1 and A2 diverge only marginally by 2050 – the difference is less than 0.5°C. However, regional differences become evident sooner: for example, the regional circulation models project that the minimum temperature of the coldest month is already 4°C higher in the A2 scenario than in B1, and precipitation of the driest month is 7% higher in B1 than in A2 by 2050.
structure). The impact depends on the type of bioenergy and the reference habitat that is replaced. Agricultural crops have more negative impacts than woody bioenergy plants, such as short rotation coppice willow and poplar (Paterson, 2009; Rowe et al., 2009; Fletcher Jr. et al., 2011). However, expansion of such woody bioenergy plantations would negatively impact habitat availability of 28% of European species but only 10% of the species would be able to benefit from it (Louette et al., 2010).

Integrated assessment models (IAMs) of climate and land-use change have been used in assessments of global bioenergy potentials in different socioeconomic scenarios and under various constraints. However, specific local, regional and landscape-scale opportunities and constraints are important for assessing the impacts of bioenergy-related land-use change (Davis et al., 2011) and for mitigating the negative impacts from bioenergy (Gaucherel et al., 2009), but have not been addressed in the global scenarios. Habitat replacement and land-use displacement are important to consider also because emissions from direct and indirect land-use changes associated with bioenergy can significantly reduce or even multifold exceed the mitigation effect of the bioenergy that replaces fossil fuels in the energy system (Fargione et al., 2008; Repo et al., 2014).

The impacts of either climate change (Lawler et al. 2009; Thuiller et al. 2011; Barbet-Massin et al. 2012) or bioenergy (Eggers et al., 2009; Hellmann & Verburg, 2010; Louette et al., 2010) on species distributions have been quantified in several studies, but the impacts of the two factors have not been analysed together to date (but see Alkemade et al. 2009). Understanding the impacts of both climate change and mitigation action is necessary for planning proactive biodiversity conservation and planning sound energy policy.

### Table 1. Comparison of the 2 and 4 degrees worlds

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<th>4 degrees world</th>
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<td>Mitigation</td>
<td>Adaptation</td>
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<tr>
<td>Respective SRES scenario up to 2050</td>
<td>B1</td>
<td>A2</td>
</tr>
<tr>
<td>Use of bioenergy</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Both mitigation and adaptation actions are needed and taken in both scenarios, but their emphasis varies depending on the scenario.

### 2. AIMS OF THIS THESIS

Empirical observations of climate change impacts, predictive tools and approaches, and appropriate policy responses are developed in separate fields of research with different methodologies and cultures. This thesis aims at bringing these three aspects together to explore responses to climate change from the perspective of biodiversity in the European Union. I seek to answer three overarching questions:

1. When climate change responses are identified using predictive tools, do they reflect available empirical observations of impacts?

2. How can spatial conservation prioritization tools inform the conservation action with respect to different responses to climate change?

3. How far can informed policy planning get with available knowledge, tools and best practices, and where do they need improvements?

The thesis consists of five chapters that address these overarching questions with various approaches and sets of more detailed questions (Table 2.1.). Chapter I looks into EU biodiversity policy in light of needs arising from climate change, with a focus on bridges between climate change impacts to appropriate conservation responses and further to policy. Chapter II evaluates approaches to reducing uncertainty in conservation prioritization based on ensemble modelling of species distributions. The current standard, pre-selection consensus approach, is compared to a novel post-selection approach. The chapter also discusses why it is critical to assess the reliability of species distribution modelling in any given conservation planning context. Chapter III builds
Table 2.1. The specific and overarching questions addressed in the five chapters of this thesis.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Specific questions</th>
<th>Overarching question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>What conservation actions are suggested as responses to climate change impacts on biodiversity in scientific literature?</td>
<td>1,3</td>
</tr>
<tr>
<td></td>
<td>Can the current tools available through the EU biodiversity policy facilitate such responses?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>How could the policies and measures be developed or implemented to better meet the needs of biodiversity?</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Would conservation decisions based on ensemble predictions of species distributions be different depending on how the ensemble is pre-processed?</td>
<td>3</td>
</tr>
<tr>
<td>III</td>
<td>How do the allocations of biodiversity funding in the EU reflect the distribution of the current Natura 2000 network and other political and economic factors, such as the economic status of the receiving region?</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Do the allocations reflect spatial conservation priorities beyond the current Natura 2000 network considering current and future needs?</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>In light of empirical evidence, how does bioenergy-related land use affect biodiversity?</td>
<td>1,2,3</td>
</tr>
<tr>
<td></td>
<td>Why and how could modelling studies be more strongly linked with empirical impact studies?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>How could global land-use scenarios serve bioenergy impact assessments and policy planning?</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>How much pressure is exerted on European bird species of conservation interest directly by climate change and indirectly by bioenergy feedstock cultivation by 2050?</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Is there potential for spatial conflict between priority areas for bird conservation and predicted bioenergy cultivation areas?</td>
<td></td>
</tr>
</tbody>
</table>

methodologically on the findings of chapter II to explore the balance between various aims of biodiversity funding in the EU and how allocations of the funds reflect those aims. Chapters IV and V explore the balance between mitigation benefits and adaptation drawbacks of bioenergy as regards biodiversity conservation. Chapter IV discusses bridges from local bioenergy impacts to scenario-based impact assessments from a conservation scientists’ perspective. Chapter V examines the balance between mitigation benefits from bioenergy and potential spatial conflict with conservation priorities from the perspective of European birds (Figure 2.1.).

3. MATERIAL AND METHODS

My thesis combines a variety of approaches to explore the three themes (Figure 3.1.). The current status in science and policy are synthesized in literature reviews (chapters I and IV). Ensemble distribution modelling of bird species is combined with spatial conservation prioritization to explore the approach from a methodological perspective (chapter II) and potential matches, mismatches and conflicts with current policy practices and future land-use projections (chapters III, V).
3.1. STUDY AREA

This thesis is focused on biodiversity policy and climate change in the European Union (EU), which encompasses 28 countries on the Eurasian continent, i.e. the Member states. Most studies are therefore carried out with policy literature, biodiversity data and future projections within the EU (chapters I, III, V). The data in chapter II, with a more methodological focus, comprises the whole Europe. Reviews of scientific literature in chapters I and IV are not limited to Europe.

3.2. REVIEWING LITERATURE

Two chapters in this thesis are based on review of literature. Chapter I is based on reviews of current literature on 1) observed and predicted climate change impacts on biodiversity; 2) science-based adaptation options for addressing those impacts; and 3) to what extent those recommendations are covered in the European Union biodiversity policy today. The impacts were classified into four categories: changes in species distributions, phenological responses, physiological responses, and changes in communities and ecosystems. The adaptation
When climate change responses are identified with predictive tools, do they reflect empirical observations of impacts? How can spatial conservation prioritization tools inform conservation action with respect to climate change mitigation and adaptation? How far can informed policy planning get with available knowledge, tools and best practice?

Data

Birds of the Western Palearctic

Climate Data
- WorldClim

Future Climate Projections
- RCA3 ECHAM5

Land Cover Data
- GlobCover

Future Land Cover Projections
- IMAGES2.4

Funds Distribution Data
- European Commission

Scientific Literature

Policy Literature

Current Bird Distributions — Current Priorities

Future Bird Distributions — Future Priorities

Ensemble distribution modelling; BIOMOD

Spatial conservation prioritization; Zonation

Figure 3.1. The five chapters of this thesis discuss three themes with various data and approaches.

options were then assessed from the perspective of these impacts, i.e. which impacts can be addressed with the adaptation options suggested in scientific literature. This part was largely built on a recent systematic review of such adaptation options by Nicole Heller and Erika Zavaleta (Heller & Zavaleta, 2009). The third part was based on scientific articles that have assessed EU biodiversity policy in the light of climate change adaptation, as well as recently published EU policy documents in the context of climate change and/or biodiversity conservation.

Chapter IV explores the role of global scenarios in quantifying the impacts of climate change and bioenergy on biodiversity. It is a review of the literature on 1) empirical studies which have compared biodiversity in bioenergy production habitats and other reference habitats, and 2) modelling studies which have projected biodiversity impacts of bioenergy-related land-use change.

3.3. BIRD DISTRIBUTION DATA

Bird distributions in Europe, both current and projected future distributions, have a central role throughout the thesis (chapters II, III, V). Breeding range data of 156 species that are listed in the Annex I of the EU Birds Directive which gives them the highest legal conservation status at the EU were used. Extent of occurrence maps from The Birds of the Western Palaearctic database (BWPi, 2006) have been digitized at a resolution of 50x50 km (Barbet-Massin et al., 2012a).

Birds are often considered less vulnerable to climate change due to their relatively good dispersal abilities. Nevertheless, bird communities have not been able to track their respective climatic envelopes, and the shifts have been slower than for e.g. butterfly species (Devictor et al. 2012). Future projections of availability of suitable space, in terms of climate and land use, have found the majority of European bird species to lose range in the coming decades (Barbet-Massin et al. 2012). The distributions and ecology of birds have been well documented in a manner that supports their use as a model taxonomic group in large-scale global change and conservation studies. Furthermore, birds are a relevant group in terms of conservation policy, as the EU Birds Directive places them at the heart of the EU biodiversity policy.
3.4. CLIMATE AND LAND COVER DATA IN BIRD DISTRIBUTION MODELS

Five climate variables from the WorldClim database (Hijmans et al., 2005) represented current climate in the bird distribution models (chapters II, III, V): temperature seasonality (standard deviation *100), maximum temperature of the warmest month, minimum temperature of the coldest month, precipitation of the wettest month and precipitation of the driest month. Such variables describe the variability of the climatic conditions directly experienced by the species and are more informative than mean values.

Projections of future climate under two contrasting (B1 and A2, representing the 2 and 4 degrees scenarios, respectively; see Box 1.) socioeconomic scenarios were based on a set of regional climate models (RCM) in chapters III and V. Projections of monthly temperatures and precipitation for the years 2001–2050 had been generated by the Rossby Center Regional Climate Model (RCA3; Samuelsson et al., 2011) and were driven by the

Box 2: Retention and expansion areas

Complementing protected area networks with larger and more numerous protected areas has been identified as a key adaptation measure. Protected area networks can facilitate adaptation and range expansions by allowing larger population sizes. Complementing the existing network is a necessary response to changing species distributions. Two important questions arise: where should those new protected areas be established and how should they be managed so that they would fulfil their purpose?

The core of a species’ current range is most often the location where climatic suitability is highest at present, and where population densities are also the highest. Prioritizing the range core is therefore advisable to allow large population sizes (Araujo et al., 2004; chapters II, III, V) and receive most attention in the planning done with the present situation in mind. Retention areas are those parts of a range that are projected to retain climatic suitability in the next decades, i.e. they are climatically suitable for the species both now and in the future. They may be marginal today, but could make good conservation priorities anticipating the future (Araujo et al., 2004; chapters III, V). Management of retention areas could aim at increasing the capacity of the population to source dispersers to areas that are becoming suitable (Vos et al., 2008). As the likelihood of persistence is highest in retention areas, they represent a ‘low-risk’ priority. However, current and future ranges do not overlap for all species, and retention areas may be too restricted to guarantee long term persistence. Expansion areas, i.e. those areas which are projected to become suitable for the species, and where the species would need to disperse and establish (chapter V), present the biggest challenge for conservation management: they would need to be managed so that new colonisations and establishment are facilitated so that species can fill their suitable climate space. Range expansion is not only a matter of climatic suitability, but depends also on population dynamics, dispersal ability of the species in question, habitat availability and species interactions (Whittaker et al., 2001; Soberón, 2007; Vos et al., 2008), which all add to the uncertainty of successful expansion. Furthermore, management for expansion would require a shift in the mindset, given that conservation conventionally aims at preserving species and habitats in some ‘natural’ state (Pressey et al., 2007).

Figure 3.2. Current core, retention and expansion areas in a schematic representation of the current and future ranges of a species.
global ECHAM5 (Roeckner et al., 2003) circulation model.

Current land cover originated from GlobCover 2009 (Arino et al., 2012) level 1 classification: built-up areas, arable lands, permanent crops, grasslands, forests, and others. Land cover variables were used in bird distribution models in chapter II.

3.5. BIOENERGY PRODUCTION PROJECTIONS

The analysis of mitigation benefits and conservation conflicts of increased bioenergy use (chapter V) was based on previously published scenario outputs from the integrated assessment modelling framework IMAGE 2.4 in two contrasting socioeconomic scenarios, the 2 degrees and 4 degrees scenarios (MNP, 2006; OECD, 2012; see Box 1.). Here, land use for bioenergy under these two scenarios is allocated by ranking grid cells according to their suitability. Bioenergy is only allowed on abandoned agricultural land and on part of the natural grasslands, and not allowed on water scarce areas or severely degraded areas. The allocation produces maps which describe the distribution of different land cover types.

3.6. ALLOCATION OF BIODIVERSITY FUNDS

Alignment of biodiversity funding with conservation priorities (chapter III) was analysed with data on allocations of LIFE funds and the 2007–2013 period of Structural and Cohesion Funds (SCF). The data on allocations of the SCF was available for us at the second level of the Nomenclature of Territorial Units for Statistics (NUTS), where the Member states are further divided into 254 subnational regions, such as states, provinces, or planning regions hereafter referred to as NUTS-2 regions (European Commission, 2004). The regional SCF allocations were adjusted with country-level purchasing power parity (PPP) to account for price level differences across countries.

The SCF funds are classified to 86 priority themes (European Commission, 2012). Out of these, we used the totals of estimated break-downs for the three priority themes directly relevant for biodiversity: “Promotion of biodiversity and nature protection (including Natura 2000 areas),” “Promotion of natural assets”, and “Protection and development of natural heritage”, with a total of around 5 billion euros allocated for the 2007–2013 budget period. Approximately 1.2 billion euros have been allocated through the Nature strand of LIFE funds since 1992.

3.7. SPECIES DISTRIBUTION MODEL ENSEMBLES

Ensemble modelling of species distributions is a central method in this thesis (chapters II, III, V). This technique is based on using several statistical models to relate species occurrences to environmental factors. The resulting set of predicted distributions can then be used as such (chapters II, III) or summarized into a consensus projection (chapter V) in conservation prioritization.

The models of bird distributions were calibrated with data across the whole Western Palearctic region, which extends south, north and east of Europe, to cover the species’ niches as comprehensively as possible (Barbet-Massin et al., 2010).

An ensemble of predicted species distributions was obtained for each of the 156 species. The ensemble included projections based on five modelling techniques: Generalised Additive Models (GAM), Boosting Regression Trees (BRT), Classification Tree Analysis (CTA), Multiple Adaptive Regression Splines (MARS) and Random Forest (RF), all implemented in the BIOMOD2 package in R (Thuiller et al., 2009). A five-fold calibration of five statistical models yielded an ensemble of 25 predicted distributions for each species.

In chapter II, alternative approaches to using the ensembles of projected distributions in reserve selection were explored. The ensemble was summarized into four different consensus projections: 1) Committee averaging (MeanTSS), where probabilities of occurrence from different models were first transformed to presences and absences with a threshold that maximizes the value of the True Skill Statistic (Allouche et al., 2006) and then averaged (Thuiller et al., 2009); 2) Weighted mean probability (MeanWMP), where a weight based on the evaluation scores was first assigned to the probabilities
and no transformation to presences and absences occurs (Marmion et al., 2009; Thuiller et al., 2009); 3) Binary committee averaging (BinTSS), where the committee average probabilities were transformed back to presences and absences with the threshold that maximized the TSS score during the cross-validation procedure; 4) Binary weighted mean probability (BinWMP), where the weighted mean probabilities were transformed to presences and absences with a threshold that maximizes the TSS of the ensemble predictions (Thuiller et al., 2009).

Raster grids of the standard deviation across the ensemble for each species and grid cell were also produced. The standard deviation grids were used together with the weighted mean probability in an approach called distribution discounting (DistrDisc; Moilanen et al., 2006) that has been previously implemented in the conservation planning software Zonation (see below).

Datasets for the “post-selection consensus technique” were produced by randomly sampling one probability value out of the 25 values available for each species in each grid cell and repeated this sampling 100 times, thereby achieving 100 datasets altogether.

The same ensemble of models was used to project the bird distributions into the year 2050 under two climate change scenarios (see 3.4.). The future projections of bird distributions were used in two climate scenarios in chapters III and V.

In chapter III, retention areas, i.e. areas where the climatic conditions were predicted to remain suitable for a species (see Box 2.) were identified. These retention areas were then used as a basis for identifying priority areas for future conservation with the post-selection consensus technique.

In chapter V, both retention and expansion areas, i.e. areas where the climatic conditions were predicted to become suitable for a species in the future but where the species is not present at the moment (see Box 2.) were identified. I used the committee average consensus projection as a basis for identifying conservation priorities based on future climatic suitability, and a binary committee average as a basis for determining retention and expansion areas. I quantified the change in suitable range size due to climate change based on the projected current and future distributions, and the additional change in availability due to land use for bioenergy production based on an overlay of the projected bird distributions and land-use projections of the IMAGE scenarios.

3.8. RESERVE SELECTION WITH ZONATION

Priority areas for conservation were identified in chapters II, III and V using the Zonation v.3.0 software for spatial conservation prioritization (Moilanen et al., 2012). Zonation identifies areas that are important for retaining suitable areas simultaneously for all biodiversity features included in the analysis. The output of Zonation is a hierarchical map of the landscape, based on the biodiversity value of the sites. Such maps can be used to identify networks of areas which represent as much of the biodiversity features as possible while minimising cost or area required. The software operates through backwards-iterative heuristics, at each step calculating conservation value for each site and removing the one with the lowest conservation value. The algorithm called Core Area Zonation calculates the conservation value $d_i$ for each site as

$$d_i = \max(q_{ij}w/c),$$

where $q_{ij}$ is the proportion of the distribution of species $i$ located in site $j$ among the sites that are remaining in the landscape, $w_j$ is the species-specific weight for species $j$ and $c_i$ is the cost of site $i$. As all species were weighted equally and information about land cost in our analysis was not used, the conservation value was purely determined by the species that had the largest proportion of its remaining distribution in cell $j$.

Chapter II explores the outcome of alternative approaches to ensemble projections of species distributions in reserve selection. A conservation priority ranking was derived with each of the four “pre-selection consensus” datasets; a conservation priority ranking that considered uncertainty through the distribution discounting analysis within Zonation (Moilanen et al., 2006, 2012) using the MeanWMP dataset in combination with the standard deviation across the ensemble for each species (DistrDisc; here, the standard
deviation of each species and grid cell is subtracted from the probability of occurrence for that species and cell; and a "post-selection consensus" reserve network by first deriving a conservation priority ranking for each of the 100 datasets sampled across the full ensemble, and then calculating the mean rank for each cell across these rankings and re-ranking the cells by the mean rank).

The performance of the ensemble prediction datasets in reserve selection was assessed against three different controls and against each other. Similarity between networks was quantified as: 1) pairwise spatial overlaps between the highest 10% priorities of ensemble prediction versus control solutions; and 2) pairwise correlations between the overall priority rankings of ensemble prediction and control solutions. The performance of our methods was compared to a null control by quantifying the number of times each species was better represented in the ensemble prediction-based networks than in the networks based on random ranking of cells. Representativeness of species, according to data in the evaluation datasets, in the reserve networks was quantified based on the ensemble prediction datasets. Pairwise Wilcoxon signed-rank tests were used to determine whether species are consistently better represented in one network or another.

In chapter III, the conservation priority networks were based on the current distributions of species, as well as based on predicted retention areas. The post-selection consensus technique was used in these rankings. Areas which are currently not protected in the Natura 2000 network were of particular interest, and these were identified using an analysis variant that identifies areas that best complement what is already protected. These rankings were then compared with the distribution of biodiversity funding in the EU.

In chapter V, the conservation priority networks were based on the current and future distributions of species, as well as their predicted retention and expansion areas. Here, too, areas which are not currently included in the Natura 2000 network were identified. The best 10% of the conservation priority rankings were used as the sets of priority areas for which potential conflicts with bioenergy feedstock cultivation were identified. The proportion of the priority areas that overlap with bioenergy cells was calculated and the overlap was compared to the expected overlap, based on 10% of cells selected randomly.

4. RESULTS

4.1. EU BIODIVERSITY POLICY: UNDERUSED OPPORTUNITIES AND GAPS TO BE BRIDGED

Science-based adaptation options for biodiversity conservation do not cover all observed and predicted impacts of climate change (chapter I). Most of the suggested adaptation measures were biased towards shifts and contractions in species distributions. Furthermore, the recommended adaptation measures were often generic and rule-of-thumb-like, whereas guidance on deriving spatially specific, appropriate adaptation measures is urgently needed.

Recommended conservation action can be divided in three broad categories:

- **enhancing conservation where species currently occur**, thereby indirectly addressing extinction risk and facilitating phenological and physiological responses via allowing larger population sizes and minimizing other synergistic threats

- **facilitating species distribution shifts** by securing connectivity and assigning conservation priority to areas that are, for example, suitable for species both currently and in the future, future ranges of species, or jointly forming bioclimatically representative networks of habitats, and

- **adjusting conservation priorities and objectives** in light of the conservation needs arising from climate change impacts: for example, do lists of priority species and habitats reflect the status and conservation needs of those species and habitats also when considering climate change? How do the anticipated climate change impacts affect the conservation status of a species?

The existing EU biodiversity policy has more potential to support effective adaptation than what its current interpretation and practice allows, although there seem to be gaps that cannot be addressed with the existing policies. For example, the single most often repeated adaptation recommendation is increasing connectivity in the landscape, and the Bern Convention’s Standing Committee has introduced this measure in
their guidance on the adaptation of biodiversity to climate change. This means that the Birds and Habitats Directives should be implemented so that connectivity is ensured. Nevertheless, the literature review pointed to a gap in how member states implement the directives with respect to connectivity. Recent guidance documents on Green Infrastructure (European Commission, 2013a) as well as incorporating climate change adaptation into the mandatory Strategic Environmental Assessments (European Commission, 2013b) and Environmental Impact Assessments (European Commission, 2013c) in context of development were identified as examples of tools that can facilitate effective adaptation measures, if implemented with this aspect in focus.

The most important gaps in the EU policy, as identified in chapter I, were 1) conservation targets are insufficiently in line with conservation needs, mostly due to lack of regular and systematic monitoring and assessment mechanisms; 2) the Habitats and Birds Directives may not entail sufficient tools to address the dynamic nature of the species and habitats they aim to protect; 3) neither the EU biodiversity strategy nor guidance on climate adaptation of the Natura 2000 network acknowledge the need to further strengthen the network through conservation and restoration, although this need has been identified in the scientific literature; and 4) the Habitats and Birds Directives lack an obligation to coordinate their implementation internationally, which limits cross-national collaboration in target setting.

4.2. BIODIVERSITY FUNDING REFLECTS CURRENT EFFORT AND IS POORLY ALIGNED WITH CONSERVATION NEEDS

Chapter III reveals that while distribution of EU biodiversity funds reflect the extent of existing Natura 2000 areas in a region as well as the economic need for community funding, there is a mismatch between future conservation needs and the current practice of allocating funds for biodiversity conservation in the EU. The level of funding per region was most strongly correlated with the size of Natura 2000 area per region, followed by the area of the region, and regional gross domestic product, which is negatively correlated to funding. Correlations between funding and conservation needs beyond the current Natura 2000 were either weak or missing altogether.

4.3. CLIMATE CHANGE CAUSES LARGER RANGE CHANGES THAN BIOENERGY IN THE EU

A key result of chapter V was that climate change drives larger changes in range size than bioenergy in the EU. The magnitude of range contractions was higher in the 4 degrees scenario than in the 2 degrees scenario, with a median contraction in climatically suitable range of 40% in the 4 degrees scenario compared to 28% in the 2 degrees scenario, both when considering only climate and the joint impacts of climate and bioenergy. Overall, the effect of climate change on species range was projected to be much larger than the effect of bioenergy in the particular mitigation scenarios used in the analyses. Additional impacts from climate change in the 4 degrees scenario were larger than land use impacts from bioenergy in the 2 degrees scenario, when compared to the impacts of 2 degrees of climate change only (Figure 2 in chapter V).

4.4. BIOENERGY IMPACTS: LIMITED IN EXTENT YET POTENTIALLY IN CONFLICT WITH CONSERVATION PRIORITIES

Review of the empirical evidence in chapter IV suggests that the impacts of bioenergy on biodiversity are determined by 1) the type of bioenergy (Haughton et al., 2009; Questad et al., 2011; Robertson et al., 2011a, 2012; Werling et al., 2011; Harrison & Berenbaum, 2012; Myers et al., 2012); 2) the reference habitat, i.e. what type of land use is replaced with bioenergy production (Felten & Emmerling, 2011; Questad et al., 2011); 3) landscape structure (Robertson et al., 2011b, 2013; Baum et al., 2012); and 4) management activities (Myers et al., 2012). The main indicators used in empirical studies were the number and abundances of species in bioenergy plots as compared to a reference habitat (e.g. Brin et al.
Modelling studies, in contrast, typically use different types of indicators and focus on the extent and impact of habitat change associated with bioenergy production, in terms of suitable habitat for specific species (Eggers et al. 2009; Louette et al. 2010), the replacement of pristine habitats (Alkemade et al. 2009) and the loss of high nature value habitats (Hellmann and Verburg 2010).

Chapter V assessed the impacts of bioenergy-related land use on availability of suitable habitats for bird species under a climate change scenario that involves strong mitigation action that includes increased use of bioenergy. In this scenario, the overall use of biomass for energy is in the low end of globally estimated sustainable potentials (160 EJ/year in 2050 while the estimated sustainable potentials range between 130 and 500 EJ/year, after accounting for food, water and biodiversity conservation needs; Beringer et al., 2011; Dornburg et al., 2012) and consists of woody biomass from plantations as well as forest residues. As collection of forest residues does not change the land cover type even though it has documented negative impact on species depending on coarse woody debris and deadwood, only the bioenergy plantations could be included in the analysis. Within the EU, bioenergy plantations have a limited impact on the availability of suitable habitats for bird species: the median change in suitable range size due to bioenergy was -2.6% with a range between -38% and 4%. However, only seven generalist species were predicted to gain habitat with bioenergy plantations. While the magnitude of climate change impacts was stronger than the impact of bioenergy, bioenergy was predicted to have a negative impact on a larger proportion of the species (96%) than climate (36% of species in the 2 degrees scenario and 38% of species in the 4 degrees scenario).

Further spatial overlap was found between regions that are projected to be favourable for bioenergy plantations and regions identified as conservation priorities under climate change. The overlap with bioenergy ranged from 1.9 to 4.2% of the conservation priorities, depending on the prioritization criteria, and was significantly higher than random overlap with three out of four prioritization criteria (current, future, and retention priorities).

4.5. FOCUS ON UNCERTAINTY AND LIMITATIONS

A cross-cutting theme of my thesis was uncertainty which has organic connections to climate change at various levels.

There seems to be a knowledge gap between climate change impacts on biodiversity and the science-based recommendations to address those impacts (chapter I). Large uncertainties related to the impacts and appropriate responses in turn make it difficult to design effective policies and measures that cover all impacts. However, many of the knowledge gaps and uncertainties may never be bridged, and responses to climate change are more urgent day by day. Certain conservation actions such as establishing more and larger reserves as well as increasing connectivity were found to address several climate change impacts either directly or indirectly. Prioritizing such actions would therefore be a smart and robust strategy. The uncertainty also means that it is difficult if not altogether meaningless to make detailed plans spanning far into the future. Regular updates and enhanced monitoring of conservation objectives are therefore advisable to enable informed decisions of effective conservation actions.

The focus of chapter II was uncertainty related to predicted species distributions. The large variability in predicted distributions from alternative statistical techniques has been previously established (Buisson et al., 2010; Garcia et al., 2011), and ensemble modelling of species distributions has been recommended as a solution (Thuiller, 2004; Araújo & New, 2007). The different ways in which summarizing ensemble predictions affect conservation planning outcomes were evaluated and commonplace consensus methods, applied before the conservation prioritization phase (pre-selection consensus), was compared to a novel method that applies consensus after reserve selection (post-selection consensus). While networks based on predicted distributions were more representative of rare species than randomly selected networks regardless of the way the predicted distributions were used as input in reserve selection, the novel method resulted in better representation of rare species than pre-selection consensus methods. Based on this case study, it seems that retaining information about the variation in the predicted distributions in conservation prioritization
provides better results than summarizing the predictions before conservation prioritization.

There seems to be a gap between empirical studies of bioenergy impacts on biodiversity and the outputs of global scenarios with which it would be important and interesting to evaluate, for example, the overall impacts of a given level of bioenergy production at a global or, in our case, continental scale (Chapter IV). Most importantly, currently available global scenarios do not capture all impacts, such as changes in forest habitat quality or small-scale landscape structure even though those have been identified as key factors in empirical studies.

5. DISCUSSION

5.1. WHEN PLANNING CONSERVATION RESPONSES TO CLIMATE CHANGE, BE AWARE OF THE BLIND SPOTS OF PREDICTIVE TOOLS

Identifying appropriate conservation responses to climate change requires understanding what the future might be like, what challenges lie ahead and how these challenges compare with each other. Predictive tools such as scenarios and statistical models are essential tools for describing the potential futures in quantitative terms. These tools necessarily simplify and reduce the complex dependencies. When such tools are used to identify or assess appropriate responses, understanding the biases and limitations becomes essential so that any conclusions derived with such tools can be subjected to follow-up questions that can account for the shortcomings of the quantitative techniques.

Assessing the numerous scientific recommendations for conservation responses to climate change revealed that the responses mainly address species range shifts, while specific actions to counter disrupted species interactions have not been proposed, and few suggested actions address phenological shifts or evolutionary changes (Chapter I). Phenological shifts, evolutionary adaptation and ecological interactions indicate ecological and evolutionary processes that are reflected in the pattern of species distributions: when species fail to adapt or vital community interactions are disrupted, changes in occurrence patterns follow. Protected area designation, restoration and management are the prevailing procedures in the conservation toolkit, and this is heavily pattern-oriented. Focus on conserving pattern in biodiversity remains the paradigm although a shift towards preserving the processes that produce and maintain biodiversity has been suggested (Pressey et al., 2007). Increasing attention on ecosystem services (Mace et al., 2012) and insights into how processes can be inferred from pattern (Davies & Buckley, 2011) has led to attempts to use such pattern-based indicators of process in conservation planning (Maes et al., 2012; Zupan et al., 2014). This seems to be a promising avenue for future research and response planning, although the theory of how the conservation of these processes should look like in practice and how exactly it will facilitate adaptation to climate change remains to be developed.

While species distributions are a pattern resulting from the interplay of various ecological, evolutionary and demographic processes (including phenology, adaptation, and ecological interactions), current species distribution models do not account for these processes. Integrating those processes into modelling is currently under development, and alternative frameworks have been proposed (Guisan & Rahbek, 2011; Kissling et al., 2012; Thuiller et al., 2013). Kissling et al. (2012) suggest using species interaction matrices in multivariate regression models. Thuiller et al. (2013) present an integrated model which builds on metapopulation theory and accounts for abiotic constraints as well as dispersal, biotic interaction and evolution. These developments can link process to pattern more explicitly. Operational methods, practical tools and guidelines are yet to be established and tested, which makes applications to reserve selection currently unfeasible. Despite the shortcomings, species distribution modelling remains the “best available tool” for forecasting changes and identifying adaptation needs in a quantitative manner over large geographic scales and large numbers of species. This can explain why changes in species distributions are the number one climate change impact that suggested conservation responses address.

Integrated assessment models (IAMs) provide land-use scenarios based on socioeconomic and policy storylines. Global scenarios are an appealing tool for assessing the impacts of bioenergy on biodiversity, as they capture both direct and indirect land-use change in relation to meeting a given global energy demand. However, IAMs have important limitations which affect what interpretations and conclusions can be drawn from analyses based on such scenarios (Chapter IV).
IAMS produce future maps of land use often based on rather simplified rules (for food crops and bioenergy crops). According to empirical studies, important factors that determine the impact of bioenergy on biodiversity include landscape structure and management practices (Londo et al. 2005; Rowe et al. 2011; Northrup et al. 2012). However, the IAM projections are not detailed or high-resolution enough to capture such detailed patterns.

More detailed policy storylines would enable building more detailed, regional scenarios. IAMs could provide the boundary conditions for such scenarios. For example, the European Union targets for renewable energy and member state strategies for meeting these targets could inform the regional scenario work on more detailed distribution of bioenergy demand and inform policy planning about potential sustainability conflicts, based on which policy could be revised.

Investments in energy infrastructure are far-reaching; biomass-burning power plants built today are still online in 2050. Land use cannot be projected that far into the future accurately and certainly with high spatial resolution. Uncertainty accumulates in predictions over time, which implies that scenarios cannot be interpreted as predictions of the future. Instead, scenarios can help identify potential problems in the developments they describe, and help to design policy through which those problems can be avoided.

5.2. SPATIAL CONSERVATION PRIORITIZATION CAN INFORM ASSESSMENT OF RESPONSES TO CLIMATE CHANGE

Even though observations and predictions of biodiversity pattern lack important considerations of the underlying processes, they can provide useful insights into policy assessment. Spatial conservation prioritization tools provide information of conservation value in an aggregate, spatial format. This pattern can be compared with spatial patterns in other matters of interest, such as past and future developments in other societal sectors. Spatial conservation prioritization tools have been used to identify priority areas for conservation under climate change (Carroll, 2010; Carvalho et al., 2011; Kujala et al., 2013) but further comparison to other spatial projections are not common.

In my thesis, I compare spatial data or projections with spatial conservation priorities in two examples.

Combining spatial data of funding allocations and conservation value allowed for an analysis of how the largest sources of EU biodiversity funds, the SCF and Life, are aligned with biodiversity conservation needs under climate change (chapter III). By comparing the distribution of funds to priority areas for conservation in the current situation and in the future, it was possible to explore the balance between current and future biodiversity needs in conservation funding. The distribution of EU biodiversity funding reflects current spatial conservation effort, i.e. the existing Natura 2000 network and the financial needs of regions. This is a positive finding. On the other hand, the allocation of funds is not aligned with conservation needs arising from climate change as well as from the fact that the majority of biodiversity in the EU remains insufficiently protected (BirdLife International, 2004; Condé et al., 2010). This was not a surprising finding, given that such considerations have not been the basis of funding allocation to date.

The balance between mitigation and adaptation actions is another interesting dimension (chapter V). The impacts of climate change are already felt today (chapter I), and adaptation is necessary in every future scenario. Successful adaptation becomes more feasible when the expected impacts are smaller as a consequence of effective mitigation. Climate change impact studies from other policy sectors have concluded that a 4 degrees world may require “transformational adaptation beyond systems as we understand them today” or lead to a collapse in certain regions of the world and societal sectors, such as farming in sub-Saharan Africa (New et al., 2011).

36–38% of bird species of conservation concern are projected to lose suitable climate space in the EU by 2050 (chapter V). For those species, the range contractions were substantially smaller in the 2 degrees scenario than in the 4 degrees scenario. The same was true also when the land-use impacts of increased bioenergy use in the 2 degrees scenario were taken into account. This result is in line with previous studies concluding that mitigation of climate change is a key strategy in biodiversity conservation (Heller & Zavaleta, 2009; Warren et al., 2013) and that achieving conservation goals is much less costly under a low climate change scenario (Kujala et al., 2013).
The bioenergy land-use projections used in chapter V should be regarded of a ‘best-case’ scenario from a sustainability perspective. The total amount of bioenergy was in the low end of estimates of global sustainable potentials after accounting for various other land-use needs, such as agriculture, water and biodiversity. They were based on global scenario outputs from the integrated assessment model IMAGE (MNP, 2006). The biomass was wood from short rotation coppice plantations and forest residues, and it was mostly used in combined heat and power generation. Empirical studies indicate that such woody bioenergy plantations are less harmful for biodiversity than agricultural bioenergy crops (chapter IV). Short-rotation coppice can at best increase heterogeneity at the landscape level, and provides suitable habitat for a larger number of species than agricultural croplands. However, the impacts from harvesting of forest residues is not visible in such global scenarios although empirical studies have found considerable negative effects on deadwood-dependent forest species (chapter IV). The results are therefore likely to underestimate the negative impacts from the bioenergy scenario on forest species.

Nevertheless, the results indicate potential for spatial conflict with conservation priority areas and the areas that are suitable for bioenergy production. As the scenarios assume rather strict sustainability considerations, it is clear that such considerations must be in place also in the EU policy, in order to avoid more pronounced conflict. For example, the sustainability criteria for bioenergy need to be clarified, especially by defining “areas with high biodiversity value” (Eickhout et al., 2008) so that they also encompass priority areas for conservation beyond what is currently protected. Similarly clarified criteria must apply to imported biomass as well.

If only ‘conservation priorities’ were something that could be objectively and universally defined! Chapters III and V have identified priority areas for conservation based on current and projected future distributions of bird species of conservation interest in the EU. One algorithm was used to identify areas that would best complement the existing Natura 2000 network, and the assessments were based on those areas. When comparing relative funding to relative conservation value, it is clear that the conclusions depend on the choice of species as well as on the approach. With another set of species the conclusions may have been the same or different.

Surrogacy, i.e. whether the diversity patterns in one group of species can be assumed to represent the diversity patterns in others, seems to depend on species group and area (Rodrigues & Brooks, 2007).

The choice of criteria is justified regardless of the surrogacy value of the group of birds in question, as all the bird species included in the analyses are assigned a legal conservation status through a political process. In other words, the EU is committed to protecting these species. The species distributions were projected in the future with state-of-the-art methods and priority areas were identified with a state-of-the-art spatial conservation prioritization tool. Conservation focus on retention areas is a sound strategy, and focus on expansion areas is likewise well founded (see Box 2.). However, the possibility to identify sound and well justified conservation priorities in a variety of ways needs to be recognized.

Indeed, different people and organizations have proposed alternative criteria for identifying conservation priorities. One review estimated that 79 percent of the terrestrial area of the Earth is priority according to one scheme or another (Brooks et al., 2006). ‘How much is enough’ is a central debate in conservation science, and literature suggests protecting up to half of land area may be necessary in order to halt biodiversity loss (Noss et al., 2012). The question clearly cannot be answered through science alone, as it entails accepting certain risk levels and levels of loss and essentially has elements of value judgments (Wilhere, 2008).

5.3. METHODOLOGICAL DEVELOPMENT NEEDS TO BALANCE INCREASED COMPLEXITY WITH BEST PRACTICES AND PRACTICAL VALUE

Action based on evidence faces a paradox: evidence points to the need for rapid action to counter biodiversity loss under climate change. Yet we do not have precise information of even the current whereabouts of most species, let alone the precise impacts climate change will have on them in the future. Action must therefore make use of the best available tools and knowledge, and policies and measures need to facilitate this.

An example of ‘best available tools’ is ensemble modelling of species distributions that addresses uncertainty arising from statistical model choice (Araújo & New, 2007;
Marmion et al., 2009). Ensemble modelling results in more accurate predictions of species distributions than any single modelling technique (Araújo et al., 2005) and represents the state-of-the-art in complementing existing species distribution maps and projecting those distributions into the future. Chapter II explored how different ways of summarizing ensemble predictions affect conservation planning outcomes.

Chapter II presents a new approach to using ensemble model outputs in reserve selection: the post-selection consensus approach, where the full range of predictions is sampled to provide input for spatial conservation prioritization. In our study, the post-selection consensus approach resulted in consistently better conservation outcomes for rare species than using a pre-selection consensus summary of the model predictions. However, species with very few occurrence records typically had a low agreement between models, and were often represented poorly in the resulting reserve networks. Species with very few occurrences could therefore be best included in the planning exercise by directly using the available observation data instead of modelled distributions, while using predicted distributions for the rest of the species (Carvalho et al., 2010).

The analyses were based on empirical data that does not allow testing the methods with respect to their performance in future projections. Virtual experiments would be better suited for such an analysis (Zurell et al., 2010; Langford et al., 2011). A key question in this regard remains how robust different approaches are to increased uncertainty under climate change? The emphasis on robustness should become even more pronounced when distributions are projected into the future, and uncertainty is added from several socioeconomic scenarios and alternative climatic circulation models on top of the uncertainty that arises from the statistical models for SDMs (Buisson et al., 2010; Garcia et al., 2011).

Conservation decisions based on predicted species distributions are sensitive to the approach to summarizing the output of ensembles, which also means that the need to carefully contemplate the use of SDM outputs in spatial conservation prioritization is highlighted. First and foremost, assessment of the adequacy of the species occurrence data for SDM is critical. Data error, uncertainty and model reliability have attracted considerable research interest over recent years (Reddy & Dávalos, 2003; Graham et al., 2004; Barry & Elith, 2006; Barbet-Massin et al., 2012), and spatial conservation prioritization maps are only as reliable as the input data behind those maps. Neither pre- nor post-consensus reserve selection are reliable if error and bias in the original data render model predictions unreliable. Following best practices identified by SDM research (Barry & Elith, 2006; Elith et al., 2006; Guisan et al., 2006) is essential in conservation planning as well as other fields of application.

Conservation science has not defined appropriate measures to address certain climate change impacts, especially disruptions of ecological interactions (chapter I). This gap in adaptation measures and the uncertainties in forecasting the impacts also underline the need to minimise those impacts by means of mitigation. Chapter I also reveals an urgent need for scientific guidance on identifying appropriate adaptive responses in any given circumstances. At the moment, the suggested actions are often generic and lack specificity: how to choose which actions are the most appropriate in a particular case?

Projections and forecasts can help identify the key challenges and assess their relative importance (as in chapter V) but neither the projections of future conservation priority areas nor scenarios of future land use are accurate or comprehensive enough to serve as a basis for detailed spatial planning. Uncertainty in future predictions also points to the need for robust strategies. Increasing the coverage of protected area network is a simple example of a strategy that reduces sensitivity to errors, while simultaneously increasing the likelihood of population persistence (Cabeza & Moilanen, 2003; Hannah et al., 2007).

5.4. CONSERVATION BIOLOGIST’S OBSERVATIONS AND RECOMMENDATIONS FOR EU BIODIVERSITY POLICY UNDER CLIMATE CHANGE

5.4.1. Policy allows proactive conservation, practices need revision

The interpretation and implementation gaps are pronounced in context of the Natura 2000 network. Recent case law by the European Court of Justice has
clarified that conservation objectives for the Natura 2000 areas do not need to be ‘specified for each species considered separately’ (Trouwborst, 2011). Legally, this allows a more proactive and flexible planning approach to the Natura 2000 network. Scientific assessments have identified a need to complement the current protected area network as the current ones become climatically unsuitable (Araújo et al., 2011; Maiorano et al., 2011), and extensions to the network are legally possible and even mandated. However, the EU biodiversity strategy takes on a static interpretation as it considers the Natura 2000 network to be ‘largely completed by 2012’ (European Commission, 2011a), and the guidance for climate adaptation in Natura 2000 areas (European Commission, 2013d) focuses on improving the resilience of individual areas and connectivity of the network, instead of the representativeness and adequacy of the network as a whole.

The directives are based on the principle of subsidiarity, which gives the Member States the freedom to implement them largely as they see fit. International coordination of the implementation is therefore lacking. International coordination would deliver more efficient outcomes (Montesino Pouzols et al., 2014), and as the dynamics of species and habitats do not respect country borders, such collaboration is ever more important to address climate change. A new Natura 2000 biogeographical process aims at facilitating information exchange and cooperation between Member States and different stakeholders in order to take on a more biogeographical approach to the favourable conservation status (European Commission, 2013d), although it is not clear how this collaboration will feed into assessments of conservation status and needs of target species and habitats.

The Bird and Habitats Directives oblige regular status assessments of target species and habitats as listed in annexes I, II, IV and V (HD) and annex I (BD). However, the threat status and therefore conservation needs of species and habitats is likely to change. As a mechanism to assess the adequacy of the annexes themselves is missing, there is no legal demand to assess the adequacy of measures from the perspective of biodiversity as a whole. Reassessment of the annexes to the directives has been suggested as a response (Hochkirch et al., 2013), although defining conservation targets and priorities is not purely a scientific issue, as the ‘what to protect’ question should also reflect societal values and perceptions.

European Commission has produced a range of guidance documents in order to help policy planning and boost mainstreaming of climate change adaptation in biodiversity conservation, and mainstreaming climate change and biodiversity considerations into spatial planning and regional development. These guidance documents cover management of Natura 2000, integrating climate change and biodiversity in Environmental Impact Assessment and Strategic Environmental Assessment, and enhancing connectivity by means of green infrastructure. Furthermore, the European Commission is currently defining restoration targets and priorities in context of the CBD target of restoring 15% of degraded ecosystems and habitats. These endeavours may alleviate the problem of underrepresentation of landscape connectivity (Dodd et al., 2010) and habitat restoration (Verschuuren, 2010) in the current practice of Member States striving for favourable conservation status of target species and habitats, but their non-binding nature faces the risk of falling in the interpretation and implementation gap.

5.4.2. Allocation of funds needs stronger links to biodiversity goals

Analysing the allocations of funds available for biodiversity conservation from biodiversity’s perspective revealed that funding is not aligned with climate change adaptation needs (chapter III). There are three lessons to be learned from these findings. First, the allocation of SCF funds is missing a clear connection to the EU biodiversity strategy. The contribution of candidate projects to the overall goals of the strategy would be particularly important, and the need to use resources in an optimal way is a recognised challenge in the strategy itself. As the Cohesion Policy projects are geared towards integrated projects with multiple objectives in the current EU budget period, the need to explicitly assess the projects true relevance for biodiversity conservation becomes increasingly important. Whether this bears weight in the allocation of the SCF funds, however, remains unclear.

Second, the indicators through which the SCF-funded projects are evaluated need to include a relevant indicator of biodiversity conservation. Over the 2007–2013 period, seven core indicators were used to evaluate project outcomes in the environment theme:
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additional population served by water projects, number of waste projects, number of projects on improvement of air quality, area rehabilitated (km²), number of risk prevention projects, number of people benefiting from flood prevention measures and number of people benefiting from forest fire protection and other protection measures (European Commission, 2013e) – but not one for biodiversity. As the emphasis is shifting towards integrated projects with several environmental and non-environmental goals, the need for a biodiversity-relevant evaluation criteria for the outcome becomes even more pronounced, if the funds are supposed to effectively support biodiversity.

Third, the lack of transparency in the distribution of EU funds to projects is a major obstacle for science-based improvements towards more effective spending of the limited resources. An overview of all EU funding that directly or indirectly contributes to biodiversity conservation is challenging to assess and quantify (Kettunen et al., 2009). In chapter III, it was not possible to disentangle neither the biodiversity-relevant funds under the Common Agricultural Policy framework nor SCF funds from previous budget periods. A transparent and biodiversity-relevant coding and monitoring system for the current budget period 2014–2020 would be a remarkable improvement in this respect.

Recent positive developments in part address the concerns raised by these findings. The European Commission has recently provided guidance for integrating climate change and biodiversity into the strategic environmental assessment (SEA) of spatial planning and development projects (European Commission, 2013b), which is highly relevant for SCF-funded projects. LIFE programme has a more pronounced focus on climate change over the current budget period, as a share of the funds are distributed through a separate sub-programme for Climate Action – this may enable climate policy mainstreaming to various policy sectors but requires careful planning so that climate action does not become disjoint from the Environment sub-programme. Furthermore, the programme is expected to explicitly take into account synergies and conflicts between biodiversity conservation and climate change (European Commission, 2011b).

6. CONCLUSIONS

6.1. TOP 3 SUGGESTIONS TO IMPROVE POLICY

Recent guidance documents for adaptation to climate change in the Natura 2000 areas, integrating climate change and biodiversity in SEA and EIA, and green infrastructure describe best practices. Implementing these best practices comprehensively would likely bring substantial benefits for biodiversity compared to current practice. Compliance with the SEA and green infrastructure guidance should be required from projects that receive funding from the Structural and Cohesion Funds.

Biodiversity project funding from the SCF funds needs to be explicitly linked to the biodiversity strategy goals and assessed from the perspective of biodiversity needs. Indicators of project success should include an indicator relevant for biodiversity.

Mitigation of climate change is a key strategy for biodiversity conservation, as it makes effective adaptation more feasible. Bioenergy can play a role in deep emission reductions, but sustainability criteria need to be clarified so that they fully account for biodiversity impacts in order to avoid spatial conflict with conservation priority areas.

6.2. TOP 3 SUGGESTIONS TO IMPROVE SCIENCE

Recent scientific literature has proposed more than one hundred adaptation actions for biodiversity conservation. The next great thing would be to proceed from making generic recommendations to guidance on how to decide what to do where. How should protected area management be balanced between facilitating the establishment of new species’ populations and persistence of those species that are already there? How should conflicts between contradicting management goals be resolved?

Scientific assessments can better inform sustainable bioenergy policy planning if empirical evidence of the localised impacts of bioenergy on biodiversity is bridged to the overview provided by global...
scenarios. This can happen through regional policy storylines where the boundary conditions are provided by global scenarios and a regional model is parameterized using information from the empirical studies. Spatial conservation prioritization tools can also inform land-use scenario development by providing information on biodiversity conservation needs.

Quantifying and assessing the consequences of prediction uncertainty in spatial conservation prioritization based on predicted species distributions is an important field of development, as spatial conservation prioritization tools are used increasingly in real life, and planning is also moving to the direction of anticipating future change. Conservation planners need clear guidelines for collecting and preparing their data for modelling.

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