Aletta Bonn, Nicholas Macgregor, Jutta Stadler, Horst Korn, Sarah Stiffel, Katrin Wolf and Nikki van Dijk

Helping ecosystems in Europe to adapt to climate change

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Cover picture: Sand dunes in Druridge Bay, UK (© Natural England / Graeme Peacock)

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1 Summary

This report summarises much of the work done by, and for, the Climate Change Group of the European Network of Heads of Nature Conservation Agencies (ENCA) between 2011 and 2013. The ENCA Climate Change Group is made up of experts in climate change and ecology from government conservation agencies across Europe. Current members of the group include representatives from conservation agencies in England, Germany, Switzerland, Wales, Scotland, Czech Republic, Finland, Spain, Netherlands, Austria, Norway and the Dutch province of Gelderland. The group is chaired by Natural England.

Climate change increases the need for a cross-European approach to conservation, for example because of likely shifts in species' ranges and the increased need to manage large scale ecosystem processes, such as hydrology, that cross national borders. While there is still a lot we do not know about the effects of climate change on the natural environment, and about appropriate adaptation strategies, there is great potential to share information among the different European countries and to learn from each other's approaches and experiences.

The role of the group is to share knowledge and develop and promote best practice on:

- adaptation for biodiversity and ecosystems
- the wider role of nature conservation in helping society adapt to climate change (and in reducing greenhouse gas emissions)

Through this we hope to further promote the integration of the findings of impacts and adaptation research into conservation practice, and help conservation practitioners learn from the experiences of colleagues dealing with similar conditions, issues, threats and opportunities in other parts of Europe.

In April 2011, the German Federal Agency for Nature Conservation (BfN) with the support of the University of Greifswald and in collaboration with the European Network of Heads of Nature Conservation Agencies (ENCA) organised the 'European Conference on Biodiversity and Climate Change – Science, Practice and Policy' in Bonn, Germany (Korn, Kraus & Stadler 2012). The main goal of the conference was to debate the question of how scientific evidence can be better integrated into political decision making processes and implemented in practice. Based on information presented in talks and posters during the conference and in the final panel discussion, the ENCA Climate Change Group has agreed the following conclusions and recommendations. These cover three broad topics: communication and sharing information; implementing adaptation; and further research priorities (See Appendix 11.1). One of the general conclusions of the conference in 2011 was that more work needed to be done to explore what adaptation might involve in practice.

To address the outstanding issues, the ENCA Climate Change Group convened an expert workshop 'Implementing adaptation in nature conservation in Europe' in Edinburgh in September 2011 to explore the opportunities and challenges of climate adaptation in nature conservation in Europe. The emphasis of the 2011 ENCA workshop was to increase our understanding how these climate adaptation principles can be put into action for different ecosystems, what this might involve in practice and how action should be best implemented. The 2011 workshop was intended as first step towards this (see section 4.1 for workshop structure. Sections 4.2-4.8 detail the information on different ecosystems). The workshop focussed on mountain and subartic ecosystems including peatland ecosystems, freshwater and riparian ecosystems, forest ecosystems and coastal ecosystems. For this report, we have put peatland ecosystems in a separate section. We have also included a short section on grassland ecosystems and urban ecosystems, as they are becoming increasingly important both for conservation of biological diversity and for the ecosystem services they provide to people. Section 4.9 provides an overview and summary of the general discussions. Climate adaptation for the conservation of biological diversity and natural capital will also ensure in many cases the continued delivery of ecosystem services and contribute to Ecosystem based Adaptation (EbA). We briefly provide an overview of key concepts in section 5, while a detailed review on ecosystem based Adaptation and Mitigation in the

German speaking countries has been commissioned by the Federal Agency of Conservation (BfN) to be published in summer in 2014 (Naumann *et al.* in press).

Two additional pieces of research work were done to complement the conclusions of the workshop. The first of these was a review focussing in depth on two aspects of adaptation management, namely increasing connectivity (section 6) and approaches to translocation or assisted migration (section 7), where species will not be able to move through the network without help. We reviewed the rationale, opportunities and risks for these approaches.These measures were listed as potential adaptation activities for almost all ecosystems considered in the Edinburgh workshop. Key adaptation principles and draft guidelines on dealing with the impact of climate change on the management of Natura 2000 sites have recently been published by Bouwma *et al.* (2012) on behalf of the European Commission and we therefore refer to these. A fundamental aim is to increase resilience within the site and within the wider network, and allow for species and ecosystems to adapt to climate change.

Second, we conducted a survey of climate adaptation planning and conservation measures in European conservation projects (section 8). Empirical studies of effects of adaptation management actions for biodiversity are currently quite scarce in the published literature. In a comprehensive review of recommendations for biodiversity management for adapting to changing climate, for example Heller & Zavaleta (2009) could only find five empirical studies on effects of adaptation actions out of 133 examined papers. The remaining published literature provided mainly theoretical consideration of principles, inferences from large scale observations, modelling approaches and small scale trials of actions, which mirrors our results of an intense literature review. We have therefore included selected case studies in the text, while their success has rarely been monitored or scientifically evaluated, yet. This is of course also due to the fact that climate change is a slow process and very often masked by other land use and socio-economic pressures. To help address this knowledge gap, and to broaden the geographic scope discussed at the Edinburgh workshop, we therefore conducted a survey of conservation projects across Europe with site managers, receiving responses from 72 projects from 16 European countries. This process was highly informative.

Finally, a second joint European Conference was held by the German Federal Agency for Nature Conservation (BfN) and the European Network of Heads of Nature Conservation Agencies (ENCA) on ‘Climate Change and Nature Conservation in Europe - an ecological, policy and economic perspective’ on 25. – 27. June 2013 in Bonn, Germany. This conference brought together experts from practice, policy and science across Europe to highlight and debate the importance of adapting to climate change in conservation from an ecological, policy and economic perspective, and showcase successful conservation partnerships across Europe. The conference was attended by 160 participants from 22 countries. Discussions at the conference in the plenum and in eight parallel interactive sessions (mainly focusing on ecosystem types) led to a series of recommendations for climate change-adapted nature conservation in Europe (Korn *et al.* 2014).

These were taken up in a follow-on workshop by the ENCA Climate Change Group and developed into a specific set of ENCA recommendations for putting adaptation principles into practice, see section 3.

2 Acknowledgements

We are extremely grateful to everyone who participated in the ENCA workshop 'Implementing adaptation in nature conservation in Europe' in Edinburgh in September 2011 and at the ENCA meeting following the 2013 conference in Bonn. All participants actively contributed to this report through discussions at the workshop, presenting and discussing case studies and commenting on the draft summary of conclusions.

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We are also grateful to all presenters and participants at the 2013 conference in Bonn for their active contributions and helping to make discussions during the conference stimulating and productive.

3 2013 ENCA Climate Change Group recommendations for putting adaptation principles into action

The following recommendations were developed by the ENCA Climate Change group at a follow-on workshop to the 2013 conference workshop session outcomes and plenary discussions at the joint ENCA/ BfN conference 'Climate Change and Nature Conservation in Europe – an ecological, policy and economic perspective' on 25.-27 June 2013 in Bonn, Germany (Korn *et al.* 2014). These recommendations build on the 2011 ENCA recommendations (Korn, Kraus & Stadler 2012) (App 11.1) and the discussions of the 2011 Edinburgh workshop, and focus on ways forward to put adaptation principles into action. They were welcomed by the ENCA network at its 13th plenary meeting in October 2013 in Bonn. The recommendations highlight four main points to enable to take significant steps towards implementation.

1. **Enhance communication and cross-sectoral collaboration for integrated adaptation management and planning. This should be considered as an ongoing process in order to reduce the risks of maladaptation and to address the time lag between research and implementation and the existing uncertainties**. Specific actions include:
   - Ensuring cross-sectoral and transboundary cooperation for the long term. Linking conservation managers, scientists, and decision makers from various disciplines and sectors into advising bodies to move towards coherent policy delivery and action.
   - Employing resources for forecasting and joint participatory spatial planning approaches (e.g. the Polyscape adaption scenario approach using Google Earth).
2. **Communicate the potential losses and gains from climate change and the multiple benefits of adaptation to increase the awareness and response of policy makers and the public**. Encourage joint action and acceptance of responsibility by:
   - Showcasing success stories as well as learning points from failures.
   - Promoting a meaningful interface and active knowledge exchange and collaboration between practitioners, scientists and policy makers (including cross-boundary collaboration). This can be achieved through encouraging engagement among multiple stakeholders, supporting interface communicators and facilitating networks.
   - Creating clear, simple indicators for the public (e.g. red list and vulnerability index).
   - Enhancing communication and awareness-raising of climate change impacts in nature conservation, risks and opportunities, and adaptation options through ecosystem-based solutions. One particularly important example is water (European Commission 2012): biodiversity strongly depends on healthy water systems and is influenced by availability, quality and temperature of water. Natural systems, forests and properly managed arable systems (e.g. organic farms) have the ability to store and retain water in the sub-soil; protecting and enhancing these areas can play a major role in supplying water (to both natural areas and for other land uses) in dry periods or retaining it in flooding events. This makes ecosystem-based adaptation an important tool in preserving both ecology and economy, and the multiple benefits of such approaches need to be communicated to decision-makers and the general public.
   - Highlighting the benefits people derive from nature and the synergies and trade-offs of management options for bidoiversity and human well-being by

linking to TEEB international and country studies (The Economics of Ecosystems and Biodiversity www.teebweb.org).

- o Conducting a European assessment of climate and ecosystem service change and adaptation options.

3. **Foster action: optimize the current investments into Green Infrastructure and Natura 2000 that deliver the ability to adjust to change (with a focus on enlarging, connecting and improving areas)**
   This can be achieved by:

   - o Setting clear priorities (what action is most important, and where).
   - o Fully integrating consideration of the potential effects of climate change into conservation site management, especially in Natura 2000 sites. Climate change adaptation may require adjustment of current management goals and practices, and ENCA will need to consider these align with the Habitats Directive.
   - o Applying the EU 'Guidelines on dealing with the impact of climate change on the management of Natura 2000' (Bouwma *et al.* 2012).
   - o Harnessing the opportunities provided by the generic requirement for all EU funds (including LIFE+), to have a significant percentage of ca 20% focused on climate change delivery including adaptation. Therefore ENCA might take on an advisory and coordinating role in fostering action on climate change, including ecosystem-based adaptation (EbA) and ecosystem-based mitigation (EbM), in LIFE+ bids through habitat restoration, enhancement and protection. This may concern especially habitats with carbon rich soils such as peatlands, and joining up initiatives across Europe.
   - o Reaching out to other cross-sectoral EU work programmes on climate mitigation and adaptation to include nature based solutions (as well as to avoid trade-offs with other mitigation options, e.g. through biofuel production)

4. **Monitor and increase understanding of change: promote long-term ecological research and monitoring across European ecosystems to assess impacts of climate change. Use demonstration sites and experimental approaches to assess effects of adaptive management, and encourage recording of change at conservation site level to enable learning and understanding of effects**.

   - o Targetting research to review and synthesise existing climate adaptation actions in conservation across different European countries (similar to the PEER review on national adaptation strategies (Swart *et al.* 2009)). This would help to improve our understanding of the factors that support or constrain adaptation and how ENCA could help address them. It is particularly important to consider the Mediterranean, which has been under-represented in past surveys and discussions. Joint research by ENCA agencies would help to address this.
   - o Investigating the role of micro-climate and heterogeneity in safeguarding existing conservation sites and contributing to conservation strategies.
   - o Realising consistent monitoring programmes across Europe.
   - o Engaging in the European Biodiversity Observation Network (EU BON www.eubon.eu), the Long-term Ecological Research Network (LTER www.lter-europe.net), Future Earth (www.futureearth.info) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES www.ipbes.net).
   - o Developing simple protocols for conservation managers to monitor change and engage in citizen science approaches to enhance data collection and increase the sense ownership local communities have for conservation areas.

4 ENCA Workshop on Adapting to climate change in nature conservation in norther and western Europe (Edinburgh 2011)

Climate change is already affecting Europe's ecosystems, and potentially severe effects on biodiversity and ecosystem function can be expected in the future (EEA 2012). This presents great challenges for nature conservation, which needs to take appropriate action to help the natural environment adapt despite uncertainty about the timing and magnitude of possible climatic changes and their consequences for complex natural systems.

A range of very good principles and overviews have been developed for adaptation in conservation (Hopkins *et al.* 2007; Smithers *et al.* 2008; Heller & Zavaleta 2009; Bouwma *et al.* 2012; Mosbrugger *et al.* 2012; Essl & Rabitsch 2013), and these are starting to become established in conservation thinking and planning. But there is now a clear need to go beyond these principles and explore what specific action might be required, and what the challenges and issues might be, in different places and for different ecosystems and species. An important aspect of this is to learn from action that is already taking place. Here, there is great potential to share information among the different European countries and to learn from each other's approaches and experiences.

To start to discuss and explore these issues, a workshop was held in September 2011 in Edinburgh by the ENCA Climate Change Group. The workshop brought together climate change adaptation experts from government, non-government and research organisations from a range of European countries.

The aims of the workshop were to:

- Share information from examples of adaptation in action, from conservation projects in a range of different ecosystems
- Discuss in detail some of the adaptation experiences, challenges and possible approaches and actions for specific ecosystem types and produce a set of conclusions on how adaptation can be put into practice

This part of the report summarises the conclusions of the workshop and later discussions by the participants. It is hoped that this will help to provide some insights into the different approaches to adaptation that could be taken, and how these might vary in different biogeographic areas.

4.1 Scope and structure of the workshop

The ENCA workshop discussed four broad ecosystem types found in many parts of Europe:

- mountain and subarctic ecosystems including peatland ecosystems,
- freshwater and riparian ecosystems,
- forest ecosystems and
- coastal ecosystems.

Much of the workshop was spent in discussion in groups, each group focusing throughout the day on one of the general ecosystem types above. These groups discussed a series of topics and specific questions within them:

- **Climate impacts**. Groups identified and discussed the range of consequences of climate change on 'their' ecosystem that had either been observed or were projected to occur. In identifying these impacts, we considered effects on individual species, on species interactions, and on ecosystem structure and processes. Impacts/ consequences that were, in the opinion and experience of participants, of greatest conservation concern were identified by scoring each impact as high, medium or low impact (based initially on scores from 1-5).

- **Setting adaptation objectives.** The groups discussed what adaptation goals might be appropriate for the ecosystem in question, given the impacts that had been identified. To structure this discussion, the following categories of goals were considered: maintaining current species populations and assemblages in the face of climate change; managing species movements and changes in assemblages; managing interactions between species; maintaining ecosystem structure and processes; reducing exposure to direct threats and extreme events; reducing anthropogenic pressures.

Following on from this, the groups discussed how these goals might need to be changed and modified in future. The groups also discussed the implications of focusing effort on individual species versus overall ecosystem structure and process. Finally, participants discussed how existing conservation projects they were aware of were approaching adaptation.

- **Adaptation actions.** Groups then discussed the specific management actions, and some of the policy decisions needed to support those actions, that would be required to achieve the adaptation goals that had been identified. Actions were identified at different spatial scales, from an individual conservation site up to national and European level, and at different points in time/under different levels of climate change (in three time categories: now, up to 2050/under 'moderate' climate change, past 2050/under extreme climate change).

- **Information and monitoring.** Groups discussed and recorded any obvious knowledge gaps relating to both future environmental changes and the effectiveness of different management actions, things that should be monitored, and any new management approaches that should be tested in line with an active adaptive management approach.

- **Barriers and opportunities**. Finally, most of the groups considered potential barriers to action (and opportunities that might facilitate action) arising from the following areas: public opinion and perception, inertia from past or current conservation approaches; conservation policy; funding, land use and resource constraints; the influence of other sectors; other issues including gaps in knowledge. These barriers were considered in relation to four aspects of adaptation: identifying appropriate goals; taking action; monitoring change; and testing new approaches and changing goals and actions.

The group discussions were supplemented by 16 short talks, and one poster, giving examples of practical conservation projects across north-west Europe that are planning or already carrying out action in response to climate change (see case study boxes and Appendix 11.2). Given the countries participants at the workshop came from (Scotland, England, Wales, Norway, Netherlands, Germany, Switzerland), the implicit focus of the workshop was on ecosystems and conservation issues in northern and western Europe.

The following sections summarise the workshop discussions for the different ecosystem types and reflect the assessments of the participants.

4.2 Mountain and sub-arctic ecosystems

Mountains and subarctic ecosystems are predicted to be particularly affected by climatic changes across Europe. Changes in temperature, altered snow and ice cover conditions as well as freeze-thaw cycles, such as unusual early spring events leading to episodic melting can disrupt biological dynamics of cold adapted species. This may lead to disturbed seasonal timing of reproduction and development. Warmer, drier summers may lead to moisture stress in plants, as well as influx of new competitors, predators, parasites and diseases (Callaghan *et al.* 2004).

Figure 1: Mountain range in Beinn Eighe National Nature Reserve, Scotland © John MacPherson/ Scottish Natural Heritage.

4.2.1 Climate impacts and conservation issues

Table 1: Climate impacts and conservation issues for mountain and sub-arctic ecostems

Changes and consequences	Level of concern for conserva-tion
Higher (winter) temperatures, loss of permafrost and permanent areas of ice and snow, as well as droughts in summer leading to changes in species composition and species loss - reduction in the available area for, and eventual loss of, specialist high altitude and high latitude species, especially snow bed communities Björk & Molau 2007)* - frost damage to plants (Inouye 2008)* - false 'spring events' and early hatching of insects with subsequent mortalities (Descimon *et al.* 2006)*	High
Higher temperatures, changing precipitation, snow cover and snow melt leading to changes in ecosystem functioning - Increase in flood events* (Beniston 2000) - changed flows of rivers in winter, spring and summer, incl. increased number and severity of water stress events - consequently leading to increased soil erosion, release of dissolved organic carbon and possibly heavy metals (especially in disturbed areas with damaged vegetation cover) - Melting of most glaciers (within next 10 years) - Increased decomposition in previously cold soils releasing nutrients and carbon	High/Medium
Range contractions and altitudinal and latitudinal distribution changes in cold-adapted species (Parmesan 2006; Chen *et al.* 2011)*. Data from the Alps and Norway show significant upward and latitudinal movement of some plant species, (e.g. Grabherr, Gottfried & Pauli 1994; Walther, Beißner & Burga 2005; Lenoir *et al.* 2008)*.	Medium
Range expansion: Expansion of competitor species from lower altitudes and latitudes negatively affecting threatened or endemic mountain/sub-arctic species (Callaghan *et al.* 2004, or see e.g. Arctic fox more threatened by competitor red fox, Post *et al.* 2009)*. This will lead to increasing diversity of species communities but reduced specialisation.*	Medium

Expansion of invasive non-native species (Walther *et al.* 2009)	Medium
Constraints on upward movement of species as a result of increased windspeed, leading to range contractions (Crabtree & Ellis 2010)	Medium
Change in avalanches as a result of increased temperatures (non-conclusive evidence in literature (Martin *et al.* 2001; Eckert, Baya & Deschatres 2010))	Medium
Possible increased snow cover in some places because of increased precipitation	Low
Expansion of pest and disease (e.g. tick population) uphill affecting mammal and bird populations (Gilbert 2010)*	Low

* Asterisk indicates changes that have already started to be observed

Figure 2: The cold-adapted Apollo butterfly (*Parnassius apollo*) has declined on plateaus in France below 850m over the last 40 years. Large increases in overwintering temperatures can lead to 'false spring' events in insects as seen in this butterfly (Descimon *et al.* 2006). (Photo © Guy Padfield)

4.2.2 Setting conservation objectives in a changing climate

Assisting current populations and assemblages to cope with change

When considering how to reduce climate pressures on current species and ecosystems, controlling for other factors in order to put species/systems in a 'good place' to deal with climate change can be lower in this type of environment because of a strong link between climate and species distributions (the reason that climate envelope models work particularly well in northern latitudes), and a relatively lower impact of non-climate factors (except perhaps nitrogen deposition) than in some other ecosystems. Nevertheless, some general aims can be identified:

- Protection of potential refugial areas (such as gorges or shaded slopes) and where relevant ensuring appropriate shelter/habitat heterogeneity through vegetation cover, to provide niches for species to persist in situ
- Keeping vegetation cover intact to reduce exposure to heat and storms at microhabitat level
- Achieving an appropriate level of habitat disturbance. Here, there is a potential tension between improving the status of existing systems by minimising disturbance but at the same time allowing some disturbance that might be essential to enable species to move

Facilitating and managing species movements

Many mountain and sub-arctic areas are quite contiguous relative to other ecosystems, and have the potential to support relatively large scale movements of species. The varied topography of mountain ecosystems also supports this, as a small degree of altitudinal movement has the same effect as a much larger distance of latitudinal movement (Chen *et al.* 2011).

- Restoring sufficiently large patches of vegetation and, where necessary for the dispersal requirements of particular species, connections between them, will be important
- Possibly establish habitat for species projected to move into an area and adoption of a more flexible approach to management of habitat in protected areas accordingly
- More international cooperation on species protection. Species are currently protected at the national level. This may need to change in order to promote better species conservation across borders (in some exceptional cases even translocation to different areas). Conservation managers may also need to think about preparing landscapes for new species.

However, mountain and sub-acrtic ecosystems also contain areas with clear limits to connectivity. High mountaintops can in effect be islands, with species with low dispersal ability left with 'nowhere to go' experiencing severe range contraction, particularly to escape invading competitors from lower altitudes. Likewise, cold sheltered areas and places such as frost hollows, supporting cold-adapted species and snow/ice ecosystems, might have limited potential to be 'joined up'. Translocation may become particularly relevant in these cases (see section 7). However, due to the topographic variability in alpine landscapes Scherrer & Körner (2011) suggest that all but the species depending on the very coldest micro-habitats may find thermally suitable 'escape' habitats within short distances, although there might be competition for these cooler places in a given site.

Managing interactions between species

While overall species movements are inevitable, and should be facilitated, there could be negative consequences

- Predator/herbivore control might be needed if changing assemblages introduce unacceptable pressures on species at lower trophic levels
- Maximising the quality and variety of habitat will provide a food resource for the maximum number of species, and reduce the risk of negative effects of competition
- Control diseases where necessary
- Reduce disturbance to make habitat less permeable to invasive species

Reducing exposure to direct physical threats and protecting against extreme events and reducing anthropogenic pressures

While some mountain and sub-arctic areas are under less pressure from humans than many other ecosystems in Europe, there are still important measures that could be taken to reduce anthropogenic pressures and so maximise the environment's ability to withstand and adapt to the impacts of climate change. This might be particularly the case in lower altitude and latitude areas of this biome, where the relative importance of land management as a driver of change in the landscape approaches the dominant role it has in lowland agricultural areas.

- Management of grazing to ensure appropriate numbers of herbivores in the ecosystem. The appropriate numbers of animals, and the timing of their presence, will vary from place to place depending on the particular vegetation communities and the particular social values and conservation goals in place. In some places this could mean greatly reducing current grazing levels; in others (such as Norway, where open upland meadows are important areas of biodiversity) maintaining or even increasing grazing to counteract a trend of abandonment of traditional farming

- Monitoring, and if necessary regulating the impact of tourism, to avoid the opportunities for greater human recreation leading to trampling damage of fragile alpine vegetation and loss of some of the species it supports
- The Edinburgh workshop focussed mainly on northern mountain ranges, including the Alps, while pressures for southern mountain ranges may include altitudinal shifts of agricultural land use pressure, as conditions in lowlands become less suitable. These need to be addressed.

It is clear that successful adaptation will require a balance, including management of tension between possibly competing goals. These could include for example enhancing stability and resilience to change in ecosystems and keeping assemblages stable and resilient while allowing a necessary level of disturbance and heterogeneity, or balancing adaptation for biodiversity with provision of other ecosystem services.

Changing goals over time

With advancing climatic change, there are two clear possible thresholds to be anticipated

- Ciritcal range contractions: species running out of available area on mountaintops, northern coastal areas, or 'squeezed' against arctic areas
- Species loss: Specialised cold-adapted communities lost from areas such as palsa mires and other permanently frozen ecosystems, if these exceed a maximum temperature and melt

It is not clear how to detect when a critical threshold has been reached in order to change objectives and management action. It will be important to put in place good adaptive management approaches in which monitoring and review is built into the management cycle, and to ensure that sites or species are 'given up on' only when it is clear that adaptation is no longer effective. Pearce-Higgins (2011) has suggested an approach for upland Scotland. A more flexible approach to conservation, more tolerant of changes and taking a wider geographical perspective, might be needed.

Translocation is seen as last resort and knowledge on longterm effects and best practice is scarce (see discussion section 7). Consideration should be given to the precautionary principle, while at times possibly early action may be required before populations are lost.

4.2.3 Adaptation actions

Table 2: Adaptation actions for mountain and sub-arctic ecostems

Individual site/reserve scale	
Actions to take now	Increase habitat quality on site, e.g. by increasing heterogeneity to allow for microrefugia (e.g.reduce grazing pressure in some places and increase grazing in others, as appropriate) Reduce other pressures, e.g. through predator control Review conservation plans to make sure they encompass potential climate change impacts
Additional actions in the longer term (to 2050 and beyond)	Translocation*: be aware of long-term genetic variability of populations and include variability in assisted migration programmes Ex-situ conservation* Managing future non-native invasive species and diseases* Plant trees to regulate microclimates to protect other species (not appropriate in those areas in which encroaching tree lines are seen as detrimental to conservation goals)**
Catchment / landscape scale	
Actions to take now	Raise awareness of climate change to stakeholders Develop regional plans for multiple conservation objectives delivered in the full suite of areas, rather than each site trying to do everything* Landscape scale management, e.g. stock management through appropriate grazing regimes or soil management in agricultural systems e.g. terracing
Additional actions in the longer term (to 2050 and beyond)	Allow disturbance in some areas to create recipient sites for incoming species** Increase resilience within site network by filling in gaps with ‘stepping stones’ and corridors* / Incentivise functional networks (through rural development programmes) Define localities suitable for target species in 2050** Allow for greater percentage of woodland on appropriate soils and where appropriate for conservation goals*
National/ European scale	
Actions to take now	Improve prioritisation and conservation listing across national borders. Develop international processes for deciding management targets at a continental (trans-border) scale** In selected areas, promote traditional management of important cultural landscapes to meet threats of abandonment Think big – coordinate policy efforts across sectors and pool funding
Additional actions in the longer term (to 2050 and beyond)	Potentially review habitat designations to accommodate change (i.e. when habitat is changing due to climatic influences, adress whether assigned FFH habitat type need to be changed to conserve a different set of species/habitat features)** Identify mountain ‘stepping stones’ on national and international scales to enhance connectivity** Secure large mountainous areas for species like reindeer, which would act as ‘umbrella species’ to enable the possibility for migration of other species

* Actions that would in at least some parts of Europe be slightly new (e.g. a change in the extent, or approach to, current management); ** actions that are entirely new

4.2.4 Information requirements

Table 3: Information requirements for mountain and sub-arctic ecostems

Information requirements regarding ecology, ecosystem function and about likely environmental change
Develop better indicators of ecosystem health. Develop better methods to detect critical slowing down and thresholds to be able to change management
Identify how species underpin ecosystem functions, and how to prioritise these functions in conservation management. Identify consequences of change at the ecosystem level
Foster effective downscaling of climate models to allow for fine-scale insights into potential range changes for protected area acquisitions
Identify which species and assemblages are most at risk and their dispersal ability
Identify keystone species and work in detail on their vulnerability to climate change
With increasing expansion of species, identify the extent to which competition is a problem for other species (i.e. should we prevent or encourage expansion)
Investigate potential influence of micro-climate to recreate refugia within sites
Assess potential and nature of societal developments to be expected to affect the alpine regions. Address cumulative effects of impacts on the alpine environment
Information requirements regarding the effectiveness of actions
Trial different adaptation options – empirical research underpinning effectiveness of options is very important
Use a modelling approach to up-scale adaptation options at landscape scale
Identify how different policies and regulations such as the Water Framework Directive or the Common Agricultural Policy can contribute to climate change adaptation and plan now for effective actions to be delivered on the ground
Explore strategies for assisted colonisation and ex-situ techniques e.g. propagule selection. At what point do we consider them to be ineffective and hence choose to change our approach?
Identify how development plans need to be constructed to include the concerns of biodiversity
Assess potential limits of adaptation action (see e.g. Pearce-Higgins *et al.* 2011)
Monitoring Needs
Establish effective baselines particularly for cryptic species, e.g. soil organsims, to help detect change
Monitor change and involve stakeholders in monitoring
Identify and monitor species that are critical for ecosystem functioning and ecosystem service delivery
Monitor species most at risk, southern-range margin populations and wintering populations of high-arctic breeders (i.e. migratory wildfowl and waders)

4.2.5 Barriers and opportunities

The greatest opportunity was seen in exchange of information and sharing good practice. There are still knowledge gaps in understanding of impacts of climate change on mountain and subarctic ecosystems, especially on the likelyhood of reaching thresholds and therefore the need for action. The group felt it was necessary to have honest discussions also about potential for failure of management actions to increase learning and avoid a blame culture. In general, communication of climate change adaptation to the general public is perceived as crucial to generate support for political action and proactive conservation management.

Box 1: Feasibility of translocation in montane environments: a lichen-focused field trial

Rob Brooker (James Hutton Institute)

Translocation has been widely discussed as a possible climate change adaptation option for biodiversity conservation. However, despite the discussion, empirical evidence is lacking as to its practicality and effectiveness. A major question - highlighted by an initial literature review (Brooker *et al.* 2011) - is whether it is possible to actually predict where suitable recipient sites will be at more than just a very coarse regional scale. An assisted migration trial is being run in the Cairngorms using the arctic-alpine lichen *Flavocetraria nivalis*. This joint project between the James Hutton Institute, Scottish Natural Heritage and the Royal Botanic Gardens Edinburgh, assesses whether we can develop approaches to predict suitable recipient sites for the species, both under the current climate and under future climate scenarios.

Figure 3: Assisted migration trial in the Cairngorms using the arctic-alpine lichen *Flavocetraria nivalis* (photos © David Genney, Scottish Natural Herritage / Rob Brooker, James Hutton Institute).

4.3 Peatland ecosystems

The Edinburgh workshop discussed peatland ecoystems in conjunction with mountain and sub-arctic ecosystems. For this report, results are reported in a separate section. As some issues overlapped, we refer to section 4.2 where appropriate.

Figure 4: Eroded blanket bog, Bleaklow © Aletta Bonn

Like mountain tops, many peatlands form some of the most near-natural habitats, as – due to their waterlogging and inaccessibilty - they are often considered of marginal economical value to agriculture, especially in uplands (Bonn *et al*. 2009). In lowland areas, however, they have largely been transformed by land use for agriculture, forestry and peat cutting coupled with amelioration and nutrient input through fertiliser and atmospheric deposition. Due to associated drainage they now contribute up to 25% of all greenhouse gas emissions from the European agricultural sector (Joosten, Tapio-Biström & Tol 2012). In a damaged state, they are particularly vulnerable to deterioration due to climate change and become themselves sources of greenhouse gas emissions (Essl *et al.* 2012), while near natural peatlands have been shown to survive phases of climatic warming well (Charman *et al.* 2012).

Conservation and restoration of peatlands can therefore form an efficient measure to adapt peatlands to climate change and to contribute to mitigation of climate change as highlighted in the ‘Aichi targets’ adopted by the Conference of the Parties to the UN Convention on Biological Diversity (CBD) at its tenth meeting, held in Nagoya/Japan in 2010 (CBD Decisions X/2 and X/33).

4.3.1 Climate impacts and conservation issues

Table 4: Climate impacts and conservation issues for peatland ecosystems

Changes and consequences	Level of concern for conservation
Higher temperatures and consequently lowered water table will enhance decomposition rates resulting in decreased stability of peatland functioning and biodiversity	High
Effects on ecosystem services due to desiccation of peatlands, particularly in already damaged peatlands, while less of a problem in healthy peatlands (Bonn *et al.* in press) - Reduction of peatland carbon store - Increased GHG emissions contributing to further amplification of climate change - Increase in rlease of peat coloured water (increase in dissolved organic carbon) - Increase in nutrient leaching - Loss of environmental archive in peat soils	High
Effects on species interaction - Increased potential for invasion by non-peatland species - Loss of stepping stone habitat or refugia for non-peatland specialists - Trophic level interaction: drought in spring and summer causing reductions in invertebrate prey species and/or asynchrony with predators, and consequent reduced breeding success	High/Medium

of avian predators* (Carroll *et al.* 2011)	
Loss of coastal peatlands because of sea level rise (e.g. in SE England)	Medium
Increasing spring rainfall decreasing breeding success of raptors and grouse in west Scotland	Medium
Upward/northward movement of increasing numbers of pests and diseases into areas previously unaffected. (e.g. the fungus *Phytophthora* on bilberry *Vaccinium myrtillus*)*	Medium
Increase in wildfire and increase in consequent damage without appropriate management (e.g. wildfires in Russia in abandoned peatlands, that have previously been drained for agricultural use, but now have no fire risk management anymore)	Medium

* Asterisk indicates changes that have already started to be observed

4.3.2 Setting conservation objectives in a changing climate

Assisting current populations and assemblages to cope with change by maintaining ecosystem structure and processes and reducing exposure to direct physical threats and protecting against extreme events

- Key to increasing resilience in peatlands will be the maintenance and restoration of hydrological processes to reduce risk of drought and its effects on species, erosion and carbon loss (Bonn *et al.* in press).

Facilitating and managing species movements

- Many peatland plant species are wind dispersed as shown for Sphagnum species, they are capable of long distance dispersal (Sundberg 2013). Establishment probably rather depends on environmental conditions and competition, and initial planting through propagules might be needed on heavily eroded sites. For small isolated fen sites and rare plants or invertebrates, species movement might be a problem and creating stepping stones may aid migration.
- Peatlands themselves may act as stepping stones for non-peatland specific species and are important for migratory birds

Managing interactions between species

- Manage invading competitor species by raising water tables and/ or enlargening sites.

Reducing anthropogenic pressures

- Onsite pressures: Better management of burning regimes, forestry and grazing practice as well as game management may form part of an adaptation strategy (see Pearce-Higgins *et al.* 2011) to minimise risk of erosion, loss of carbon and loss of species
- Minimise offsite threats: atmospheric nitrogen deposition, pollution and drainage effects from adjacent sites
- Sustainable integrated planning systems are needed to manage ecosystem services required from peatland areas (e.g. clean water provision, climate regulation, potentially renewable (wind) energy provision) without adverse affects on the environment
- Peatland restoration will improve the integrity of the hydrology and re-establish vegetation to reduce ongoing damage and increase resilience.

Changing goals over time

- While conservation currently focusses on the last remaining semi-natural sites, it will be worthwhile to consider an ecosystem based approach to climate mitigation for reducing significant CO_2 emissions from heavily degraded peatlands which are currently under agricultural or forestry land use through restoration.

- This could include finding new avenues for paludiculture on wet peat soils (www.paludiculture.com) and new finance schemes, e.g. through MoorFutures (www.moorfutures.de) or the UK Peatland carbon code (www.iucn-uk-peatlandprogramme.org/peatland-code/about)

Box 2: Palsa mires and reindeer: conservation challenges in northern Europe

Linda Dalen (Norwegian Directorate for Nature Management)

Palsa mires (mires with ice cores) are particularly vulnerable to climate change and at the same time vulnerable to other disturbing factors that can reduce the permafrost, such as damage from motorized vehicles and other human activities. Palsa mires are on the Norwegian red list for Nature types from 2011. Several of the palsa mires are also within nature reserves. Through the palsa mire project the mires are being monitored and efforts are being made to increase people's awareness of the vulnerability of this fragile ecosystem.

Norway is now the only country in Europe which still has remnants of the original wild reindeer population. Wild reindeer require large mountainous areas that are becoming smaller as a result of climate change causing the treeline to rise. These areas are also under pressure from other factors (e.g. roads, cabins, other infrastructure), and the conservation focus is to reduce the stress from these non-climate factors.

Figure 5: Palsa mires, characterized by mosaic complexes with areas of permanently frozen hummocks, peat areas without permanent frost and ponds, are particularly vulnerable to melting as a result of climate change. In Norway, it is thought that these mires in marginal range areas could be lost within decades (photo © Annika Hofgaard).

4.3.4 Adaptation actions

Table 5: Adaptation actions for peatland ecosystems

Individual site/reserve scale	
Actions to take now	Re-vegetate peat / promote erosion control* Ensure appropriate management regimes onsite and offsite
Additional actions in the longer term (to 2050 and beyond)	Develop paludiculture approaches on degraded agricultural peatland sites
Catchment / landscape scale	
Actions to take now	Manage hydrology - Blocking of drains, including spatial planning assessment of effectiveness - Manage water retention through land cover* Facilitate coordinated action across sectors and land holdings –incentivise cooperation, possibly pay for ecosystem services or use regulation*
Additional actions in the longer term (to 2050 and beyond)	Work with stakeholders towards long-term sustainable catchment management, realising biodiversity and ecosystem benefits from peatland
National/ European scale	
Actions to take now	Moratorium on development and biofuel production on peat
Additional actions in the longer term (to 2050 and beyond)	Develop proxies for peatland GHG emissions to include in national accounting and to include in possible voluntary carbon markets

* Actions that would in at least some parts of Europe be slightly new (e.g. a change in the extent, or approach to, current management); ** actions that are entirely new

4.3.5 Information Requirements

The group discussed information requirements together with those for mountain ecosystems; see above section 4.2.

Specific additional information requirements for peatlands include close monitoring of effects of land use change and climatic change on peatland water tables, vegetation and greenhouse gas emissions and developing proxies derived from these observations to assess and monitor change across Europe following the Greenhouse gas Emission Site Type (GEST) approach, a proxy for greenhouse gas emissions based on broad vegetation types and water level (Couwenberg *et al.* 2011). These could then be used to assess success of restoration and provide the basis for payments for ecosystem services, as trialled with the MoorFutures voluntary finance scheme in Germany (www.moorfutures.de/en). In addition, it will be useful to assess the level of resilience to climate change for peatlands outside suitable future climate envelopes (Clark *et al.* 2010) to survive climatic changes and maintain provision of habitat for some species and ecosystem services.

Box 3: Restoring peatlands for climate change adaptation and mitigation

Peatlands are hotspots for biodiversity and ecosystem services (Bonn, Rebane & Reid 2009, Bonn *et al.* in press). They are a priority ecosystem for action under international agreements dealing with climate change and biodiversity. They are vitally important in the global carbon cycle and UK greenhouse gas budgets, representing the single most important terrestrial carbon store in the UK. Blanket and raised bog peatlands cover around 9.5% of the UK land area and store at least 3.2 billion tonnes of carbon. A loss of only 5% of UK peatland carbon would equate to the total annual UK anthropogenic greenhouse gas emissions. Healthy peat bogs have a net long-term 'cooling' effect on the climate.

However, less than 20% of the UK's peatlands are undamaged, and even the best protected sites (under EU wildlife legislation) have suffered, with less than 50% in a favourable condition. When drained, peatlands waste away through oxidation, adding carbon dioxide to the atmosphere – then, they are a liability. Climate change and adverse management can exacerbate the effects of drainage, resulting in increased GHG emissions to the atmosphere, poorer water quality and potentially exacerbating costly flood events.

Nevertheless, much of the damage could still be reversed. Restoration is cost-effective in reducing emissions of carbon to the atmosphere, improving water quality (reducing the costs for drinking water treatment) and conserving biodiversity. Peatland restoration can also help with climate change mitigation and adaptation. There are several successful landscape scale restoration projects in the UK, for example blanket bog restoration in the Flow Country in Scotland, Lake Vyrnwy and Migneint in Wales, Exmoor, Dartmoor, Peak District and Pennines in England and restoration of lowland raised bogs in Cumbria, Lancashire, and Northern Ireland, using grip and gully blocking, bare peat re-vegetation and removal of afforested trees to enhance the delivery of biodiversity and ecosystem services and make the peatlands and their services more resilient to climate change.

The IUCN UK Peatland Programme (Bain *et al.* 2011) suggests a four pronged peatland strategy – this can be easily adapted to a general approach

1. Conserving peatlands in good condition, through management that maintains a favourable state, and preventing further damage to healthy peatlands (even the best protected peatland sites have suffered, with less than 50% in a favourable condition, so the first priority must be to prevent any further deterioration).
2. Restoring partially damaged peatlands through land-use changes and active habitat management to return them to a peat forming state with typical peatland vegetation and animal species (including blocking drainage ditches, altering livestock numbers or adjusting burning management).
3. Intervening to repair severely damaged peatlands through major operations, such as woodland removal, gully blocking and re-vegetating bare peat.
4. Communicating the contribution peatlands make to meeting environmental, economic and social goals – critically, to help combat climate change and to halt the loss of biodiversity.

Figure 6: Damaged blanket bog peatlands, such as in the photo on the left in the Peak District, UK, are a major source of greenhouse gas emissions and are susceptible to further erosion and loss of carbon as a consequence of climate change (Joosten, Tapio-Biström & Tol 2012). Restored peatlands (right) emit less greenhouse gases (Worrall *et al.* 2011) and may even actively sequester CO_2 from the atmosphere, and will be much more resilient to the effects of climate change. (photos: Blackhill before and after restoration © Moors for the Future)

4.3.6 Barriers and Opportunities

Major policy barriers to sustainable peatland management include CAP payments towards agricultural land use on peatlands, market incentives for biofuel production, and renewed interest by Baltic governments in using peat as a source of fuel. Cultural barriers in e.g. Ireland are the prolonged conflicts on peat cutting on blanket bogs. Opportunities are provided by the cost-effective option of using peatland restoration as an ecosystem based approach (EbA) to adaptation and mitigation of climate change by reducing emissions through rewetting (Bain *et al.* 2011). The latter can be realised if awareness can be raised with the general public and policy, and appropriate indicators, such as GEST, see above(Couwenberg *et al.* 2011), can be developed to measure change. National climate funds could be created to foster EbA approaches, and ways need to be found to incorporate restoration funding in CAP payments (second pillar).

4.4 Coastal ecosystems

Coastal ecosystems are expected to be particularly impacted by climate change, due to rising water temperatures, rising sea levels and increased acidification, as well as salinisation of coastal groundwater (IPCC 2013). This impacts on coastal regions, that not only host sensitive ecosystems but also harbour high human population densities, which presents a challenge to management.

Figure 7: The island of North Uist in the Outer Hebrides, Scotland, supports a complex system of saline, brackish and freshwater ecosystems, including rock basin lagoons © Stewart Angus

The implicit focus of this discussion group was on coastal ecosystems in Scotland, the Netherlands and England. The focus is on coasts but includes some marine changes that might affect coastal species. There is a lack of information on the Mediterranean coastal ecosystems, although they have been predicted to be heavily impacted by a changing climate (EEA 2012). There are currently major research projects in the CIRCLE-Med consortium on the way (Basilico, Mojaïsky & Imbard 2013).

4.4.1 Climate impacts and conservation issues

Table 6: Climate impacts and conservation issues for coastal ecosystems

Changes and consequences	Level of concern for conservation
Sea bird declines as a result of changes in sea temperature and prey populations* (Sandvik, Coulson & Sæther 2008)	High
Loss of freshwater coastal grazing marsh because of sea level rise	High
Acidification causing (Fabry *et al.* 2008)* - changes in balance of plankton communities - softening of shells	Medium
Sea level rise and increased storms leading to loss in coastal flood protection and coastal squeeze* (overview in Nicholls & de la Vega-Leinert 2008)	Medium
Salinity encroachment affecting coastal wetlands (already seen in areas such as north west Netherlands)* and groundwater, leading to loss of freshwater wetlands and their species if compensatory areas are not available	Medium
Coastal squeeze leading to - sand dune damage (depends on space for management) - loss of saltmarsh* and loss of mudflats and therefore of important bird breeding and feeding sites (Hughes 2004) - loss of semi-natural grassland on coastal fringe	Low
Higher sea surface temperatures leading to - more extensive algal blooms (Davis *et al.* 2009)* - increased pests and disease incidences (for discussion see Rowley et al 2014)*	Low

- changes in coastal marine ecosystems at lower trophic levels*	
Increasing salt spray causing change in distribution of sensitive plants*	Low
Increasing storms affecting sensitive species e.g. terns, shags	Low
Increased freshwater runoff events affecting in-shore communities. Possible local deaths of sensitive species or alternatively mitigation of sea level rise impact on lagoons	Low
Higher air temperatures leading to - increased fragility of dune systems (e.g. scrub invasion, further lowering water table) - risk of wildfire*	Low
Sea level rise preventing river discharge efficiency, affecting delta habitats	?
Changes in seasonality and range of variation at all [trophic] levels	?

* Asterisk indicates changes that have already started to be observed

Box 4: Opportunities to reduce the impacts of marine climate change on seabirds

Richard Luxmoore (National Trust for Scotland)

The seas around Scotland have already seen marked evidence of increasing temperatures, comparably far greater than those observed on land. These, in turn, have had a demonstrable impact on plankton communities. Seabirds, at the top of the marine food chain, potentially provide a powerful indicator of these changes. As they are long-lived and faithful to a relatively small number of discrete breeding colonies, they are particularly vulnerable to change. Few studies have been carried out on the impacts of climate change on seabirds but one exception is the Black-legged Kittiwake (Frederiksen *et al.* 2007). This species is declining throughout most of its range and, in the North Sea, this is associated with declining stocks of the main food source, sandeels which, in turn, are linked to rising sea temperatures. Sandeels have been the target of commercial fisheries and evidence points to these exacerbating the influence of declining sandeel stocks on kittiwakes. A similar situation has been reported in northern Norway, where the main food of kittiwakes is the capelin. Management of commercial fisheries therefore has the potential to offset the impact of climate change on seabirds.

Figure 8: A decline in the numbers of kittiwakes in Scotland and northern England appears to be linked to the effects of warming sea temperatures on their sand eel prey (Frederiksen *et al.* 2007) (photos: kittiwakes © Laurie Campbell (www.lauriecampbell.com), sandeels © Mark Thomas).

4.4.2 Setting conservation objectives in a changing climate

Assisting current populations and assemblages to cope with change by maintaining ecosystem structure and processes and reducing exposure to direct physical threats and protecting against extreme events

- Restore and maintain natural coastal processes.
- In some cases accept shifts in the ecosystem, e.g. water becoming more saline. This may require consideration of how individual sites relate to others to ensure sufficient compensatory areas if possible. Enable coastal roll-back.
- Increasing quantity and heterogeneity of habitats especially salt marsh, lagoons, shingle banks and mudflats
- Managing grazing regimes with flexible and adaptive management on key areas e.g. around sand dunes and cliff top maritime heaths

Facilitating and managing species movements

- Creation of new habitats to link, connect or act as stepping stones between existing habitats.
- Creation of new habitats to replace/complement vulnerable areas and so support breeding of key species; including identification and conservation of new areas likely to be receptor sites for species (e.g. if coastal processes move shingle banks along coast out of current conservation sites)
- Trans-location of species as last option– need to identify desirable sites

Managing interactions between species

The control of invasive species was seen as crucial, e.g. mink, rats or also sea blackthorn. Otherwise, it is important to recognise that the loss of prey species due to e.g. changes in sea surface temperatures, will impact on predators (Frederiksen *et al.* 2007).

Reducing anthropogenic pressures

- Promote precautionary ressource management in fisheries.
- Reduce non-climatic pressures, such as diffuse pollution, litter, eutrophication as well as human disturbance of sites, including inappropriate coastal land management and shore line development management.
- Consider land use change to revert reclaimed land, especially agricultural land, to coastal habitat
- Assess whether to resist or allow change on a site-by-site basis, while considering the relationship and ecological linkages between different sites

Changing goals over time

- Management may need to respond to obvious tipping points on the coast beyond which major physical changes will occur, e.g. inundation, peninsulas becoming islands. Sea level rise can be sudden and significant and management may need to accept loss (based on land value and population). In the mind of the public and politicians a key tipping point that triggers a demand for action might be a severe inundation leading to economic damage caused by storm and high tide combination added to poor sea defence management. This could lead to good or bad adaptation decisions, i.e. build a higher wall or employ managed realignment. Changing long-term aims may require a long lead in time and working with partners.
- There is a need to build in greater flexibility and 'no-regrets' strategies in coastal management. In the 1960s and 70s management used to stabilise sand dunes to protect the coast, now management needs to allow the coast to move to protect. This is in part due to better knowledge of sediment movements.

- Individual species also have physiological limits (e.g. water temperature for sand eels). This could lead to some sea birds disappearing. Then a review of Special Protection Areas (SPA) under the Birds Directive might be needed, e.g. to assess whether an area would need to be de-designated as tern colonies disappear as a result of erosion and sea level rise
- Objectives can only change if there is sufficient monitoring data. It is therefore important to monitor site objectives and links to climate change and build regular review periods into objectives e.g. every five years.
- In some cases action is needed before habitats or sites get too threatened. A possibilitiy is to use a 'limits of acceptable change' approach and to re-agree responses at key triggers.

4.4.3 Adaptation actions

Table 7: Adaptation actions for coastal ecosystems

Individual site/reserve scale	
Actions to take now	Develop climate change adaptation plans for sites based around management of habitats** Identify protected areas that need to be extended to allow for the movement of coastal habitats and start the necessary legal process for managed realignment** Incorporate indicator species reporting in the coastal ecological surveys (Scottish Natural Heritage is conducting this since 2000) Retain natural sediment functionality as determined through discussions among coastal specialists Precautionary management of prey fish stocks Create alternative nesting habitats e.g. new shingle banks in response to decrease in breeding areas. Reducing other non-climate pressures
Additional actions in the longer term (to 2050 and beyond)	Facilitate discussion on land use change and managed realignment in the future with local communities to adapt and allow the coast to change. People, however, rarely accept the level of change that can occur at the coast.
Catchment / landscape scale	
Actions to take now	More managed realignment* Encourage land managers to consider sustainable practices in regard to protecting soils and water Community awareness raising in at risk areas Select indicator species to monitor current and future changes at a regional scale*
Additional actions in the longer term (to 2050 and beyond)	Enable coastal roll back and encourage creation of new coastal wetlands* Identify sites for habitat creation to replace those which will be lost* Precautionary management of fisheries – especially of prey species*
National/ European scale	
Actions to take now	Select marine Special Protection Areas (SPAs) under the Birds Directive for sea bird feeding areas and design appropriate management measures Scottish Land Use Strategy translated into a regional indicative map of land use for the future** Integrate national biodiversity strategies and national adaptation strategies*
Additional actions in the longer term (to 2050 and beyond)	Re-visit and review designations of coastal protected areas* Consider ecosystem approaches in coastal protection plans*

* Actions that would in at least some parts of Europe be slightly new (e.g. a change in the extent, or approach to, current management); ** actions that are entirely new

4.4.4 Information requirements

Table 8: Information requirements for coastal ecosystems

Information requirements regarding ecology, ecosystem function and about likely environmental change
Understand the contribution of marine and coastal habitats to provision of ecosystem services better and the impact of climate change. Understand likely effects and location of sea level rise and coastal erosion, and whether changes to coastal habitats such as machair, salt marsh and lagoons are likely to happen suddenly or gradually.
Information requirements regarding the effectiveness of actions
What are the social and economic benefits of ecosystem based adaptation to climate change? When should action be taken to manage change? Is it better to anticipate change and 'manage' it or allow it to happen naturally? Management needs to know when a threshold has been breached.
Monitoring Needs
Enhanced monitoring on coastal change using remote sensing, such as LiDAR technique Include 'measuring' benefits for human adaptation in biodiversity adaptation project monitoring Ensure site managers are recording actions which have climate change adaptation components Increase frequency of seabird population monitoring to assess impacts of marine climate change. Use seabirds as an indicator and also study their feeding ecology. Enhance monitoring of change in plankton composition in response to environmental change (as plankton forms basis of marine food chains)

4.4.5 Barriers and Opportunities

A major barrier to coastal management identified is the opposition of individual land owners and the agricultural sector to managed realignment, as it is seen in conflict with maintaining food security. Conservation legislation may also act as a barrier, as designations center around key species rather than ecosystem functions. Opportunities for funding land use change to allow coastal re-alignment could be created through using rural development programme funds.

Box 5: Wildlife conservation and flood prevention on the Forth

Jim Densham (RSPB)

At the heart of central Scotland, the Inner Forth has a long history of industrial and agricultural use that has resulted in loss of valuable intertidal habitat over centuries. High tides, storm events and rising sea levels are more frequently combining to place the hard sea defences under pressure. The remaining mudflat and saltmarsh areas continue to be valuable for wildlife but these too are under pressure from development and from sea level rise.

RSPB Scotland has a vision for large-scale habitat creation across 2,000 ha of land within sight of the Forth in the Falkirk and Alloa area. It is centred on the coastal realignment and habitat creation work already underway at the RSPB's Skinflats nature reserve. The aim is to work in partnership with local councils, Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH) and land managers to create a network of new saltmarsh, mudflat and reedbed habitats. This will benefit wildlife, bring protection from coastal flooding, carbon storage in the saltmarsh and improved access and recreation.

Figure 9: Scotland's first managed realignment project at RSPB Nigg Bay reserve © RSPB

4.5 Freshwater and riparian ecosystems

Climate change will have impacts on rising water temperatures and alteration in stream flow regimes. Changed patterns in precipitation, extreme weather events and timing of snow melt will have direct and indirect effects on lake, riverine and riparian ecosystems (Adrian *et al.* 2009; Kernan, Battarbee & Moss 2010), possibly also including an increase in the intensity of flooding events. Intact and restored floodplains can also serve as important floodwater retention areas and thereby provide cost effective ecoystem-based adaptation to climate change.

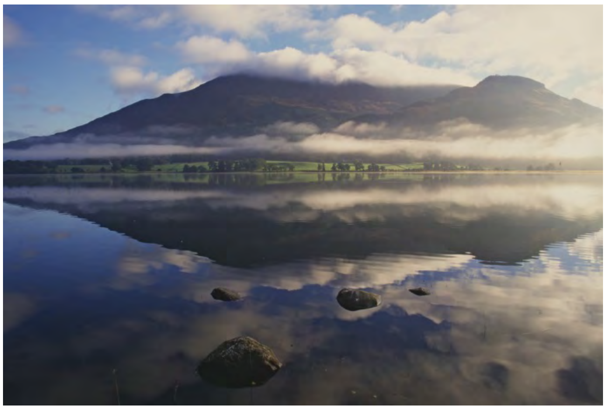

Figure 10: Bassenthwaite Lake National Nature Reserve, Cumbria © Natural England/Peter Wakely

4.5.1 Climate impacts and conservation issues

Table 9: Climate impacts and conservation issues for freshwater and riparian ecosystems

Changes and consequences	Level of concern for conservation
Population decline in cold water fish due to temperature rise, e.g. Arctic Charr Winfield *et al.* 2010)*, Paran or Salmon, e.g. in southern chalk rivers. Loss of cold-adapted stream macroinvertebrates (Domisch *et al.* 2013)*	High
Physical effects from storms and flood events on river bed and riverine species: increased washout of salmon or pearl mussel	High
Phenological change and phenological asynchrony across trophic levels (Thackeray *et al.* 2010)*	High
Algal blooms and eutrophication due to higher water temperatures and lower rainfall and lower flow rates with associated implications for public health and water filtering organisms (Note: While phenological advances in phytoplankton blooms may be associated with climate change (Winder & Schindler 2004), bloom timings reflect population dynamics that are also influenced by light and nutrient availability, grazing and sedimentation (Thackeray, Jones & Maberly 2008) and have – for the UK overall – not advanced statistically in the last 30 years (Thackeray *et al.* 2010).	High
Loss of freshwater coastal grazing marsh because of sea level rise	High
Decreased stability of peatlands in riparian wetlands due to higher temperatures and a lowered water table that will enhance decomposition rates (Reduction of the carbon store, increased flux of greenhouse gases, decreased nutrient retention,and increased potential for invasion by non-wetland species)	High
Increased rate of drawdown levels in spring and summer – especially in the south east UK affecting conditions for breeding birds and other taxa	Medium
Shift in species composition due to flow alteration (Döll & Zhang 2010)*: Flow dependent species declining relative to species less reliant on flow (e.g. roach) as flows decrease due to drought	Medium

Changes in communities in ephemeral headwater reaches of chalk streams	
Increased fragmentation of river habitats as a result of drought and low flows	Medium
Physico-chemical changes inducing biological changes with effects on productivity, phenology, trophic structure, species competition (for lakes see Adrian *et al.* 2009)* Increased windiness, decreased stability of lower water column – less stratification in lakes / or higher stability in stratification due to higher temperatures (Livingstone 2003)* Changes in chemical conditions - surface temperature, nutrient changes, alkalinity/acidity, carbon flux, dissolved organic carbon (DOC), light Morphological change - hydrological regime, retention time/flow, sediment transfer (Lane *et al.* 2007)*, shoreline complexity, habitat structure Increased frequency of saline inundation of coastal freshwater and brackish wetlands making conditions unsuitable for species associated with these habitats Increased risk of dissolving heavy metals or other toxic substances from contaminated alluvial sites due to flooding events	Medium
Increased risk of spread of invasive non-native species (Rahel & Olden 2008)*	Medium
Effects due to adaptation of other sectors, e.g. agriculture or energy or change in personal human consumption of water during heat stress, may lead to higher water consumption (e.g. irrigation, cooling water, showers) that may affect water levels in rivers and ground water	Medium
Destabilisation of riparian sites due to changing water levels/flood events/storms or water drawdown Local displacement or loss of species associated with banks and alluvial sites (e.g. loss of water vole populations with increased incident of bank erosion/wash out. Loss of available nest sites for wading birds) Disturbance of carr woodland as a result of storms Increased interaction between floodplains and rivers (overall positive but might increase runoff into rivers) Colonisation of riparian wetlands by trees or reeds	Low
Temporal instability within lakes and rivers: More pulses in the system may lead to algal blooms then flushes	Low
Increased variability of river habitat	Low

* Asterisk indicates changes that have already started to be observed

4.5.2 Setting conservation objectives in a changing climate

Assisting current populations and assemblages to cope with change by maintaining ecosystem structure and processes and reducing exposure to direct physical threats and protecting against extreme events

- Support existing populations and current species assemblages by maintaining current conservation objectives and actions and setting objectives for future, identify similarities, tweak and review objectives
- Enhance systems ‘naturalness’ to increase resilience. Restore natural processes, while these may need some ‘engineering’. The concept of naturalness may, however, be difficult to achieve in modified landscapes created by anthropogenic intervention, and may not always be applicable
- Focus on resilient, functioning wetland systems. Manage hydrological regime, with emphasis on water quality and quantity as well as hydrological heterogeneity, also in morphology

- Manage for multiple benefits: choose habitats and mosaics which interact. For example deep reedbeds were dug in the Great Fen, UK, dig deeper reedbeds that can act as water storage for other parts of the system.

Facilitating and managing species movements

- Choose to conserve and enhance species with broader functional benefits e.g. beavers in northern Europe
- Manage invasive non-native species e.g. Signal Crayfish
- Use translocation as a last option – e.g. Powan (*Coregonus lavaretus*) (Etheridge et al. 2010), see also section 7

Managing interactions between species

- Accommodate coexistence of existing and new species by maintaining or adapting ecosystem structure and processes
- Manage for greater connectivity. However, this may not be possible for all species, e.g. for Arctic charr, or appropriate and desirable everywhere, e.g. to avoid movement of invasive non-native species

Reducing anthropogenic pressures

Freshwaters are strongly influenced by anthorpogenic activities in the wider landscape which are exacerbated by climate change (Lane *et al.* 2007; Adrian *et al.* 2009; Clarke 2009) Managing anthropogenic factors is therefore key for freshwater systems to increase resilience to climate change

- Manage at larger scales, i.e. landscape and catchment scale
- Reduce nutrient input from catchment as a no-regret option
- Ensure drought orders and appropriate abstraction to protect water resources. This may require regulation
- Remove physical structures
- Public pressure may insist to maintain (current) iconic species; then conservation should aim to promote other benefits alongside the conservation of iconic species e.g. Bittern

The group suggested that more work is needed on Wetland Visions and landscape wetland strategies (see e.g. www.wetlandvision.org.uk and local wetland visions listed here). In going beyond general principles and setting specific adaptation targets for fresh water, conservation needs to engage in multi-benefit initiatives to be addressed at bigger catchment scales.

Changing goals over time

Management needs to take into account when tipping points have been reached or exceeded. Tipping points in freshwater systems could occur if water levels fall below a minimum threshold for a critical period of time, if water pollution exceeds critical levels (e.g. eutrophication of lakes through release of nutrients accumulated in sediments or increased run-off due to storm events triggered by a changing climate), or as a result of saline intrusion due to sea level rise.

The group suggested to follow the RSPB approach of habitat management, that combines a 25 year management plan with annual management plan actions. A 5 year review of objectives reports on progress against targets, that is backed up by monitoring data, photos, habitat quality measures, statutory condition assessments and site audits. Methods for implementing the management plan must be practical and management changes must be permitted to adjust direction. Changes to site objectives have included lowering of targets or for targets to accommodate variability, rather than requiring a target to be met every year.

They align the management plan to the processes on sites, while the 25 year vision still holds.

4.5.3 Adaptation actions

Table 10: Adaptation actions for freshwater and riparian ecosystems

Individual site/reserve scale	
Actions to take now	Increase site resilience - increase size of existing wetlands to support larger populations and to minimise impact of disturbance - ensure long-term water supply (e.g. block artificial drainage) - Increase heterogeneity, where not in conflict with conservation interest Review site characteristics (see also information needs below) - functional site characteristics and likely changes - factors limiting site resilience Create refuge sites - new freshwater wetlands to replace coastal and brackish wetlands that will be lost through sea level rise - translocation of (only) key species that are particularly vulnerable (see section 7)
Additional actions in the longer term (to 2050 and beyond)	Monitor effects of climate change on - hydrological regime - biological diversity Restore natural morphology of river channels to make them less sensitive to changes in flow* Do nothing - allow wetlands to change as climate alters Translocate species into future climate space (see section 7)**
Catchment / landscape scale	
Actions to take now	Restore connectivity along rivers with floodplains (see section 6) Reduce external pressures, such as diffuse pollution and minimise impacts of eutrophication
Additional actions in the longer term (to 2050 and beyond)	Include areas of water storage (e.g. reed beds) in large scale restoration to hold winter water for summer use (e.g. Great Fen, UK) Reduce pollution by effective incentives Create connectivity between protected areas to allow species migration Ensure long-term funding for research and management
National/ European scale	
Actions to take now	Review information on distribution and ecological requirements of species and habitats
Additional actions in the longer term (to 2050 and beyond)	Recognise future suitable climate envelopes for species and adapt management accordingly* Focus conservation on least vulnerable areas and accept change in vulnerable areas Improve biosecurity between sites (e.g. reduce effects of zebra mussels, killer shrimp) Site new housing in regions that do not or will not experience water-shortage to reduce future abstraction pressure

* Actions that would in at least some parts of Europe be slightly new (e.g. a change in the extent, or approach to, current management); ** actions that are entirely new

4.5.4 Information requirements

Table 11: Information requirements for freshwater and riparian ecosystems

Information requirements regarding ecology, ecosystem function and about likely environmental change
Need for long term data sets across taxa to assess effects of environmental change. The maintenance of existing longterm datasets is crucial (e.g. the Environmental Change Network or the Acid Water Monitoring Network for the UK, or the European Biodiversity Observation Network (EU BON www.eubon.eu) or the European Long-term Ecological Research Network (LTER-Europe www.lter-europe.net)
Identify future societal demands on wetlands and likelyhood of socio-ecological tipping points
Information requirements regarding the effectiveness of actions
Re-assessment of water abstraction rules is needed for different rivers to allow for climate change
Research is needed to evaluate whether it would be useful to move protected areas or create new areas to mirror climate envelopes?
Evidence is needed whether upstream grip blocking reduces flooding events downstream, and in which spatio-temporal context.
Across all spatial scales learning on adaptation should be fostered through dissemination of best practice and planning case studies.
Monitoring Needs
Storing and exchanging data will be crucial to inform adaptive management on site and across sites.
Indicators and proxies of change are needed to determine the extent of adaptation necessary.
Identification and inclusion of local knowledge to involve local communities and to foster more coherent decision making for conservation and adaption to climate change (see e.g. TweedForum www.tweedforum.org).

4.5.5 Barriers and Opportunities

As a key barrier as well as an opportunity to action the group identified different language and knowledge systems, that different sectors and communities use to communicate concepts of freshwater ecosystem management. These concepts and different understandings need to be understood and used positively to work towards conservation and ecosystem based adaptation to climate change (see section 5). Here, the Water Framework Directive objective to reach good ecological status in water bodies may help to align across sectors. Water abstraction licences can also create a barrier to sustained management of the hydrological regime of conservation sites. Current policy barriers also include the fact that current approaches to river management in many areas are very focussed on ‘engineered’ solutions to climate change adaptation. Current management focusses rather on resistance to a more ‘natural’ approach to design of river channels. Floodplain restoration and dyke relocation can serve as cost-effective ecosystem based adaptation measure to mitigate and alleviate effects of flooding events. At the river Elbe, for example, the economic costs and benefits of flood control programs in the form of dike relocations and renaturation of wetlands were evaluated as part of a research project (Grossmann, Hartje & Meyerhoff 2010; Grossmann 2012). The various benefits of wetlands - such as flood control, filtering of pollutants, habitat for plants and animals (biodiversity) - were economically estimated to have an annual benefit of 1.2 billion euros. The estimated cost-benefit ratio of 3:1 of dyke relocation versus traditional flood water management (business as usual) shows that such an investment is economically efficient when all ecosystem services are considered.

Box 6: Creating natural climate buffers in the Netherlands

Robert Munroe (BirdLife International)

According to the Dutch Delta Commission, climate change will cause much greater peak river flows in winter and more frequent droughts during summers across the country. To counter these potential impacts, Vogelbescherming Nederland, VbN, (BirdLife in the Netherlands) is working with a consortium of organisations to promote 'natural climate buffers' such as developing and restoring river overflow areas and reed marshes in alluvial plains to allow water to be retained in the hinterland when there is flooding rather than overburdening the river, and, when there are dry spells, to help maintain groundwater levels. VbN are working with ARK Nature, Waterschap Rivierenland (Water Board Rivierenland), Staatsbosbeheer (National Forest Service) and private landowners, to put such a climate buffer into practice at the Ooijpolder Nature Reserve (within the Gelderse Poort Important Bird Area) on the River Waal where they are working to expand the water holding capacity of marshland areas within the perimeters of the associated dike. Natural climate buffers will develop a succession of wetlands, marshy grasslands and riparian forests that, as well as providing benefits for human climate change adaptation, will contribute to the Dutch National Ecological Network of nature reserves and natural areas connected by corridors (to be completed in 2018) that should have benefits in terms of making the landscape more permeable to species as they track their changing climate space.

Figure 11: Brochure cover of the six collaborative projects on natural climate buffers in the Netherlands as part of the HIER programme, a joint initiative of 40 charity organisations.

4.6 Forest and woodland ecosystems

Forests and woodland ecosystems cover a large area of Europe with a wide variety of habitat types that will be affected in different ways by climate change (Milad *et al.* 2011). As woodlands actively sequester carbon, woodland management also provides a major ecoystem based mitigation measure.

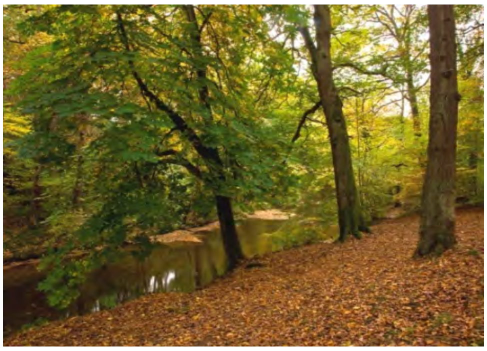

Figure 12: Beech trees in Plessey Woods, Northumberland, England © Natural England/Graeme Peacock

4.6.1 Climate impacts and conservation issues

Table 12: Climate impacts and conservation issues for forest and woodland ecosystems

Changes and consequences	Level of concern for conservation
Phenological changes and decoupling of trophic interactions (especially earlier spring phenology such as flowering and bird breeding)(Walther 2010)*	High
Spread of invasive non-native species (incl. facilitated establishment of ornamental species)*	Medium
Increased soil borne and other diseases (Brasier *et al.* 2004)* as well as pest species affecting tree species (Seidl *et al.* 2008)*	Medium
Increasing drought events leading to changes in canopy structure - less high forest - changes in light environment and ground flora species community	Medium
Species range changes, both latitudinal and altitudinal*; Rise in upper timber line (Gehrig-Fasel, Guisan & Zimmermann 2007)*	Medium
Loss of drought sensitive species (Allen *et al.* 2010), increase in drought resistent species (Lexer *et al.* 2002)*	Medium
Failure to regenerate – chilling requirements of trees not met climate is warming	Medium
Increased risk of wildfire (Malevsky-Malevich *et al.* 2008)*	Medium
Loss of bog diversity in wet woodlands due to drying	Medium
Increase in CO_2 concentration could increase tree growth in most of Europe if other factors not limiting / reduced growth in southern Europe due to heat and water stress (for discussion see Cole *et al.* 2010; Dawes *et al.* 2011; Granda *et al.* 2014)*	Low
Increased risk of windthrow (Klaus *et al*. 2011)*	Low
Changing plant assemblage composition and non-analogue assemblages (as a result of range shifts (Walther 2010)*	Low

* Asterisk indicates changes that have already started to be observed

The increase in vector borne human diseases (e.g. Lyme disease) is often associated with high levels of conservation concern. However, there seems to be little hard evidence, that the rise in tick-borne disease is linked to climate change (Randolph 2004). Other factors such as change in deer abundance or habitat structure, e.g. higher fragmentation in forests, together with human behaviour determined by socio-economic conditions in Europe might have led to this rise (Randolph 2010).

A comprehensive review of consequences and challenges of a changing climate for central European forest ecosystems and nature conservation is provided by Milad *et al.* (2011), and Millar, Stephenson & Stephens (2007), Forestry Commission (2011) and Schaich & Milad (2013) discuss forest management startegies in the face of uncertainty.

4.6.2 Setting conservation objectives in a changing climate

Assisting current populations and assemblages to cope with change by maintaining ecosystem structure and processes and reducing exposure to direct physical threats and protecting against extreme events

- Woodland management to improve structure and diversity
- Increase species diversity where opportunities exist and increase and protect habitat heterogeneity. Accordingly, avoid over-grazing by herbivores, simplifying forest structure and reducing available niches
- Create larger woodlands both in protected areas and outside designated areas
- Promote continuous cover forestry
- Ensure forest regeneration
- Improve monitoring capacity to detect change

Facilitating and managing species movements

- Establish new planting, including enrichment planting of native ground flora
- Enhance networks
  - employ integrated habitat network models to assess mosaic of habitats across landscapes to make them more permeable to species
  - consider threat by invasive species when proposing to link areas and sites .
  - use agri-environment schemes and Water Framework Directive catchment funding to finance network creation
- Translocation: there seems acceptance for some tree species translocation, but it may be more difficult to achieve assisted migration for other species, such as mammals (e.g. Iberian lynx)

Managing interactions between species

- Control competitors
  - herbivores: deer and squirrels
  - non-native invasive species
  - tree disease

Reducing anthropogenic pressures

- Reduce or remove offsite pressures such as air pollution
- Avoid fragmentation of large woodland habitats
- Manage competing land use pressures, e.g. for forestry for timber, biofuel, recreation, carbon storage and sequestration within woodlands / Promote a more balanced decision making through valuing biodiversity and ecosystem services (TEEB 2010)
- Promote adaptive fire management planning and provide ressources for fire management, especially in the Mediterranean

- Foster resilience through
  - multi-storey woodlands
  - more drought resistant species or varieties (here the debate is ongoing whether to consider genetic diversity of native species or to choose closely related species from Southern Europe rather than planting douglas fir, which is native to North America)
- Foster better governance and protection

Changing goals over time

Environmental ‘tipping points’ in forests are most likely to be caused by extreme events such as droughts, fires and storms causing major structural changes. However, some of these may be natural processes, that have been suppressed through management and may now be exacerbated due to previous build-up of biomass.

Changing objectives are likely to reflect social objectives as much as scientific reasoning. There is a need for debate about what society and conservation wants from nature, and to what extent and in which direction change can be accepted. Important for this debate is to involve all relevant stakeholders, who use or benefit from forest ecosystems.

Obverall there is a need to put changing goals into action, which may challenge existing practices. One workshop participant framed the discrepancy between thinking and action in the following way: ‘Overall [in Scotland], climate change is a consideration in woodland management to a certain extent. Many organisations and policies talk about adaptation to climate change and some of the issues listed above, for example connectivity and appropriate species to use, but on the ground delivery is different. Many of the delivery agencies are yet to convert to this ‘new way of thinking’ as a matter of course and still do things the way they always have’.

4.6.3 Adaptation actions

Table 13: Adaptation actions for forest and woodland ecosystems

Individual site/reserve scale	
Actions to take now	Extend habitat / reserve areas Management of existing woodland to increase habitat quality and population stability, e.g. - blocking drainage to retain water in wet woodlands - stand diversification (many woodland creation and management projects within Central Scotland include options for stand species and age diversification e.g. Cetral Scotland Forest (CSFT www.csft.org.uk) , Woodland Trust and Forestry Commission Scotland) Reduce other pressures, e.g. control herbivory (deer and squirrel management) or fire danger Allow for large scale natural succession areas without human intervention, see e.g. National Park Harz or Bavarian Forest National Park in Germany Input review of agri-environment schemes and rural development programmes Understand relationship between biodiversity and ecosystem services – compatibility of policy ambitions
Additional actions in the longer term (to 2050 and beyond)	Ex-situ conservation Assisted translocations as emergency measure** Allow for change: allow new forests to emerge, and allow formerly forested habitats to change*
Catchment / landscape scale	
Actions to take now	Establish large area forests* More and better managed forests (note however the need for more forest varies considerably among different regions of Europe, and the definition of ‘better management’ probably also differs.) Development of habitat network opportunity areas* Connecting woodland fragments as promoted by e.g. local biodiversity action plan (LBAP) targets for woodlands or River Basin Management Plan projects. A range of large-scale

	projects are already purchasing land or managing land between existing woodland areas Integration of river basin management planning (RBMP) and ecological network principles to identify riparian woodland opportunities for flood management/alleviation*
Additional actions in the longer term (to 2050 and beyond)	Establish large area forests to buffer offsite threats* Foster national and international ecological networks through joint planning of stepping stones and corridors Monitor impacts of translocation**
Actions to take now	Adapt forest land planning and management to include ecosystem based climate change adaptation and mitigation (section 5) Internationally concerted tree disease management Discuss the social purposes of conservation Understand relationship between biodiversity and ecosystem services at the national and international scale and compatibility of policy ambitions
Additional actions in the longer term (to 2050 and beyond)	One option is to plant exotic provenance species, adapted to drought and warmer climates* (this is already happening with douglas fir or western red cedar trees); another option and preferable for nature conservation is to foster more genetic diversity of native species at site or landscape level) Plan ex-situ choices Adapt European policies to foster more coherent policy making

* Actions that would in at least some parts of Europe be slightly new (e.g. a change in the extent, or approach to, current management); ** actions that are entirely new

Box 7: Adaptation in practice: the Climate Change Action Plan for the Public Forest Estate in England

Mark Broadmeadow (Forestry Commission)

The Forestry Commission manages 258,000 hectares of land, 205,000 ha of which is woodland. An assessment of climate risk to the current tree species distribution across the estate indicates that under a High emissions scenario and in the absence of adaptation, 24% of stands (including both native woodland and plantations of introduced species) would be deemed as unsuitable for commercial timber production by the 2050s (compared to 9% now), rising to 63% by the 2080s. This would equate to a 35% decline in productivity by the 2080s, although this statistic hides significant regional variation with more serious declines predicted for Districts in the south and east, and an increase in productivity in the north and west.

To address these climate risks, the Climate Change Action Plan details measures to diversify species, utilise genetic variability (i.e. provenance) to extend the productive range of the existing range of species and adopt alternative management systems. It also outlines measures to address other aspects of forestry practice and to respond to likely impacts on forest infrastructure. The plan aims to ensure that the Forestry Commission's estate develops sufficient adaptive capacity to maintain UK Woodland Assurance Standard certification and continue to comply with the UK Forestry Standard and its Forest and Climate Change Guidelines (Forestry Commission 2011).

Figure 13: Continuous cover forestry, an 'alternative' management system © Forestry Commission

4.6.4 Information requirements

Table 14: Information requirements for forest and woodland ecosystems

Information requirements regarding ecology, ecosystem function and about likely environmental change
Understanding how connectivity should be measured in terms of species, taxa and functional groups / Identify strengths and weaknesses of connectivity to prioritise action– what, where and when?
Identify how and when ecosystems slow down or cease to function (define functioning more clearly)
Understand how forest soil, fauna and flora change under climate change within different management regimes
Identify novel species assemblages associated with non-native tree species
Information requirements regarding the effectiveness of actions
Understand trade offs between conserving biodiversity and conserving ecosystem services
Identify how woodland species occurrence and abundance change under traditional intensive management (e.g. coppiced, pollarded) and under no interventions
Monitoring Needs
Monitor levels of connectivity and biodiversity indicators to assess whether connectivity actually increases biodiversity
Develop green mapping GIS techniques to spatially map priority areas to expand the Green Network for people and wildlife and identify coincidence with opportunity areas for urban or industrial development (see e.g. Glasgow Clyde Valley Green Network Partnership www.gcvgreennetwork.gov.uk/opportunities-mapping.html)

4.6.5 Barriers and Opportunities

The group thought that the general public may often equate woodlands with dull, dense plantations and it can be difficult to sell the idea of woodland landscape mosaics to landowners, funders and policy makers. Due to lack of or difficult access to historical information, this public perception may persist, and there may be a reluctance to accept or promote change. Woodland managers may also not be informed about the type of data needed to monitor and recognise change, although this will vary between countries, regions and sites. A recent barrier to action might be the renewed interest in wood production for biofuel and a balance needs to be found.

As often, it can be difficult to receive funding for climate adaptation. While large projects that can apply for LIFE funding, for example, have to be innovative, smaller projects are needed to trial and test new approaches and may not attract the level of funding needed.

Woodlands can contribute to ecosystem based mitigation and adaptation, especially with new planting, and thereby provide synergies to climate politics. However, also conflicts can arise between conservation and climate politics (Wüstemann *et al.* 2014), when the strive for climate mitigation and increase in renewable energy use leads to increased forest management for wood products (timber as substitution for other high energy intensive building material) and energetic use (timber /biofuel). Also for some forest managers climate adaptation of forests may include the promotion of risk avoidance strategies, e.g. through shorter crop rotations or the planting of heat resistant species, such as Douglas fir, to avoid early crop failure through anticipated increased disease or wildfire incidences. This may be in conflict with conservation goals. With regards to climate regulation capacities of woodlands, recent evidence seems to suggest – at least for German forests – that the type of forest management does not affect this significantly, as carbon can either be stored within the woodland in tree, litter and root biomass as well as soils, or in long-lasting wood products derived from forests (Rueter *et al.* 2011). Therefore, the debate should rather focus on biodiversity and other ecosystem services, such as provision of recreation opportunities or water retention, when discussing management strategies. This may be very different for woodlands in other countries, e.g. Mediterranean forests.

It can be difficult to engage people who don't 'like' woodland. Woodlands, however, may be one of the ecosystem types that people value most and are willing to pay for biodiversity conservation and as places for recreation, as shown in a recent Finish study amongst others (Elsasser *et al.* 2009; Tyrväinen, Mäntymaa & Ovaskainen 2013). In Germany, the national biodiversity strategy aims to set aside 5% of all national woodlands for natural development, which may then also create refugia for species in a changing climate. Public understanding and expectations of woodlands evolve, sometimes quite fast, and forests may be highly valued as public spaces (e.g. see public campaign in England against forest sell-offs in 2010).

4.7 Grassland ecosystems

Grassland ecosystems were not explicitly discussed at the 2011 Edinburgh workshop and therefore this section mainly relates to discussions at the 2013 Bonn conference and includes text from the conference proceedings (Korn *et al.* 2014).

Figure 14: Hay meadows in flower on Lower Derwent National Nature Reserve © Natural England/ Peter Roworth

4.7.1 Climate impacts and conservation issues

Grassland ecosystems in Europe cover an extremely broad range of land use, environmental and climatic gradients. Accordingly, current and future changes in biodiversity and functionality of grasslands are a combined result of land use and climatic change. More than for any other ecosystem apart from urban ecosystems, land use and land use change have a prevailing effect on grassland biodiversity, so that climatic effects may be less evident or more masked than in other habitats.

Overall, intensification and abandonment have already strongly reduced the extent of high nature value (HNV) grassland. While in the Alps and the uplands abandonment of economically marginal grasslands has led to natural succession (Gehrig-Fasel, Guisan & Zimmermann 2007) and loss of species rich grassland, the lowland grasslands are threatened by conversion to arable land, especially for maize crops as fodder for cattle, that are now raised indoors, or for biofuel. The discontinuation of EU milk quota in 2015, might enhance loss of grassland in Europe (Essl & Rabitsch 2013). In addition, the implementation of EU policy targets on bio-energy production over the next ten years are likely to increase the impact on European grasslands conversion (EEA 2010).

When grasslands are converted to other land use types, the level of organic matter and organisms in soil, and their CO_2 sequestration and storage capacity generally decreases. This is particularly relevant for permanent grasslands on high organic soils such as pastures (European Commission 2010), and adds to additional greenhouse gas emissions.

Elevated CO_2 concentrations affect the plant species composition of temperate grasslands, possibly through a decline in the relative abundance of grasses (Soussana & Lüscher 2007). In addition, the sensitivity of grassland ecosystems to low levels of precipitation tends to be reduced, but this induces progressive nitrogen (N) limitations on plant growth (Soussana & Lüscher 2007).

Changes in seasonality of production are likely consequences of climate change (Soussana & Duru 2007). Precipitation rates are expected to change across Europe with strong regional variation. Along with moderately rising temperatures, increased precipitation may lead in some areas to a prolonged growing season (EEA 2012). In other areas, however, decreased precipitation will lead to increased water stress. Coupled with porjected rise in extreme temperature events resulting in heat waves and drought, such as in the hot-dry summer of

2003, may lead to significant loss in productivity (e.g. loss of 20% yield loss in Germany (Osterburg *et al.* 2013)).

Warming may also alter flowering phenology and thereby decouple plant-pollinator interactions (Schweiger *et al.* 2010) and affect food web linkages (Schweiger *et al.* 2008; Schweiger *et al.* 2012). Extreme weather events, such as severe drought as well as heavy rain, are also expected to alter flower phenology (Jentsch *et al.* 2009).

In addition, linked to human responses to climate change, grasslands may be impacted by significantly reduced soil water availability due to freshwater and groundwater abstraction because of increased water requirements for irrigation of agricultural crops to maintain maximum crop yields as well as for other human consumption in industries and domestic use (IPCC 2014).

4.7.2 Setting conservation objectives in a changing climate

Key challenges to ensure resilience of grasslands under climate change include

- a better understanding of changes in land use and climate,
- an improved knowledge of impacts of changes in land use and climate on soil carbon content, and
- the identification of most vulnerable grassland ecosystem types

4.7.3 Adaptation actions

Grasslands are particularly affected by other stressors, and type and intensity of land use determines the resilience potential of grasslands under a changing climate (Essl & Rabitsch 2013). In grassland ecosystems (as well as in other agricultural ecosystems) the design of agri-environmental schemes (AES) plays a crucial role for supporting climate change adaptation. There is an urgent need for a much stronger focus on the multifunctionality of agro-ecosystems of Europe. In the light of the latest outcomes of the CAP-negotiations the 2013 Bonn conference discussion group recommended to

- use the given flexibility to shift finances from the 1st to 2nd pillar and to assure adequate co-financing for measures undertaken under the 2nd pillar,
- focus on outcome-oriented programs and monitoring,
- shift towards more flexible approaches (from “blue-prints” to adaptive approaches), and
- reduce subsidies for “bio-energy” crops

To provide synergies for both conservation and climate policy goals, there is a need to

- halt grassland conversion to agricultural fields, especially for high nature value (HNV) grasslands
- rewet agricultural fields and intensively used grasslands on high organic soils to safeguard carbon stores and reduce carbon loss from drained soils and restore habitat for species
- find sustainable use options for grasslands on high organic soils, e.g. through sustainable biomass paludiculture (Wichtmann & Wichmann 2011)

4.7.4 Information requirements

Grasslands face new challenges with climate change as well as increasing pressures from food security and (bio)energy supply goals, fragmentation as well as abandonment. Therefore decision support tools are needed that integrate knowledge from different domains, such as biodiversity and climate change science as well as farming practices (Soussana & Duru 2007). Soussana and Duru (2007) therefore identify the following priorities, among others:

- How to reduce the sensitivity and increase the resilience of grassland biodiversity to extreme temperature and drought events?
- How to protect the carbon store in high organic soils of grasslands?
- How to design innovative farming systems that conserve habitats for rare and endangered plant and animal species, while managing the functional diversity of vegetation for agricultural purposes?

4.7.5 Barriers and Opportunities

The discussants of the 2013 Bonn conference concluded that the importance of biodiversity-rich grasslands for climate change adaptation and mitigation in agricultural landscapes is currently insufficiently appreciated. There is a strong need to streamline agri-environment schemes (AES) and land use policy towards a climate change resilient trajectory which builds on multifunctional benefits and on a long-term perspective.

Several constraints for effectively adapting grassland ecosystems to climate change have been identified, which should be overcome by making use of the following activities:

- increase resources allocated in agri-environment schemes (AES) to grasslands,
- highlight the role of grasslands in climate change adaptation and mitigation (incl. soil carbon sequestration and storage, erosion prevention) by making explicit their multifunctional importance,
- and adapt guidelines to local contexts including translation of guiding documents.

Good practice examples for ecosystem-based adaptation to showcase multifunctionality and co-benefits of nature conservation projects should also be used.

4.8 Urban ecosystems

Urban ecosystems were not explicitly discussed at the 2011 Edinburgh workshop, similar to grassland ecosystems, as they often consist of semi-natural if not novel ecosystems (Kowarik 2011). While focussing on natural habitats and 'wilderness' environments, ecologists largely ignored urban areas until recently (Grimm *et al.* 2008). However, especially with rising ubarnisation, globally, and across Europe, these ecosystems become more and more important from a socio-ecological perspective. Increasingly, people perceive nature from an urban perspective, decide on nature outside cities relying on urban experience and depend on ecosystem services provided by urban nature (Kowarik in Korn, Kraus & Stadler 2012). In addition, cities have always provided hotter micro-climates, and can therefore create opportunities to study climatic effects on and adaptation of plants and animals. This section therefore mainly addresses the ecosystem-based mitigation and adaptation potential of urban ecosystems and builds on the workshop discussions at the 2013 Bonn conference and includes some text from the conference proceedings (Korn *et al.* 2014).

Figure 15: Gasometers at Camley Street Reserve, near St Pancras Station, Greater London © Natural England/ Peter Wakely

4.8.1 Climate impacts and conservation issues

Although the broad climatic changes are the same for cities and their surrounding, impacts on cities will differ. Main climate impacts identified for cities (EEA 2009) are

- Rising air temperatures (particularly extreme events such as heat waves),
- Flooding due to extreme precipitation events
- Drought and water shortage
- Biological responses to a changing climate (incl. spread of non-native invasive species).

It is well known, that cities experience higher temperatures as 'heat islands' compared to the surrounding amongst others due to lack of evapotranspiration of less plants, less air circulation and higher heat absorbtion of concrete and asphalt (Whitford, Ennos & Handley 2001; Sukkop & Wurzel 2003). There may be temperature gradients of up to 5-6°C between low density suburbs and high density city centres. Additionally, heat is stored over longer time periods.

Increased air temperatures and low air circulation in the cities also come along with a reduction in air quality, and higher ozone conzentration in the troposphere.

The warmer climate in cities is associated with a longer growing season (e.g. in Vienna, by about 10 to 20 days yearly), a reduction in frost days and a shift in phenological phases (Sukkop & Wurzel 2003), which is likely to increase with climatic changes. Especially, a higher frequency of hot nights in the summertime is expected that will impact on human well-being, but most likely also on plant and animal stress (Wilby & Perry 2006).

During extreme precipitation events in cities, rain water may not be able to infiltrate into the soil due to the high amount of artificial and sealed surface, causing flooding. Furthermore, canalisation systems of cities might not be sufficient for the increasing intensity of extreme precipitation events. Northwestern, central eastern and Northern Europe are projected to experience higher frequencies of river flooding. Coastal flooding impacts mainly big coastal cities in Belgium, Germany, the Netherlands, northern Romania and northern Italy. Here, urban ecosystems, both in floodplains and coastal areas, but also vegetated green spaces in cities with less conservation value can help ameliorate flooding effects through interception, evaporation of water during and after storm events, slowing run-off and greater infiltration capacities (Whitford, Ennos & Handley 2001).

While droughts are a phenomenon caused by climatic conditions and soil characteristics, water scarcity is to a large extent driven by human activities. Especially regions with high water demand, such as agricultural regions or cities with high population density are vulnerable, and this may affect ground water dependent ecosystems or freshwater habitats to a greater degree than in other areas.

Urban areas are known to be among the land use types with the highest richness in plant species (Kuhn, Brandl & Klotz 2004; Von der Lippe & Kowarik 2008) due to high heterogeneity of microhabitats in cities. In contrast, urban habitats may harbour reduced numbers of invertebrate species, especially less mobile species, due to e.g. high fragmentation, loss or decline in (semi)natural habitats and increase in disturbance (Kowarik 2011). These land use pressures are not necessarily connected to climate change, but are expected to rise in concordance due to demographic and social changes

Many studies have also demonstrated, that cities are often hotspots of non-native plant species (Kowarik 2011). In fact, many derelict urban–industrial areas may follow natural succession after abandonment and provide novel ecosystems with new species communities and a higher proportion of non-native species. Here, traffic routes may foster invasion processes starting from cities to the surrounding landscapes (Von der Lippe & Kowarik 2008), when climatic conditions become more viable to establishing populations outside cities.

4.8.2 Setting conservation objectives in a changing climate

In cities we find transitions between semi-natural to transformed to novel ecosystems, that have e.g. emerged after industrial rehabilitation. Novel urban ecosystems can indeed provide habitat for many species, even some Red List species, and in addition provide many vital ecosystems services, such as climate regulation, run-off regulation or opportunities for recreation.

However, the majority of endangered species in cities rely on relicts of pristine ecosystems (Kowarik and von der Lippe, unpubl.). This suggests, that from a biodiversity conservation perspective, strategies to protect (semi-)natural remnants in urban regions should be fostered and negative impacts of new urban growth on biological and environmental resources should be reduced (Kowarik 2011). In light of climate change, these habitats need to be managed to be able to withstand heat and water stress and exhibit greater resilience. This may include creation of a wider array of microhabitats with cooling islands. In addition, transformation approaches to conservation, by welcoming change, may be particularly relevant in urban ecosystems, as climatic change will be experienced at a greater pace than in rural areas.

Box 8: Protection of existing urban habitats and roadside vegetation

London's Green Corridors network, including corridors alongside waterways and railway lines, are predicted to become increasingly important for species migration due to climate change, and should be protected (Wilby & Perry 2006). Enhancing connectivity in urban environments may be an important means of maintaining biodiversity both for species that spend their entire lives in urban areas and for seasonal migrants (Rudd, Vala & Schaefer 2002).

The preservation of suburban forest patches may help to maintain biodiversity in suburban environments in Ljubljana, Slovenia (Pirnat 2000), and private gardens in cities can equally help to form an interconnected network and provide considerable biodiversity benefits (Goddard, Dougill & Benton 2010).

Roadside networks and corridors in the Netherlands, the UK and France have also been shown to have positive outcomes for a range of plant and animal species (Forman & Alexander 1998; Hopwood 2008; Le Viol *et al.* 2008; Noordijk *et al.* 2011). As wildlife corridors, however, roadside verges are probably of less value than other linear connecting features, such as waterway networks, field margins in rural areas, or parks and gardens in urban areas (Hambrey Consulting 2013).

4.8.3 Adaptation actions

In this section we focus on ecosystem-based adapation and mitigation actions for human-wellbeing. Heatwaves and flooding events in cities will influence public health, reduce productivity and constrain the functionality of (grey) infrastructure. Here, green infrastucture approaches through creation and restoration of urban ecosystems can help to foster both conservation goals as well as provide ecosystem based mitigation and adaptation measures to climate change. Above ground vegetation and especially trees can provide significant amount of carbon storage and sequestration potential and thereby contribute to climate change mitigation potential (Davies *et al.* 2011; Nowak *et al.* 2013), and add to adaptation by cooling through evapotranspiration and shading (Nowak 2010). Here, the structure and specific nature of vegetation is important, with open or dense tree cover leading to a cooling effect of 1.4 °C to up to 2.0°C in comparison to asphaltet areas, respectively (Mathey *et al.* 2011). However, trees can also add to storing heat at night in some cases by blocking wind and thereby minimise cooling. It has been shown, that especially large, open green spaces provide cooling places (Kowarik 2011), although they continue to be threatened by urban development.

In addition, innovative solutions to enhancing urban green space, including green infrastructure through green roofs (Fioretti *et al.* 2010) and green fassades (Perini *et al.* 2011; Preiss *et al.* 2013), can help ameliorate microclimates by cooling effects through attenuation of solar radiation, thermal insulation as well as enhanced evapotranspiration. For water management green roofs have been shown to significantly mitigate storm water runoff generation – even in a Mediterranean climate – with regards to runoff volume reduction, peak attenuation and increase of concentration time (Fioretti *et al.* 2010).

4.8.4 Information requirements

As urban ecosystems can have a significant function in climate change adaptation measures in cities for human wellbeing, it will be necessary to identify priorities for adaptation needs, how to plan for green spaces and how they can be best implemented (Niemelä 2014). As these questions relate mainly to socio-ecological contexts, there are some pertinent information requirements, as defined by James *et al.* (2009) and Niemelä (2014):

- What are direct and indirect effects of climate change on urban ecosystems and how will they affect quality of life in urban areas?
- How will changing social values and behaviours guide the provision and maintenance of urban green spaces in the future?

- How can the resilience and adaptability of urban areas to future economic, housing and environmental demands be enhanced through design and management of urban green spaces?

In addition it will be of interest to ask

- What are disservices of urban ecosystems to people, e.g. through allergenic plants, leaf litter etc. (Lyytimäki & Sipilä 2009), and how can they be managed?
- How can the spread of non-native species from cities (Von der Lippe & Kowarik 2008) be managed in a changing climate?
- How can we learn from cities as test-beds for climate change for climate adaptation measures in natural and semi-natural ecosystems in rural areas?
- How can conservation management and planning allow for novel ecosystems in cities to emerge and contribute as wildlife habitat as well as for provision of ecosystem services?

4.8.5 Barriers and Opportunities

While urban ecosystems or green infrastructure (gardens, wastelands, parks etc.) may greatly support and enhance climate change adaptation in urban areas for human well-being, currently, the contribution of urban ecosystems to climate change-adapted planning in cities is only insufficiently appreciated. There is an urgent need to strengthen the recognition of green spaces in urban planning. However, this is often severely limited by societal, financial and technical constraints resulting from a lack of awareness of the scale of climatic impacts on urban areas, their ecosystems and the potential to ameliorate these by nature based solutions. In addition, due to a lack of stakeholder involvement, private solutions with gardens, green roofs or green walls are limited. For public spaces there is often a lack of management skills of employing urban green infrastructure in climate adaptation in city planning departments.

To overcome these barriers to action, the value and importance of urban green spaces in cities, both public open spaces as well as private gardens etc.,needs to be communicated and made visible. Measures to do so include

- advocacy and awareness raising: visualising how urban ecosystems contribute to climate change mitigation and adaptation by making use of urban green spaces
- technical advice: promoting best practice of urban ecosystem management to adapt to a changing climate
- legislative and financial incentives to include ecosystem based mitigation and adatation (EbM / EbA, see section 5) in climate change urban planning.

In order to enhance green infrastructure as an ecosystem-based approach for adaptation to climate change in urban areas, the development and application of participatory and bottom-up approaches were considered as crucial steps by the 2013 Bonn conference participants. These include:

- Designing urban biodiversity strategies with the involvement of all stakeholders,
- Establishing advisory bodies for greening private and public investments,
- Creating new partnerships and participation platforms, and
- Strengthen the involvement of volunteers e.g. in community gardens.

Furhermore, it will be advantageous to strentghen cross-sectoral partnership to identify synergies with climate adaptation goals in other sectors, such as human health, as experience of natural areas or urban ecosystems, such as parks or also gardens, have been linked to significantly improving mental and physical health (Ulrich *et al.* 1991; Bowler *et al.* 2010). Therefore, the multifunctionality of urban ecosystems should be stressed to realise conservation of urban ecosystems as a societal goal.

4.9 Summary of the 2011 Edinburgh workshop and the 2013 Bonn conference discussions

The following is a summary of the final discussion during the 2011 Edinburgh workshop and the 2013 Bonn conference.

4.9.1 Impacts

The nature of climatic changes in Europe (David, Sandra & Nicholas 2013) and the associated impacts and vulnerabilities vary across the different ecosystems and geographically across Europe (EEA 2009). The focus of the 2011 workshop was on northern and western Europe, and it was recognised, also in the 2013 conference in Bonn, that expertise and awareness is less developed for the Mediterranean region and need to be fostered.

Many effects of climate change are already evident and have lead to deterioration of conservation areas. Impacts may be experienced through direct impacts of changing temperature or precipitation regimes as well as increased frequency or intensity of extreme events, while they are often exarcerbated by current management practices through land use and land use change.

The majority of impacts identified in mountain areas are related to temperature change. Species communities of mountain tops and the sub-arctic will be most affected by biological invasions of competing species, that can tolerate the changed environmental conditions. As key issue for coastal and freshwater systems climate impacts are likely to be exacerbated where systems do not have room to change.

It is clear that many species are moving, and in some cases there is a clear link to climate change (Parmesan 2006; Chen *et al.* 2011). New species assemblages are starting to be observed, and this trend is likely to continue. Ecosystems and species depending on permafrost, permanent snow patches and ice were also highlighted as particularly vulnerable to the effects of rising temperatures. The evidence for climate change affecting species interactions is much less clear. Many changes may already be happening, but they are not necessarily detected yet. A notable exception is the study of golden plovers and their invertebrate prey in northern upland peatlands (Carroll *et al.* 2011).

Next to climate change affecting some individual species, there is good evidence of current and future changes in ecosystem structure and functioning of peatland ecosystems. In particular, areas that are already damaged as a result of human activity are far more vulnerable to climate change and, in addition, may exacerbate climate change signals through loss of carbon from drained organic soils or fires than areas that are relatively undamaged.

In addition to the direct impacts of climate change on the natural environment above, human responses to climate change (adaptation and mitigation) will affect ecosystems, such as the construction of sea defences, flood management and fire exclusion, and recently also the emerging development of renewable energy schemes (which if appropriately sited can go hand in hand with conservation). In many cases adaptation approaches geared to safeguard economic interests run contrary to options for biodiversity conservation (Hulme 2005). These indirect impacts are exemplified for mountain ecosystems (Beniston 2003):

- Warming temperatures might cause skiing apparatus to be moved to different areas, and greater water abstraction for snow canons to compensate for reduced natural snowfalls; both potentially having negative effects on natural areas.
- Mountain areas might see increased visitor numbers, as a result of shorter winters, and also a shift in activities, for example from skiing to mountain biking; creating opportunities for recreation and engaging people with the natural environment and the need for its conservation but at the same time potentially increasing damage to vegetation and pressure for increased built infrastructure.

- In some areas, mountain water catchments could come under increased pressure as a result of increased demand for water supplies to downstream human communities.
- Wind power development, as a result of policies to reduce fossil fuel use, could also affect upland ecosystems if not covered by a strategic planning that accommodates renewable energy development without compromising other ecosystem services

In coastal and freshwater ecosystems areas, technical climate adaptation measures to flood protection such as shoreline development or fortified flood defence structures may impact on conservation areas. In forest ecosystems the renewed demand for wood as biofuel or construction material in line with climate mitigation policies, mixed with risk mitigation by planting heat stress tolerant species such as douglas fir and short rotation cropping, might exert pressure on biodiversity. In peatlands, the drive for planting bioenergy crops may lead to degradation of high organic soils through drainage with associated losses of ecosystem functioning and biodiversity. This will then increase emissions of greenhouse gases from peatlands, despite the renewable energy targets intended to be met by this management action.

Climate impacts will also interact with other effects of human land use that are driven primarily by wider socio-economic factors. One example is the increasing pressure from development in some areas, e.g. building in Norway to meet a demand for second homes or tourism development along coastal areas. This is likely to have a detrimental impact on the ability of ecosystems to cope with climate change. Another example is the trend towards land abandonment in upland areas in both Norway and the Swiss Alps, which is leading to rising treelines as trees re-colonise mountain meadows that would, before human farming, have been much more forested. Climate change is likely to further cause this change in vegetation (Gehrig-Fasel, Guisan & Zimmermann 2007). This potentially creates both problems and opportunities for conservation (as well as posing questions about the relatively importance in setting conservation goals of allowing natural processes to occur, preserving current ecosystems, and maximising overall biodiversity). On the one hand, it could mean a loss of cultural landscapes such as alpine meadows, which although being largely the result of human activity are valued both for their aesthetic value as well as their rich biodiversity. On the other hand, abandonment may lead to recovery of ecosystems such as blanket bogs and thus help to counteract several of the most serious impacts listed above.

4.9.2 Conservation objectives

Climate change is likely to exacerbate existing pressures from land use and pollution, which need to be addressed as a priority to increase the resilience of conservation areas.

Current objectives therefore focus on reduction of other threats, precautionary management and no-regret measures. In many cases a pro-active management needs to foster restoration or creation of habitats, often to compensate for damage, induced through climatic changes and/or land use pressures. To increase the natural adaptability of sites it will be necessary to focus on restoring natural processes. In the face of uncertainty of climatic impacts the focus of current conservation measures is on designated species or protected sites.

Changing objectives may include proactive management to move from resistance to accepting change. The discussion centred around the question whether there are environmental tipping points that may require a shift from a ‘resilience’ approach to accepting or actively facilitating change? Extreme events, such as fires, could be tipping points. Tipping points might be more obvious at the coast than in other ecosystems, e.g. through inundation, peninsulas becoming islands, or effects of rising water temperature for sand eels etc. (Note: it is therefore interesting to see that this awareness may have led to the production of vulnerability assessments especially for coastal habitats in the studied conservation sites across Europe, see section 8)

Adaptation to climate change in European conservation therefore needs to follow a stepwise approach as outlined by Pearce-Higgins *et al.* (2011; see Fig.16) and described in detail by Bouwma *et al.* (2012): first to increase the resilience of existing single conservation sites, followed by enhancing the resilience of the wider network of sites through increased functional connectivity (for discussion see section 6) and as a last step the possible consideration of translocation of species (for discussion see section 7):

1. Managing the condition of key sites (incl. reducing the severity of other pressures)
2. Increasing the size of key sites
3. Creating new key sites
4. Increasing functional connectivity between key sites
5. Translocation to establish new key sites

Another key discussion in the workshop considered indicators and monitoring. How will conservation managers be able to tell when it is time to change management and/or objectives? Monitoring is required to assess vulnerability of sites and to identify tipping points or critical slowing down of environmental conditions in ecosystems (Scheffer *et al.* 2012), but not all tipping points might be recognisable. Therefore it is important to manage in a precautionary way. Monitoring methods must be practical and show changes in direction, e.g. comparing historical photos. Indicators and proxies are needed to determine the extent to which objectives need to change. Increasing knowledge of processes may help to identify when conservation needs to adjust management objectives e.g. through study of sediment movement, plankton dynamics, or oscillation of water tables in peatlands.

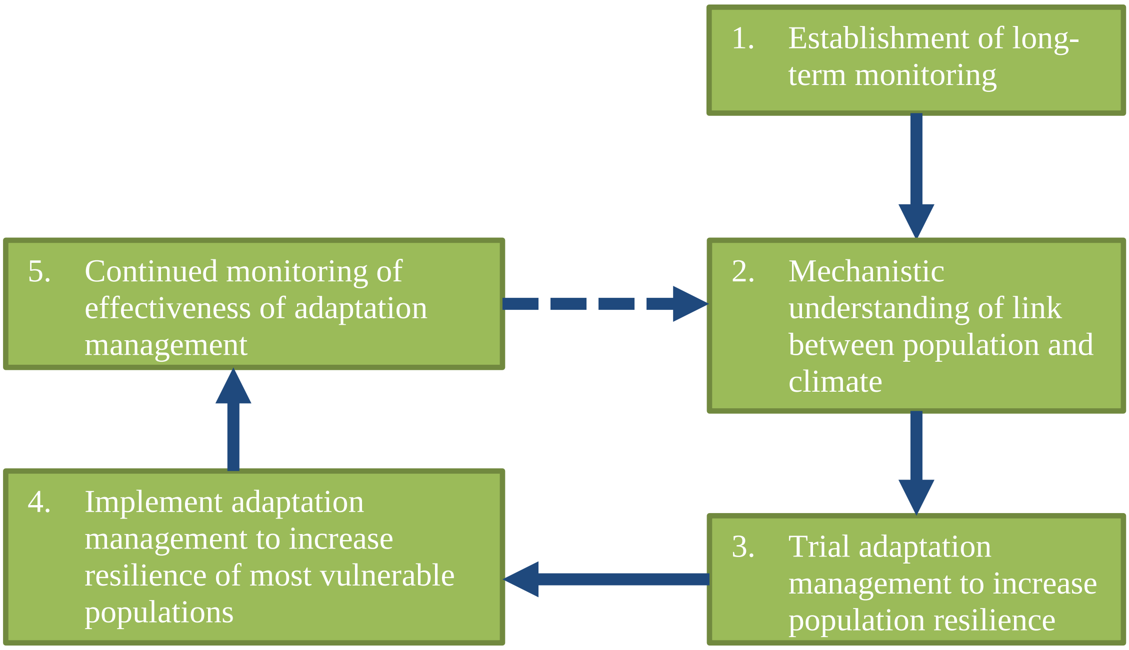

Figure 16: Schematic diagram outlining a potential approach to site-based adaptation management. If adaptation management becomes ineffective, it may be necessary to go from five to two (hence the dotted arrow). Alternatively, such a point may indicate that the limit to successful climate adaptation has been reached (with kind permission from James Pearce-Higgins, see also Pearce-Higgins (2011).

Furthermore, conservation needs to be able to change objectives and introduce flexibility, without undermining the EU 'Habitats Directive'. This partly depends on designations and legislation. Conservation management may need to be able to review designations, particularly at the coast, as designations tend to focus on key species rather than ecosystem functions. Ideally, conservation objectives must be reviewed on a regular basis. Changing long-term aims may require a long lead in time and active involvement of and working with partners. Here the RSPB approach to reserve management (Ausden 2013) may be useful as a template: a 25 year vision with 5 year management plans and annual management targets is frequently reviewed against measurable targets, monitoring data, photos, habitat quality measures, statutory condition and site audits, and adjusted as necessary.

4.9.3 Conservation of species and ecosystems

A key point for discussion in the workshop groups was the advantages and disadvantages of focusing adaptation efforts primarily on individual species or primarily on ecosystem processes and structure (see Table 15). There is an important integration to be achieved between conservation of the overall ecosystem and conservation of important individual species.

Traditionally, conservation has focussed on individual species, and many of the great conservation successes have been achieved with focused research on, and subsequent targeting of conservation action, for particular species. There is more known about individual species, in many cases, than about species interactions and the detailed functioning of the overall ecosystem, and the results of species-based conservation are much easier to measure. Species conservation is also mandated through national and international legislation, and it motivates public support for funding of conservation. In general, quanitified species based objectives may be easier to understand, to measure and to communicate to the public.

However, species conservation requires detailed research and understanding, and there are insufficient time and resources for the necessary research and action for every species. Moreover, not all species are known, and the discussion to focus conversation at the ecosystem level is not new (Franklin 1993). There can also be opposition to conservation of particular species (either for funding reasons or because of different groups of people having different values for an area – e.g. different conservation target species with contrasting habitat requirements). In addition, conserving a particular, often charismatic, species may not protect other species (Seddon & Leech 2008; Branton & Richardson 2011), nor the functioning of the ecosystem and the services it provides. Species based objectives can therefore overlook functionality of ecosystems.

Table 15: Comparison of advantages and disadvantages of using conservation approaches focussing on species and populations or ecosystem structure and processes as discussed in the Edinburgh workshop.

	Advantages of including this approach in adaptation goals	Disadvantages of this approach in isolation
Quantitative objectives for species / populations	**MONITORING** • Species are measureable and effective indicators • Monitoring of spatio-temporal range shifts in individual species easier than of complex ecosystem changes • Historically, biggest advances in conservation achieved by monitoring individual species **FUNDING** • Iconic species attract public support and funding • Aid in obtaining funding (ability to measure against indicators) • Public relates to species in terms of understanding climate change **LEGISLATION** • Mandate through national and international legislation EFFECTIVENESS • Effective for a few species / maintains conservation efforts for particularly demanding species that would be lost otherwise • Allows greater focus of effort • Often consistent with general good management • Easier to understand	**FAILURE TO PROTECT OTHER LEVELS OF BIODIVERSITY (OTHER SPECIES/ ECOSYSTEM)** • Impossible to deal with majority of species in specific detail • Danger to overlook interactions between species (food chains / competition etc) and functionality of ecosystems – risk of developing inappropriate responses • May not protect natural capital / ecosystem services and focus only on habitats with charismatic species CONFLICTING OBJECTIVES • Conflicting quantitative objectives for species between stakeholders (e.g. different views of appropriate numbers of game species) • Competing and irreconcilable objectives between species conservation goals DIFFICULTIES • Potentially impossible to achieve success • Requires detailed understanding
Broad objectives for overall ecosystem structure & function	**FUNDING** • Co-funding opportunities from other sectors **HOLISTIC, LARGE-SCALE** • Win-wins: Multiple benefits / more holistic / Ecosystem approach provides a broader view • Climate change impacts happen at the ecosystem level: species interactions and shift in community assemblages important • Possibility to achieve broader objectives beyond protected areas/species • Good for generalists • Synergies between ecosystem services **LESS CONFLICTS** • Better approach for dealing with potential conflicts/demands on land • More relevant to people with other interests (e.g. water customers) other than biodiversity FLEXIBILITY • Flexibility for accepting new species assemblages STABILITY • In combination with broader landscape approach may provide an element of stability (although flux and change of species take place) • Makes ecosystem processes explicitly part of planning	**FUNDING** • Not as attractive to funders, unless high profile 'flagship species' as marketing tool **LACK OF COMPLEMENTARITY** • Complementarity not always given between species, ecosystems and ecosystem functions • May not meet needs of specialists or maintain high diversity • Potential species loss at site scale • Species information needed to inform ecosystem-level approach • Tradeoffs between ecosystem services **MONITORING** • Evidence base is poor (success / failure) • Lack of indicators **LEGISLATION** • Legislation / targets – statutory requirements for species may not be met **CONFLICTS** • Tensions among different people because of different values placed on different services; Values will be place specific and stakeholder specific, so will vary across Europe

All the above mentioned problems apply even in the absence of climate change. Climate change, and the increasing non-linear dynamics and movement it is likely to create, would make it even more difficult to base conservation on individual species.

Conservation of broader ecosystems has a number of benefits – it might be possible, by conserving the 'stage' in reserves or the wider landscape matrix, to in turn conserve many of the individual 'actors', or - in a changing climate - at least maintain conditions suitable for new species to replace the old ones. Ecosystem level conservation, as commonly practiced in protected areas, has potential to achieve multiple benefits, for people as well as for wildlife, and therefore might be more appealing to human communities, also as a tool for ecosystem based adaptation to climate change (section 5). In this way, using synergies between nature conservation and society's adaptation goals, this approach may also offer opportunities to obtain funding from non-traditional sources, such as water companies (see Exmoor Mires Project, UK53, Appendix 11.4 in England).

However, as a strategy in isolation, ecosystem-focused conservation, too, would have drawbacks. Although species interact with each other, and there is a correlation between high levels of biodiversity and resilience of ecosystem function and service provision, there is not complete complementarity (Bonn & Gaston 2005). In many cases, the evidence base is poor and it is hard to identify meaningful indicators to measure ecosystem health. These two factors combined mean that there could be a risk of maintaining a particular ecosystem or area – at least as it is perceived by humans – but lose many of the species or genetic diversity it contains. Focusing entirely on ecosystem services, however, creates an additional risk, as a) different people, in different places, will place different value on different services, and while b) biodiversity has key roles at all levels of the ecosystem service hierarchy (Mace, Norris & Fitter 2012). Therefore, these two concepts are not synonyms, and biodiversity conservation concerns might be neglected with this strategy. A joint approach is needed.

Overall broader objectives may provide a better and more flexible approach when dealing with potential conflicts or demands on land. They can focus more on ecosystem services and can make it easier to communicate linkages between habitats and ecosystem services. However, broader objectives may also be more difficult to measure, as appropriate indicators or evidence base is not yet available.

In reality, both types of objectives – species based and ecoystem focused approaches - are required. Separating the types of objectives is inappropriate as species live within habitats and wider ecosystems and form a major component of ecosystems.

Clearly, the challenge is to integrate consideration of all levels of biodiversity into adaptation goals, the genetic diversity, species diversity and ecosystem diversity. As climate change will affect whole systems, and lead to highly complex, nonlinear and sometimes abrupt responses (Walther 2010), in some cases a greater focus on the system will be needed, with species conservation as part of a wider strategy for broader ecosystem conservation. It will be important to foster synergies and multiple benefits wherever possible without neglecting the need to understand as much as possible about the potential impacts on individual species to be able to take focused action if required. At the same time, it may be necessary to include flexibility in conservation goals to accommodate inevitable changes. In some cases, such as peatlands, the conservation of the ecosystem and the species within it go hand-in-hand through maintaining high water tables. In other cases, e.g. for the Capercaillie (*Tetrao urogallus*) across European mountain regions, protection of the ecosystem is important but not enough on its own to conserve the species, whose decline is the result of factors other than problems of ecosystem functioning (Duriez *et al.* 2007).

While the integrated approach has been practiced through protected area management, workshop participants felt that better evidence was needed for large-scale ecosystem management to deliver on the breadth of conservation objectives, and to be aware of the potential limitations. It was suggested that 'the species and populations most important in the conventional conservation agenda are not necessarily those most important for ecosystem function (soil organisms, not rare vascular plants or birds). Therefore, a) new knowledge will be needed to inform the successful conservation of ecosystem structure and function, and b) conservation objectives may need to be reconsidered, as this is not 'conservation as we have known it since 1949' (this was the year in which the legal basis of modern conservation in the UK was established).

4.9.4 Key messages for focal ecosystems

It was hard to define general messages across all ecosystems. A detailed account of climate change impacts on European ecosystems is presented in EEA (2012). It is advised to follow the adaptation principles developed by Bouwma *et al.* (2012). For the four main ecosystem types discussed in Edinburgh the group identified the following key messages.

Mountains and sub- arctic ecosystems (including peatlands)

- Impacts are already being felt.
- Conservation will need to accept that species will be lost in some locations. There is limited ability to reduce exposure to direct impacts. In addition the ability to increase the resilience of current populations is limited due to temperature effects.
- As in other ecosystems there might be opportunities to increase resilience of ecosystem structure and processes by reducing other pressures. Conservation objectives should therefore focus on reducing anthropogenic pressures, as well as on functioning hydrology (subarcrtic peatlands).
- Translocation and ex-situ conservation is likely to be more important for mountain ecosystems than for others.

Freshwater and riparian ecosystems

- Impacts likely to be felt first in Southern and South East Europe.
- Addressing anthropogenic pressures is particularly important for this ecosystem type and likely to be key to fostering resilience.
- Objectives should seek to achieve multiple benefits. Conservation should harness opportunities for ecosystem based adaptation, raising awareness of the multiple benefits of conservation with regards to climate adaptation, biodiversity and provision of ecosystem services (e.g. adaptive river management leading to e.g. flood protection, protection of carbon stores in floodplains and reduction in nutrient leaching and improvement of water quality).
- In species protection conservation should seek to align multiple benefits with the conservation of iconic species, e.g. Bittern, or focus on species that may enhance broader functional benefits of ecosystems, such as Beavers.
- Objectives need to focus on quantity and quality of water.
- Connectivity is not always appropriate for freshwater ecosystems, especially when there is a risk of invasion by non-native species.

Coastal ecosystems

- Change is inherent in coastal systems. Raising awareness and understanding with the general public about the dynamic nature of the coast and the likelihood of change will be crucial to proactive management.
- Facilitating natural processes and considering ecosystem functioning will be important for this habitat type, as well as conservation of species and protected sites.
- Increasing the quantity and heterogeneity of coastal habitats is important, and in some cases managed re-alignment of coast lines will need to be considered.
- Since there are little adaptation options for marine ecosystems, enhance resilience thorugh reduction of other anthropenic pressures.

Forest and woodland ecosystems

- Historically, there has been greater acceptance of change in this ecosystem type than in other ecosystem types.
- The challenge of balancing biodiversity and commercial objectives is most strongly articulated in this ecosystem type. There is a need to balance biodiversity objectives with ecosystem services, and it will be useful to find synergies.
- Objectives need to focus on increasing diversity and heterogeneity, and consider provenance of tree species
- Connectivity and increasing permeability is important for this ecosystem type.
- Foster large and contiguous areas which allow for natural processes to take place without management intervention to increase resilience.

5 Ecosystem-based adaptation and mitigation

While this report focusses on climate adaptation in nature conservation, this needs to be seen in a wider context. Indeed, Vignola *et al.* (2009) point out, that environmental degradation and vulnerability to a changing climate are primarily a developmental issue rather than a sole environmental problem. Accordingly, solutions will also benefit affected communities, and the concept of Ecosystem-based adaptation (EbA) provides a link between the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). The EbA concept was first introduced at the 14th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2008. Agreed by the Parties to the CBD in 2010, the 'Aichi Biodiversity Targets' include the commitment to minimize 'the multiple anthropogenic pressures on vulnerable ecosystems' (target 10) and to enhance 'ecosystem resilience and the contribution of biodiversity to climate change mitigation and adaptation' (target 15).

Box 9: Definitions Ecosystem-based adaptation and mitigation (adapted from Doswald & Osti 2011)

Ecosystem-based adaptation (EbA)

The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change (CBD 2009). This may include sustainable management, conservation and restoration of ecosystems, as part of an overalladaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities. Adaptation is facilitated through both specific ecosystem management measures (e.g. managed realignment) and through increasing ecosystem resilience to climate change (e.g. watershed management, conserving agricultural species genetic diversity).

Ecosystem-based mitigation (EbM)

The use of ecosystems for their carbon storage and sequestration service to aid climate change mitigation. Emission reductions are achieved through creation, restoration and conservation or sustainable use of ecosystems (e.g. woodland creation, peatland restoration).

Adaptation in nature conservation (main focus of this report)

Conservation action that increases the resistance and/or resilience of species and ecosystems to climate change and/or facilitates their adaptation by passively or actively managing for change (e.g. reducing other sources of harm known to interact with climate effects, conserving species genetic diversity to maximise chances of adaptation, creating, restoring or modifying habitat to reduce climate effects, and facilitating movement of species across the landscape to enable shifts in distributions)

Ecosystem-based adaptation (EbA) and mitigation (EbM) (Box 9) therefore include measures that cosider the role of nature based solutions to climate adaptation and mitigation to reduce the vulnerability of society to climate change. This necessitates a multi-sectoral and multiscale approach, involving all relevant staleholders, such as regional and national administration, businesses, local communities and NGOs (Vignola *et al.* 2009). The aim is to alleviate pressures on ecosystems to maintain a sustained delivery of their services and thereby managing ecosystems to increase the resilence of people and economic sectors to climate change.

Ecosystem-based adaptation and mitigation thereby not only work towards reducing vulnerability to both climate and non-climate risks to society but can also directly and indirectly offer multiple economic, social, environmental and cultural benefits (see contribution by Weissenberg, IUCN, to Korn *et al.* 2014). Importantly, EbA initiatives can directly complement as well as supplement disaster risk reduction measures as ecosystems, such as sand dunes or floodplains, can act as natural barriers against storm surges or flood events. EbM approaches identify the vital role of natural habitats such as healthy forests or peatlands for carbon sequestration and storage (see e.g. Box 4, section 4.3.3) .

Good practice examples of ecosystem-based approaches to climate change mitigation and adaptation in Europe have been collated and analysed in an earlier report by the ENCA / BfN group (Doswald & Osti 2011), as well as in a comprehensive report to the European Comission based on over 160 projects (Naumann *et al.* 2011). In this report, the case studies on wildlife conservation and flood prevention on the Forth (Box 5, section 4.4.3) or on creating natural climate buffers in the Netherland (Box 6, section 4.5.3) illustrate good examples of an EbA approach.

The German Federal Agency of Conservation (BfN) has commissioned the creation of a database of EbM and EbA projects in Germany, Switzerland and Austria (http://www.bfn.de/0307_klima.html). Selected case studies were documented and analysed for barriers and success factors arising in their planning and implementation (Naumann *et al.* in press). Further global EbA project databases are collated by the CBD (http://adaptation.cbd.int/) and the UNFCCC (http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/6227.php). We therefore refer to these studies and do not cover this aspect within this report in depth.

It can be useful to apply economic valuation to EbA approaches as applied in the TEEB initiative (The Economics of Ecoystems and Biodiversity, www.teebweb.org,TEEB 2010). Valuation can help to create awareness and foster greater appreciation of the significant contribution of nature and nature conservation management to the provision of ecosystem services for human well-being, also in a changing climate. This in turn can lever and justify investments in EbA measures or green infrastructure as they often form cost-effective alternatives or complementary measures to 'grey' infrastructure to adapt to a changing climate (for more information on green infrastructure see http://ec.europa.eu/environment/nature/ecosystems/).

6 Increasing connectivity as a climate change adaptation measure: review of concepts, evidence and recommendations

6.1 Introduction

As detailed in the previous sections, many species are predicted to face or are currently facing habitat range shifts and contractions linked to climate change (Warren *et al.* 2001; Walther, Beißner & Burga 2005; Hickling *et al.* 2006; Parmesan 2006; Thomas, Franco & Hill 2006; Chen *et al.* 2011). Species ranges are expected to change as temperature, wind, moisture levels and a wide range of geographical and ecological parameters are altered by climate change. Global meta-analyses documented already significant range shifts for species with an average of 6.1km per decade poleward and towards higher altitudes in mountain areas (Parmesan & Yohe 2003). Range shifts will be mediated when parameters such as moisture or wind are more important constraints than temperature (Beier 2012).

Whenever affected species can neither adapt to a changing environment nor migrate to more suitable places, they are likely to face extinction. Enhancing connectivity between habitat patches is already a widespread conservation measure (Hodgson *et al.* 2009). In the context of climate change, it can increase species resilience to a changing environment and might be a particularly relevant strategy to facilitate species' dispersal along a temperature gradient (Nuñez *et al.* 2013) or to nearby areas with suitable microclimates (Beier 2012).

Here, we briefly present fundamental theoretical underpinnings of the concept of connectivity as relevant to conservation management. We review current evidence of connectivity measures scope and effectiveness, assess their potential risks and trade-offs and present strategies for designing connectivity measures to mitigate climate change effects. When considering implementation of measures to enhance connectivity, it is essential to appreciate the multiplicity of processes embraced in the single concept of 'connectivity' and their relevance to conservation goals.

6.2 Fundamental concepts: connectivity and impact on population viability

6.2.1 The concepts of connectivity, fragmentation, and metapopulations

Connectivity refers to the movement of populations between habitat patches, and estimates the rate of immigration into a habitat patch (Hanski 1998; Tischendorf & Fahrig 2000b; Tischendorf & Fahrig 2000a). Functional connectivity is therefore the result of the interaction between structural features of the landscape (landscape or structural connectivity) and the species behaviour, i.e. its dispersal ability (Tischendorf & Fahrig 2000b), see below. Of these two variables landscape connectivity is the only variable amenable to management measures. It is influenced by a variety of parameters such as habitat area, quality and spatial aggregation, and the 'matrix' (part of the landscape which is not a suitable habitat) permeability. Both species behaviour and landscape connectivity may be affected by environmental change linked to climate warming (Luque, Saura & Fortin 2012). It is of paramount importance when designing connectivity measures to take into account the fact that increasing landscape connectivity does not necessarily lead to increased functional connectivity (Ovaskainen 2012).

Habitat fragmentation refers to the loss of connectivity between habitat patches. It broadly refers to the division of habitat in isolated fragments. In reality, habitat fragmentation often occurs together with habitat loss (in area or quality). Habitat loss and fragmentation indeed usually appear simultaneously and it can be difficult to disentangle which component eventually drives populations to extinction and in turn, which is likely to promote population viability (St-Laurent *et al.* 2009).

Species inhabiting fragmented landscapes often form a metapopulation, i.e. a population of interacting subpopulations (Ovaskainen 2012).

6.2.2 What is connectivity in the context of climate change?

The review by Crooks & Sanjayan (2006) suggests that: 'At its most fundamental level, connectivity is inherently about the degree of movement of organisms or processes – the more movement, the more connectivity'. This is a useful starting point to consider the general concept, as it focuses on the aspects of *ecological function* (i.e. movement) that connectivity is thought to maintain and improve. The benefits of appropriate levels of connectivity include (Crooks & Sanjayan 2006; Noss 2007; Schmiegelow 2007):

- Increased immigration rates to a site, thus increasing population numbers and genetic diversity and so reducing risks of inbreeding depression and demographic stochasticity. This also enables recolonisation after loss of a local population and thereby helps to maintain metapopulations.
- Facilitation of daily movements, dispersal of seeds and of juveniles and other individuals, and seasonal migration
- Increasing access to scattered resources
- Facilitating movement to other areas in response to changing conditions and extreme events
- Maintenance of ecological flows and processes and resulting ecosystem services

In the context of climate change, three benefits seem particularly important:

- The 'rescue effect' of isolated populations, which might be expected to become increasingly vulnerable to extreme events such as flood, fire, storms etc. as the climate continues to change.
- Facilitation of gene flow to increase genetic diversity (reducing vulnerability of small populations to change) and the dispersal of genotypes that are adapted to changing conditions (e.g. genotypes from warmer areas) to maximise the opportunities for species to adapt to changing conditions (Jump & Penuelas 2005).
- Facilitation of range shifts in response to changing conditions. There is evidence that organisms responded to past climate change through large shifts in geographic distributions (Davis & Shaw 2001), and of species already moving in response to the warming of the 20th century (e.g. Hickling *et al.* 2006). It is likely that large scale further movement will need to occur for species to persist, particularly given the projected rapid pace of climatic change.

There are also climate-change-related situations in which connectivity might be undesirable, such as:

- When connectivity facilitates the spread of diseases, weeds or pest species
- When connectivity leads to inundation of locally adapted subpopulations with genotypes from outside and causes outbreeding depression, along with reduced genetic variation among subpopulations as a group
- When connectivity facilitates spread of wildfires and other major abiotic disturbances
- When connectivity facilitates movement of species that are likely to put pressure on a threatened species with a restricted range (e.g. rare alpine species being preyed on or outcompeted by lowland species that are shifting up mountains as minimum temperatures rise)

It is important to realise the fundamental point that connectivity refers to the ability of species or other ecosystem components to move across a landscape and that movement is determined not just by physical features of the environment but by the characteristics of the individual/ seed/ gene etc. that is moving, such as dispersal ability, behaviour, ecological requirements while travelling across a landscape, and how it perceives the landscape. The interaction of species ecology with the physical landscape is highly scale dependent. A landscape that is well-connected for one species might present major barriers to another.

Lindenmayer & Fischer (2007) suggest that a distinction should be made between:

- *Landscape connectivity*, or the physical linkage of patches of a particular land cover as perceived by humans [also termed *structural connectivity* by some other authors]
- *Habitat connectivity* or the connectedness of habitat patches for a given species, i.e. species specific entity
- *Ecological connectivity* or the functional linkages of ecological processes at multiple spatial scales (e.g. trophic relationships, disturbance processes and hydro-ecological flows) [also termed *functional connectivity* by some other authors]

The correlation between the three categories will vary among different species. For some species, human perception of connectedness of a general land cover type (e.g. 'woodland') will be a poor proxy for how connected suitable habitat for the species actually is. Likewise, for species that can disperse large distances, cross gaps and tolerate moving through suboptimal areas, the link between habitat and ecological connectivity might be weak and connectivity of habitat might play a relatively unimportant role in facilitating movement. Conversely, landscape (or structural) connectivity does not provide functional connectivity if corridors are not used by target species.

Therefore, it is *ecological (or functional) connectivity* that conservation managers should be concerned with if we want to create a more 'connected' ecological network. Physical connectedness of landscape features or even suitable habitat, though contributing to ecological connectivity (and unfortunately often equated with it in some conservation literature), should be seen just as a means to an end for conservation of biodiversity. Its relative importance will vary between species.

6.2.3 Connectivity and metapopulation persistence

Metapopulation theory suggests that species occupying patchy habitats will persist in the long-term only if the extinctions in a habitat patch are compensated by colonization from other habitat patches. Reproductive 'sink' patches (where breeding and survival rates are insufficient to maintain long term populations) may be maintained by consistent immigration from 'source' patches, which in turn depends on connectivity. Hence persistence of metapopulations should be increased with increasing number, area and quality of habitat patches within the network as well as through connectivity between the patches (Ovaskainen 2012). Conversely, loss of connectivity, i.e. high habitat fragmentation with no connectivity between patches, can lead to metapopulation decline and extinction. Although the theory around habitat fragmentation is well developed, empirical evidence demonstrating a link between habitat fragmentation and population decline and extinction at a regional scale are scarce (Corlatti, Hackländer & Frey-Roos 2009). For example, Trenham *et al.* (2000) conducted a long term study on the California Tiger Salamander, *Ambystoma californiense* (from 1991 to 1998), and reported survival to maturity rates of less than 5%, far below the estimated 18% expected to maintain this local population giving its breeding output at the time. The authors tentatively concluded that their study population was a reproductive sink and would be doomed to extinction in the absence of substantial immigration, and that isolated breeding ponds may be insufficient for the long-term maintenance of viable populations of *A. californiense*: Here connectivity was essential. Importantly, Trenham and colleagues (2000) point out that without detailed study it may be impossible to differentiate sink and source habitats and therefore, in the absence of specific knowledge of the contributions of individual breeding habitats to a regional population, protection of areas with multiple ponds seems essential to the long term viability of this species.

6.2.4 Connectivity and local genetic diversity

Connectivity impacts on local genetic and species diversity and population structure, undermining long-term resilience against climate change. Loss of connectivity could foster loss of resilience against a changing environment in a number of ways.

Connectivity and genes: Genetic theory suggests that a reduction in gene flow between sub-populations may lead to greater inbreeding and greater impact of genetic drift, leading to a loss of genetic diversity within each sub-population, hence loss of genetic potential to adapt to environmental change (Reed & Frankham 2003; Honnay & Jacquemyn 2007). Loss of genetic diversity is thought to contribute to extinction risk, although the link between genetic connectivity and population extinction remains largely a matter of debate (Corlatti, Hackländer & Frey-Roos 2009).

Connectivity and population structure: Sub-populations in fragmented landscapes usually have a smaller effective population size and may experience lower densities and lower percentage of habitat occupation due to less effective distribution of individuals over the habitat network (Fahrig 2003; Hampe & Petit 2005), which may explain the stronger effects of large-scale disturbances in more fragmented habitat, causing temporary extinction at the regional level, as well as reduced growth rate causing longer recovery time (Foppeni *et al.* 1999; Opdam & Wascher 2004).

Box 10: Connectivity and population resilience in Dutch Sedge Warblers

Habitat fragmentation affected resistance to drought in wintering areas: Dutch Sedge Warblers *Acrocephalus schoenobaenus* that lived in fragmented marshland habitats were more strongly affected by droughts in their West African wintering area between 1973-75 and 1982-85 than those in unfragmented landscapes (Foppeni *et al.* 1999). Bird numbers in fragmented landscapes showed a larger decrease than in unfragmented landscapes, and many local populations in the heavily fragmented marshland landscape in the east of The Netherlands went extinct.

Habitat fragmentation affected population recovery: Sedge Warblers populations in heavily fragmented landscapes showed no population recovery in the eight years following the onset of a period with more rainfall in West-Africa (1985-94), while populations in unfragmented landscapes seemed to be able to recover rather fast.

Simulation models (Foppeni *et al.* 1999) suggest that bird populations in fragmented landscapes show stronger declines and less resilience than populations in unfragmented habitats in response to a catastrophe such as winter drought: in fragmented landscapes (less than 1% marshland), the relative decrease in bird number was 50% higher than in less fragmented habitats (more than 1% marshland). Furthermore, after a decrease, the recovery to initial numbers in fragmented landscapes would take about five times longer than in areas with more than 15% suitable habitat.

6.3 Risks and trade-offs

6.3.1 Risk: Loss of resilience against environmental stochasticity

Although loss of connectivity can lead to a loss of resilience in some cases, increasing connectivity may not always reverse this trend. For example, in a modelling experiment using the land snail *Arianta arbustorum* in north-eastern Switzerland (Akçakaya & Baur 1996) showed that in most cases a population network had a much higher resilience than a single population against catastrophes such as heavy rains and avalanches, though this was not the case when such events were evenly spatially distributed. Indeed, a certain degree of habitat fragmentation may sometimes buffer against environmental stochasticity: a network of several patches prevents the risk of all populations being simultaneously vulnerable to adverse conditions.

6.3.2 Risk: Dispersal of antagonistic species

A degree of connectivity loss may also prevent the spread of disease epidemics, a major biodiversity threat associated to climate change (Daszak, Cunningham & Hyatt 2000). Indeed, a long term warming trend is encouraging the geographic expansion of infectious disease ranges; vectors are changing in altitude, and extreme weather events create conditions conducive to 'clusters' of insect-, rodent- and water-borne diseases (Epstein 2001), which may leave endangered species especially vulnerable (McCallum 2012). In this context, it is of utmost importance to consider disease risks associated with connectivity measures. Yet, the effects of habitat connectivity on disease spread and parasitism rates remain, surprisingly, largely unexplored despite the abundance of literature on fragmentation impacts on population viability. Moreover, knowledge of wildlife diseases remains limited (Vögeli *et al.* 2011). While some studies suggest that pathogens prevalence increases with habitat loss and fragmentation (e.g. Mbora & McPeek 2009), others found variance among host species or no effects of fragmentation (Schmidt & Ostfeld 2001; Püttker, Meyer-Lucht & Sommer 2007; Sebaio *et al.* 2010; Johnson & Haddad 2011; Vögeli *et al.* 2011). For example, Johnson and Haddad (2011) report that in a model plant–pathogen system (the sweet corn *Zea mays* and southern corn leaf blight *Cochliobolus heterostrophus*) in a large-scale habitat corridor experiment, corridors did not facilitate the movement of wind-dispersed plant pathogens, that patch connectivity did not increase levels of fungal plant disease, and that in fact edge effects were the key drivers of plant disease dynamics. To the best of our knowledge, very few studies report evidence of increased pathogen prevalence with increased connectivity, except in agricultural pests (See Box 12).

Recent modelling studies similarly report negligible or case specific adverse consequences of increased ecological connectivity on pathogen spread (Park 2012). McCallum & Dobson (2002) suggested that where a pathogen affects only a single endangered species, the adverse consequences of pathogen movement between patches are largely counterbalanced by the benefits of increased colonization rates of patches that would otherwise become extinct. Similarly, when considering one endangered and one non-endangered host species, the model suggested that too much connectivity may lead to the endangered species' extinction only if it had higher extinction and lower colonization rates and if the non-endangered species was less susceptible to the pathogen, thus acting as a reservoir species. A model by Gog, Woodroffe & Swinton (2002), that considered pathogens affecting a reservoir of several species, found that although patch occupancy fraction may decline with increased host movement and a small amount of external pathogen input, there was a critical level of pathogen prevalence beyond which occupancy fraction continuously increases with connectivity.

Overall, McCallum & Dobson (2002) recommend that it will be preferable to support connectivity as long as the endangered species is more vagile than the pathogen reservoir, or if infection in reservoir patches is transient. With high connectivity, the proportion of patches occupied by the endangered species will decline due to infection but the species will nevertheless persist, whereas the species is likely to become extinct at low levels of connectivity. However, the plausibility of introducing completely new diseases to naïve hosts when designing corridors and other connectivity measures must be carefully considered, as well as cases where movement-based transmission is combined with other disease-transmission modes (Park 2012).

Box 11: Connectivity and pathogens: Pathogen prevalence in Dupont's Lark not affected by spatial connectivity

Vögeli and colleagues (2010) studied a total of 27 populations of Dupont's lark (*Chersophilus duponti)*, an endangered passerine, in the highly fragmented steppe habitat of the Ebro Valley in the North East of Spain. They found that the prevalence, richness and diversity of the pathogens infecting passerine Dupont's lark populations (including 26 haematozoans, bacteria and viruses) were not dependent on host densities, geographical isolation or metapopulation structure. However, they increased consistently with population size, which was the key determinant of pathogen communities regardless of the spatial arrangement of populations.

In this case, ecological connectivity did not have an effect on pathogen prevalence in the study species, but population size was the key determinant of pathogen prevalence. While there have been concerns that ecological connectivity might enable the global spread of new parasites and therefore could increase extinction risks of threatened species, modeling and empirical studies suggest that the benefits of corridors that allow dispersal of hosts among habitat patches probably far outweigh the risks of increased pathogen transmission (McCallum & Dobson 2002; Altizer, Harvell & Friedle 2003).

Box 12: Control of insect pests in agricultural landscapes: benefit of diverse landscapes

Kruess & Tscharntke (2000) conducted empirical and experimental studies on pest insect communities and their parasites inhabiting pods of bush vetch (*Vicia sepium* L.) in old meadows in south-west Germany. They found that both loss of habitat and habitat isolation lowered the level of parasitism experienced by their phytophagous insect pest species. Thus conservation of large and less fragmented habitats may enhance species diversity as well as parasitism of potential pest insects, hence contribute to the stability of ecosystem functions.

Overall, insect pest pressure on agricultural crops has been found to be lower in complex landscapes versus simple landscapes (Bianchi, Booij & Tscharntke 2006). In this case diversified landscapes, including non-crop habitats with adequate connectivity for natural enemy populations, hold most potential for the conservation of biodiversity and sustaining the pest control function of agro-ecoystems.

Connectivity may promote the spread of invasive alien species. Invasive alien species are organisms that are intentionally or unintentionally introduced to a given area outside their original range and cause severe disturbances in their new range. They are recognized as one of the leading threats to biodiversity. The fact that increasing connectivity may facilitate the spread of invasive alien species has been recognized for more than 20 years (Simberloff 1988) and warnings have been issued repeatedly (e.g. Proches *et al.* 2005; Lindenmayer *et al.* 2008). Yet few empirical and theoretical studies have tested the relationship between the degree of connectivity and the rate of spread of invasive alien species (With 2004; Alofs & Fowler 2010). Fragmentation may either reduce the interactions between native and invasive alien species by maintaining a separation in their distributions (e.g. Alofs & Fowler 2010), or facilitate the colonization of degraded or new habitats by invasive alien species (With 2004), for example via increasing landscape scale disturbances. For instance, the spread of an invasive grass species, *Bothriochloa ischaeum*, was shown to be inhibited by habitat fragmentation caused by a woody plant encroachment, and a stronger effect was found when the effects of habitat loss were removed in the analysis (Alofs & Fowler 2010).

6.3.3 Risk: Homogenization of otherwise distinct population genotypes

Species that may be most at risk from climate change are so called 'rear edge' populations: populations at the low latitude limit of a species range, usually confined to small habitat islands in a matrix of unsuitable habitats (Hampe & Petit 2005). The often small size and prolonged isolation of these populations have resulted in reduced within-population genetic diversity (e.g. Castric & Bernatchez 2003; Chang *et al.* 2004). Yet, disproportionately high levels of genetic differentiation are found between these populations, even adjacent ones, giving rise to exceptionally high levels of regional genetic diversity (Castric & Bernatchez 2003; Petit *et al.* 2003). For example, a genetic analysis of microsatellite markers of 2087 brook charr (*Salvelinus fontinalis*) a coastal fish exhibiting limited marine movements whose range recently shifted northward, showed that both the most recently colonized northern populations and the southernmost ones had lower allelic richness, together with an increase in genetic differentiation (Castric & Bernatchez 2003).

Allowing such populations to mix by implementing connectivity measures might therefore lead to the dilution of these unique population genotypes, and to the reduction of genetic diversity at the large scale (Ovaskainen 2012). Besides, too much gene flow among local populations may impede the process of local adaptation (North *et al.* 2011). Therefore, maintaining some level of habitat fragmentation may be beneficial in the long term (Ovaskainen 2012). Nevertheless, in situations where the populations concerned are not extremely rare endemics and the level of habitat fragmentation very high, the benefits of increasing connectivity will likely greatly outweigh the potential costs.

Hence, conservation management has to take into account the level of biodiversity subject to management. At the species level, enhancing connectivity may be a beneficial measure, but it may lead to loss of diversity at the community and genetic level. This is especially relevant as connectivity measures are likely to affect several species.

6.3.4 Risk: Dealing with uncertainty

According to Hodgson *et al.* (2009) quantifying connectivity per se and its benefits is plagued with uncertainty. Uncertainties in measuring connectivity include: habitat area, quality and pattern; species-specific dispersal's distances; tails of dispersal distributions; effects of source and target habitat quality on emigration and immigration; species dispersal behaviour (how do they search for habitat) and how it is affected by the matrix; and, as highlighted above, the influence of spatially correlated environmental stochasticity on metapopulation dynamics (Moilanen & Nieminen 2002). The effects of connectivity on long-term expected population size are also very uncertain (Hodgson *et al.* 2009).

6.3.5 Trade-offs: Connectivity versus increasing protected habitat area, quality, and aggregation

Whereas the total population carrying capacity of a habitat network continually increases with habitat size, it will reach a plateau after which increasing dispersal and habitat aggregation will no longer have a significant effect on population size. A number of authors (e.g. Opdam & Wascher 2004; Hodgson *et al.* 2009; Ovaskainen 2012) point out that improving habitat quality and increasing protected area size (both factors of connectivity) are more likely to increase population size than increasing aggregation of habitats and dispersal capacity, unless loss of connectivity has been identified as the main constraint. In fact, enlarging existing protected habitat area and quality rather than protecting new habitats far away from the existing sites can increase simultaneously both total area and connectivity (Lawton *et al.* 2010; Beier 2012), as currently intended by fostering larger Nature Improvement Areas as large ecological restoration zones in the UK (Lawton *et al.* 2010).

6.3.6 Trade-offs: A few large versus many small reserves: keeping a 'habitat network'

The optimal balance between maximizing connectivity by bringing all habitats into a single large conservation area, or conserving a network of many small reserves, depends on how the processes of local extinction, emigration and immigration correlate with patch area. If these are strongly positively correlated to patch area, a few large reserves is an optimal solution. In the opposite case, many small reserves (amounting to the same area) is likely a better way to maximize total population size (Ovaskainen *et al.* 2002). For example, studies of the Glanville fritillary butterfly (*Melitaea cinxia*) in Finland suggests that for this species an intermediate level of connectivity would be the optimal solution (Ovaskainen & Hanski 2004). Conversely, a study on wood decaying fungi showed that the same amount of resources was more effective when concentrated rather than isolated at sparse locations within the landscape (Hottola, Ovaskainen & Hanski 2009) (see also Vuilleumier *et al.* 2007).

6.3.7 Trade-offs: Costs of connectivity measures

Resources to be allocated to conservation projects are often scarce and connectivity measures can be expensive to implement. For example in the Netherlands, construction of an ecoduct for road crossing normally requires 3 to 4 Mio Euros, whereas typical prices for land acquisition are around 40.000 Euro per ha (Ovaskainen 2012). Conservation managers must therefore carefully weigh the costs and benefits of implementing connectivity measures, and consider available alternatives to promote population robustness in the face of climate change. These include maintaining and increasing the area of high quality habitat and controlling other anthropogenic threatening processes (Hodgson *et al.* 2009). Expensive ecoducts are, however, by no means the only way to improve connectivity and a host of advocated measures are reviewed below.

Figure 17: An ecoduct in the Netherlands © Rijkswaterstaat, The Netherlands

6.4 Connectivity in practice: How to implement connectivity

Functional connectivity may be enhanced by a number of ways such as improving habitat quality of source and receptacle habitats, reducing inter-patch distances or increasing the permeability of the matrix. We review below the most recommended strategies to improve connectivity (Heller & Zavaleta 2009). Connectivity measures serve to facilitate four types of movements: local movement (to forage, for example), dispersal of individuals to other habitat patches, nomadism by wide-ranging species and seasonal migration (Bennett 2004).

It is important to remember that movement across a landscape involves three stages:

- emigration (leaving an area),
- movement to a new site, and
- imigration (establishing in the new site).

All three need to be considered; measures to increase numbers of species emigrating and their success in becoming established at new sites are as important as facilitating movement.

6.4.1 Improvement of source habitat

In order to provide sufficient connectivity, conservation management needs to ensure or increase the quality of existing occupied habitat and increase species population sizes in order to increase propagule pressure and/or number of dispersing individuals.

6.4.2 Creation or enhancement of sink habitats

To be able to migrate, animals and plants must first have suitable habitats where to migrate to. Creating or preparing habitats in the matrix to receive migratory organisms is therefore one way to enhance connectivity (Hannah, Midgley & Millar 2002; Millar, Stephenson & Stephens 2007). For example Hódar, Castro & Zamora (2003) recommended reforestation at higher altitudes adjacent to natural stands in order to facilitate tree migration under climate warming in Mediterranean Scots pine forests. In the EU Life project, 'Management and Connectivity of Amphibians in the Cultural Landscape of Lower Saxony', the remediation to intensive land use systems that remove ponds and close migration corridors was to recreate specific types of reproduction pond sites in order to improve coherence and connectivity between populations to ensure colonisation of restored habitats (http://ec.europa.eu/environment/life/project/Projects/index.cfm).

6.4.3 Corridors

The most widely advocated connectivity measure is the creation of corridors (Heller & Zavaleta 2009): Corridors can serve to enhance ecological connectivity at very different scales: at the local level (for example a tunnel or bridge to enable animals to cross a road to reach their spawning, mating or feeding grounds), at the regional (connecting two large protected areas to increase habitat availability and access to suitable locations) or national and international levels (connecting a network of protected areas at the national or European scale), as well as the global level, such facilitating the continental migration of migratory birds (Bennett 2004; Kettunen *et al.* 2007)

In terrestrial environments, corridors are often physical linkages and may vary from narrow to broad landscape corridors. Measures for narrow linear corridors, such as rivers, hedgerows or forest corridors, include:

- Protecting existing urban riparian habitats, railway lines, roadsides and urban parks and forests (Wilby & Perry 2006) (Box 8)
- Protecting natural corridors, such as hedgerows and rivers. A typical example is the mitigation of migration barriers to fish, as illustrated by three EU Life projects in Sweden, Poland and France respectively (Box 13).
- Creating ecoducts and other man-made crossing structures, which has become commonplace worldwide (Taylor & Goldingay 2010) (see Box 14)

Box 13: Protection of natural corridors – experience from LIFE projects in Sweden, Poland and France

In Sweden, road infrastructures and dams represent important migratory barriers in rivers – for example, it is estimated that 5000 to 8000 culverts prevent fish migration in Norrbotten and Västerbotten counties: they prevent the Atlantic salmon (*Salmo salar*) and the brown trout (*Salmo trutta*) from reaching suitable habitats for spawning, and indirectly affect freshwater pearl mussels which need Atlantic Salmons or brown trout's to reproduce. Culverts also forces otters to cross roads, leading to high rates of mortality. The EU life project 'ReMiBar - Remediation of migratory barriers in Nordic/Fennoscandian watercourses –' aims at mitigating these migratory barriers to restore connectivity in Swedish rivers, notably through culverts restoration and actions to facilitate safe road crossings for otters.

In Poland, the EU Life project 'Niebieski korytarz Regi - The construction of the blue ecological corridor along the valley of Rega river and its tributaries' aims at restoring the connectivity between two Natura 2000 protected sites in the Rega basin: the mouth of the Rega river and the Brzeźnicka Węgorza. Spawning channels are being cleared from a number of hydro-technical structures by building fish passes to create an ecological corridor and spawning grounds created or restored for the reintroduced Atlantic Salmon and trees being planted along the river bank to decrease water temperature.

In France, the EU Life project 'LIFE Continuité écologique - LIFE ecological continuity, management of catchment area and associated patrimonial fauna' in the Natural Regional Park of Morvan in Burgundy aims at enhancing the viability and numbers of populations of crayfish *Austropotamobius pallipes*, the fresh water pearl mussel *Margaritifera margaritifera*, the thick shelled river mussel *Unio crassus*, the European brook lamprey *Lampetra planeri*, and the European bullhead *Cottus gobio* via restoring river connectivity to enable a natural recolonisation of their natural habitats, which will also indirectly benefit all species of aquatic flora and fauna within the streams. This is achieved through restoration of degraded habitats such as the rehabilitation of 5 km of streams, removing obstacles in streams to improve connectivity, creating fordings or watering places and permanent crossing points to protect the banks from cattle and agricutural and forestry vehicles, removing invasive alien species along the banks and replanting natural vegetation as well as removing invasive alien crayfish, and changes in agro-silvicultural practices along the banks
(source: http://ec.europa.eu/environment/life/project/Projects/index.cfm) .

Creating broad landscape corridors is mainly achieved by:

- Improving the connectivity of a whole region to connect two protected areas via a set of defragmentation and habitat restoration measures (see Box 15)
- Establishing new protected areas to connect large regions in the landscape or two larger protected areas, which has mainly been considered in North America (Shafer 1999; Scott, Malcolm & Lemieux 2002), but might be considered in Europe, too. For example, a new protected area was created in the Rocky Mountains of Canada to restore a regional corridor for endangered nomadic wolves (*Canis lupus*), by imposing strong limitations to human activities in the Cascade Corridor (six kilometres long) to restore connectivity through the Bow River Valley in Alberta's Banff National Park, and successfully enabled wolves to move through the corridor and inhabit new ranges (Bennett 2004).

Box 14: Creation of ecoducts in the Netherlands

In the centre of the Netherlands, the area of Veluwe, the largest lowland nature area in North Western Europe rich in biological diversity, falls within two national parks and hosts many large mammal species such as the red deer (*Cervus elephus*), fallow deer (*Cervus dama*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). An existing two-lane road between Apeldoorn and Arnhem was upgraded to a four-lane motorway in 1988, and fenced to prevent the incursion of animals onto the road. To prevent the isolation of mammal populations in the South Eastern corner of the Veluwe from the main populations in the centre of the region, two ecoducts were built across the new motorway: 'Woeste Hoeve' and 'Terlet'. A monitoring programme demonstrated that the large mammal species indeed used the ecoduct, and almost immediately after the motorway was opened. The impact of these ecoducts on the long-term viability of the deer and wild boar populations were not evaluated, yet they prevent a decline in the extent and quality of habitats available to the main mammal populations in central Veluwe, by providing a linkage route to the older and richer forest habitats at the east of the road (Bennett 2004).

There are many other examples of ecoducts in Europe, and the Netherlands alone have over 600 wildlife crossings (including underpasses and ecoducts) that have been used to protect the endangered European badger (*Meles meles*), as well as populations of wild boar, red deer, and roe deer (Taylor & Goldingay 2010).

Box 15: Habitat connection and improvement along the Insubria ecological corridor between the Alps and the Ticino valley in Italy (LIFE+ TIB project)

In Lombardy, the area between Campo dei Fiori and Ticino River parks provides a natural north-south corridor between the Pre-Alps and the Po Plain, rich in natural habitats of high conservation value such as mountain habitats, relict moorland, pine groves, oak and hornbeam forests, pristine river ecosystems and wetlands. It harbours highly valuable species, including the Ferruginous Duck (*Aythya nyroca*), endemic amphibian species (e.g. the common Spadfoot Toad (*Pelobates fuscus insibricus)*; the Italian Agile Frog (*Rana latastei*) and Italy's most rare and threatened mammal, the River Otter (*Lutra lutra*), which has been reintroduced in the region.

Yet Lombardy is one of the most densely populated areas of Europe and urban areas have extensively sprawled over the last 50 years, extending linearly along major roadways, inflicting habitat loss and fragmentation of the natural ecosystems of the region. The LIFE+ TIB project (www.lifetib.it) aims at halting biodiversity loss in the region by increasing the functionality of this important wildlife area, which spans a total of 15 000 ha and hosts 14 Natura 2000 network sites. This will be achieved by improving and restoring natural habitats and through connectivity measures targeting roads and waterways. Some of the specific measures being implemented include a defragmentation programme for taxa with different degrees of mobility. The ecological coherence of the region will further be improved via other measures which will indirectly reinforce connectivity by improving the overall quality of habitats in the region. Measures include:

Defragmentation targeting roads

- Improvement of existing underpasses
- Building of new underpasses for amphibians and small animals (minimum 50cm wide rectangular concrete constructions under roads)
- Building of underpasses for small- and medium-sized animals using pipe-jacking techniques (circular cross-sections with a minimum diameter of 1 meter and a maximum 1.5m for roads that are slightly raised with respect to surrounding land)
- Building of underpasses for small- and medium-sized animals underpasses using cut-and-cover techniques (1 meter wide square or rectangular cross-sections for roads at even level with the surrounding land)
- Building of a 10 m wide overpass

Defragmentation targeting waterways via the improvement of three culverts, by clamping a series of stones to one side of the culvert and to the riverbed to build access ramps.

Direct restoration and habitat management actions

- Restoration of existing, and creation of new, wetlands
- Creation of pools for amphibians
- Removal of invasive tree species
- Addition of log pyramids to woodlands to increase habitat availability for saproxylic species that are associated with dead or decaying wood
- Planting of white willow (*Salix alba*) trees
- Building of dry stone walls, once a common feature of farmland landscapes in the Pre-Alps and important habitats for reptiles
- Placement of visual bird-scaring devices on power lines

Education programmes of community schemes

- Encouraging farmers to access community funds for planting hedgerows, woodlots, and other natural elements useful for biodiversity

- Awareness programmes

Via a combination of measures targeting habitat restoration and migration facilitation, the project will therefore enhance connectivity throughout a whole ecological corridor linking two important protected areas and two distinct regions: the Alps in the North and the Po Plain in the South, and the corridor will become part of a wider ecological network, the Rete Ecologica Regionale (RER). This is likely not only to enhance biodiversity conservation, but also to facilitate the future dispersal and migration of species moving to higher latitudes due to the effect of climate change.

Corridors may also consist of functionally connected corridors of habitat patches acting as stepping stones in the wider landscape (matrix), i.e. an array of small patches of habitat that species use during movement for feeding and resting (Kettunen *et al.* 2007). Stepping stones corridors can be created by

- Protecting existing habitat patches (see Box 16)
- Restoration of potential habitat patches: An example of stepping stone corridor creation includes the South Essex Stepping Stones project, where habitat enhancement and creation work in 'brownfields' on a landscape scale across the South Essex region will be implemented to create habitat links throughout the region to allow the dispersal of invertebrates (source: www.buglife.org).

Box 16: Butterfly re-colonisation of habitats through stepping stones in the UK

In the UK, the silver-spotted skipper butterfly (*Hesperia comma*) was historically widely distributed in dry or calcareous grasslands and heathlands grazed by rabbits or livestock across southern and eastern England. Yet after the progressive conversion of unimproved grasslands to arable land during the first half of the twentieth century, and the overgrowth of many areas of grassland following the plummeting of rabbit populations after a *Myxomatosis* outbreak, the distribution of the silver-spotted skipper contracted to just 46 sites in ten regions.

In the succeeding years, rabbit populations gradually recovered and livestock farming expanded: new areas of suitable habitat became available to the remaining butterfly populations. A monitoring programme carried out in the period 1982–1991 showed that the silver-spotted skipper colonized 29 'empty' habitat patches and disappeared from ten occupied patches, while over 100 apparently suitable habitat patches remained unoccupied. Analysis of the spatial dynamics of the butterfly's dispersal showed that the probability of colonization was dependent above all on two factors: closeness of the habitat patch from an occupied patch, and size of habitat patch. Where the patches were less than 8.5 kilometres apart, and large enough, they functioned as stepping stones across the landscape (Thomas and Jones 1993).

A further survey of the entire British range of *Hesperia comma*, conducted in 2000, confirmed the importance of distance-dependent colonization for the maintenance and expansion of this butterfly population. A fourfold increase in population numbers and a 10-fold increase in habitat area occupied compared to 1982 was recorded. The maximum distance butterflies could travel to colonize a patch was 9km, comparable to 1982-1991 data. Furthermore, the probability that a habitat patch would be colonised by 1991 or 2000 increased with the proximity to a patch occupied during a previous survey (Davies *et al.* 2005).

This example highlights the importance of landscape-scale level conservation management and the need to focus on the surroundings of protected areas, as well as the process of 'stepping stone' habitat colonization and the importance of maintaining habitat networks to sustain healthy populations.

In the marine environment, the corridor concept also applies, yet in a rather different way (Bennett 2004). There are three main kinds of linkages in seascapes:

- marine corridors (for example straits used by certain species during migration, for dispersal or to move between spawning and feeding grounds)
- estuarine linkages, i.e. the ecosystems formed by the interaction between a river and the sea
- coastal linkages, where species such as turtles and seals rely on littoral shallows or the presence of a coastline.

6.4.4 Matrix management

Connectivity can also be enhanced via another type of linkage, i.e. forms of landscape matrices that allow a species to survive during movement between habitat patches. Matrix management is the second most popular recommendation for improving connectivity (Da Fonseca, Sechrest & Oglethorpe 2005; Heller & Zavaleta 2009). Simulation models suggest that improving the matrix quality could counteract the increased extinction risk due to island habitat losses by as much as 60% (Fahrig 2001). Carroll *et al.* (2004) showed by using spatially explicit population models that if matrix quality were to decline, the area of protected sites would need to greatly increase if populations of large predatory mammals in North American parks were to remain viable. Matrix improvement can take place at different spatial scales and for different landscape types. It must also be kept in mind that measures which improve the quality of the overall landscape, including sustainable-use areas (see below), can contribute to restoring connectivity (Kettunen *et al.* 2007). Overall, matrix management includes as many ecological as social measures, as in most cases 'non habitat' landscapes consist of human settlements or landscapes extensively used by people.

Matrix management measures include:

- **'Softening' land use via agri-environment schemes (AES):** agricultural landscapes are a major source of habitat fragmentation for wildlife (Cushman 2006; Krauss *et al.* 2010), and agri-environment schemes that improve matrix quality by 'softening' agriculture could play an important role in reducing fragmentation effects at the landscape level (Smallshire, Robertson & Thompson 2004; Vickery *et al.* 2004). For example, models across a farmland matrix suggest that restoring field margins to grassy banks (an option already available in a number of agri-environment schemes) would increase butterfly movement rates. European farmland bird declines can largely be attributed to agricultural intensification. Current agri-environment practices include activities such as organic and integrated farming, or planting trees and shrubs to create shelterbelts and hedgerows in farmlands (Donald & Evans 2006). They are central to certain biodiversity conservation programmes and targets, such as the English Government aim to reverse the decline of the 20 species in the Farmland Bird Index by 2020 (Vickery *et al.* 2004). Animals with intermediate dispersal ability, such as reptiles, amphibians, mammals and some invertebrates, are most likely to benefit from matrix management measures (Donald & Evans 2006). Sustainable practices can be seen as an extension of AES to other ecosystem management practices, where human communities 'soften' land use through sustainable or less damaging practices, such as low intensity forestry or alternatives to building sea walls (Bennett & Mulongoy 2006). In addition, while agri-environment schemes typically address environmental management at the farm- and field-scales, there is increasing evidence that incorporating the landscape-scale would increase scheme effectiveness (Lawton *et al.* 2010; Franks & Emery 2013).
- **Creating buffer zones around reserves** which aim to protect the network from potentially damaging external influences by limiting acceptable land uses (Semlitsch & Bodie 2003; Thorell & Gotmark 2005) and flexible land use zoning at reserve boundaries to allow for land swaps in the future as species distributions shift (Heller & Zavaleta 2009 and references within). The ecological benefits of buffer zones include

(Martino 2001): protection from human encroachment, protection from storm damage, enlargement of the reserve area and hence, reduction of the edge effects, and enhancement of the environmental services provided by the reserve, as suggested for forests (Götmark, Söderlundh & Thorell 2000; Millar, Stephenson & Stephens 2007).

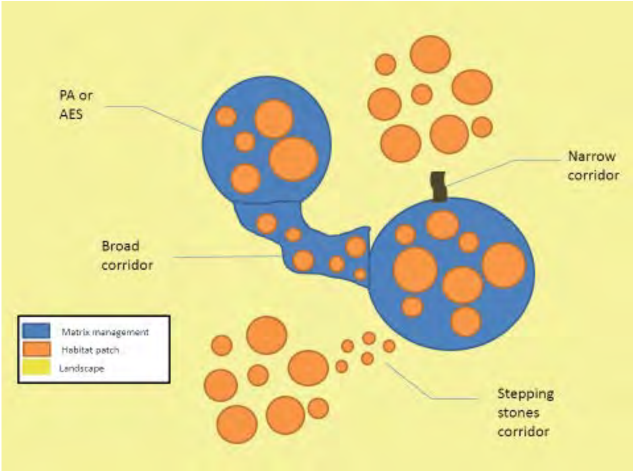

Figure 18: Schematic overview of some different types of connectivity measures: broad and narrow corridors, stepping stone corridors, matrix management (PA: protected area; AES: agri-environment scheme; adapted from Bennett 2004).

Attributes of species most likely to benefit most from matrix management measures are listed in Box 17 below.

Box 17: Some characteristics of species likely to benefit most from matrix restoration

(adapted from Donald & Evans (2006) with kind permission of the Journal of Applied Ecology)

1. Species with high habitat/climate envelope specificity, or species whose climate envelopes are predicted to move most; these species' ranges are likely to change most and their transitional and final ranges are likely to be smallest (Hobbs & Hopkins 1991).

2. Species with poor dispersal powers relative to the gaps between fragments; these are likely to be less able to occupy new sites than species with high dispersal powers (Gaston & Blackburn 2002).

3. Species with low survival or persistence in hostile matrix habitats.

4. Species with high habitat specificity; their transitional and final ranges are likely to contain little of the right habitat (Julliard, Jiguet & Couvet 2003) and they may be less able to cross matrix habitats.

5. Species occupying habitats that are already highly fragmented.

6. Species occupying habitats that are particularly vulnerable to climate change; in western Europe these include native pinewoods, calcareous grassland, mesotrophic lakes and riverine and wetland ecosystems (van Ierland *et al.* 2001).

7. Species that are limited to higher latitudes and altitudes; their ranges are likely to become smaller and more fragmented under climate change.

8. Species with seasonally variable food requirements; these may require specific combinations of habitats and the ability to move between them.

9. Species with small or widely fluctuating populations; increasing connectivity might be more effective at preventing the extinction of small populations than larger ones (Henle *et al.* 2004).

10. Species requiring moist or wet soil habitats; wet habitats of ecological importance are likely to become more fragmented under climate change (Naden & Watts 2001)

11. Larger species, species at higher trophic levels, species that require large areas of habitat and habitat interior species; these generally require larger areas of habitat, necessitating more movement between patches (Dorp & Opdam 1987; Soulé & Gilpin 1991).

12. Species dependent on climax, rather than seral, habitats; these tend to have lower fecundity, dispersal ability and tolerance to fragmentation (Travis & Dytham 1999; Opdam & Wascher 2004).

13. Species with relatively small brain size; these are less adaptable to environmental change and do less well in hostile matrices (Shultz *et al.* 2005).

14. Species showing other traits, including low reproductive output, low tolerance of disturbance, low survival in matrix habitats and highly social behaviour, that make them particularly sensitive to fragmentation (Hudgens & Haddad 2003; Henle *et al.* 2004).

6.4.5 Ecological networks

Ecological networks are built to enhance the protection of core protected areas and the connectivity at the regional and European level (Bennett & Mulongoy 2006; Kettunen *et al.* 2007). Importantly, there are several instances where protected area systems are called ‘ecological networks’ even if there may be little ecological connectivity amongst the sites. The Natura 2000 network for example mostly consists of a collection of unconnected protected areas (Kettunen *et al.* 2007). Yet this collection of Natura 2000 protected areas (established under the 1992 Habitat Directive European legislation) forms a strong basis for building effective ecological networks in Europe and at the regional level. A number of past and current projects aim at targeting ‘ecological coherence’ both within and between these sites: there were 61 projects listed under the theme ‘Ecological coherence’ in the EU Life projects database in April 2013. Increasing the connectivity between these sites can be achieved via any or a combination of the methods listed in the previous sections (Kettunen *et al.* 2007). A favoured method is the building of large ecological corridors to link two nature reserves, as illustrated in the case study on habitat connection and improvement along the Insubria ecological corridor between the Alps and the Ticino valley in Italy (Box 15).

Typically ecological networks comprise core areas, most often protected areas, sustainable use areas, and corridors (Bennett & Mulongoy 2006; Kettunen *et al.* 2007; Lawton *et al.* 2010). They also commonly include nature restoration or nature creation areas, i.e. areas with a high potential to develop into valuable habitats, which can serve to connect core areas. Several national ecological networks have already been developed, such as the National Ecological Network in the Netherlands (Jongman & Pungetti 2004; von Haaren & Reich 2006). Jongman and colleagues (2011) also developed an indicative roadmap for a Pan European Ecological Network (PEEN), following the Pan European Biological and Landscape Diversity Strategy (PEBLDS)(Council of Europe 1996), while it remains a challenge to develop a common approach among the over 100 European-wide agencies that are responsible for biodiversity conservation (Jongman *et al.* 2011) (for priority setting see also (Vos *et al.* 2008).

6.4.6 Connectivity measures: reported effectiveness of corridors

Using corridors for conservation is increasing despite a lack of consensus on their effectiveness. Gilbert-Norton *et al.* (2010) conducted a meta-analysis of 78 experiments from 35 studies to assess corridor effectiveness, and notably whether corridors indeed increase movement of plants and animals targeted, whether their effectiveness differs among taxa and between manipulative and natural experiments, and how changes in experimental design influence findings. They found that corridors increased movement between habitat patches by approximately 50% compared to patches not connected with corridors, and were more important for the movement of invertebrates, non-avian vertebrates, and plants than for birds. After controlling for taxa differences and experimental design (whether studies controlled for distance between patches), they found that natural corridors existing in the landscapes prior to the study showed more movement than man-made corridors created for the study. Hence this study suggests that corridors are generally effective at increasing movement between populations, while it is of special importance to protect and enhance existing corridors.

Importantly, the empirical basis for whether corridors in turn support overall population viability through gene flow is less clear (Corlatti, Hackländer & Frey-Roos 2009; Clevenger & Sawaya 2010). Gilbert-Norton and colleagues (2010) examined whether corridors were actually used by animals and plants, but not the effects of corridors on population dynamics. Indeed, the fact that animals use corridors for their movements does not necessarily mean that these are effective for achieving biodiversity conservation goals, namely to increase population viability of threatened species and prevent a decline for common species (Ovaskainen 2012). For example, Corlatti, Hackländer & Frey-Roos (2009) conducted a review of the scientific literature on population genetic consequences of crossing structures such as ecoducts, and found no evidence that such structures enable gene flow and mitigate genetic problems associated with small population size (Ovaskainen 2012).

Overall it is clear, however, that without high quality donor or source areas with viable populations, the effectiveness of corridors will be of little relevance. In general larger core areas are likely to support larger populations of individual species as they are less likely to fluctuate to local extinction with extreme events due to greater physical heterogeneity and thus greater habitat diversity in most cases, and in addition suffer from less ‘edge effects’ (Lawton *et al.* 2010). In this way, they should support more stable metapopulation dynamics and function as core sites for corridors and enhance connectivity.

Box 18: Connectivity measure effectiveness - Ecological corridors for Clouded Apollo butterfly populations in southern Finland fail to provide connectivity

In an attempt to counteract the negative effects of small population size, such as inbreeding depression in the endangered Clouded Apollo butterfly (*Parnassius mnemosyne*), Ovaskainen *et al.* (2008) tried to increase the connectivity between two butterfly populations in Southern Finland by cutting a semi-open corridor through the forest between their respective habitat patches. The following summer, many butterflies were present in the corridor area, which abounded with nectar plants Clouded Apollo butterflies use during their adult life stage. The corridor was thus considered successful.

Yet, mark recapture studies conducted prior to and after the creation of the corridor showed that there was no increase in the number of butterflies that moved from one habitat patch to the other. Indeed, butterflies showed a marked preference for the corridor area and progressed through it so slowly that they were unlikely to reach the other end through their lifetime. In the absence of a corridor, butterflies emigrated out of their habitat patches less frequently, but moved faster in the matrix (closed forest and cultivated fields). As a result, they had a higher probability of reaching the other habitat patch. Hence the corridor did not provide effective connectivity between patches. It may have been successful would the distance between patches have been shorter or the patch areas smaller.

This study is a stark example of how cautious one must be when measuring corridor effectiveness, and how connectivity critically depends on the interplay between landscape structure, such as patch area and distances between patches, and dispersal behaviour.

6.5 Connectivity design for climate change adaptation

Connectivity is the most often cited recommendation for adaptation to climate change measures in the peer reviewed literature (Opdam & Wascher 2004; Heller & Zavaleta 2009) . Yet, to the best of our knowledge, only a few papers (Rouget *et al.* 2003; Williams *et al.* 2005; Beier & Brost 2010; Nuñez *et al.* 2013) have explored how to design connectivity corridors for climate change (see also Beier 2012). In this section, we review the most up-todate recommendations for enhancing connectivity as a means of adapting to climate change adaptation and argue that all recommendations made in the previous sections equally apply in the context of climate change.

6.5.1 Type of species likely to benefit from climate change connectivity measures: predicting climate change impacts

Our predictions of which type of species are most likely to benefit from climate change connectivity measures are directly derived from our predictions of which species are most likely to experience a deterioration or shift or their habitat range due to climate change. These predictions are still debated and are based on differing rationales:

a) Species which evolved in predictable environments

For example, Opdam & Wascher (2004) argue that those species that have evolved in stable, predictable environments with low natural dynamics and a continuous habitat, but which have become highly fragmented due to anthropogenic disturbances, will be more likely to be restrained by spatial configuration in face of climate change effects than species of more dynamic habitats. Such ecosystems include forests, fresh water marshland, heath and grassland. Opdam & Wascher (2004) oppose these ecosystems to those intrinsically highly unpredictable where species might be less susceptible to anthropogenic fragmentation, such as coastal, agricultural and 'early succession stages of' ecosystems. Furthermore, for species with generalized resource requirements (typically of low conservation priority as a consequence), connectivity within and among these habitats is less likely to be an issue (Henle *et al.* 2004; Hottola, Ovaskainen & Hanski 2009).

b) Species at range margins

Recent climate change has shifted many species' distributions poleward and upslope (Warren *et al.* 2001; Parmesan & Yohe 2003; Parmesan 2006). Based on these observation, a number of authors (Opdam & Wascher 2004; Hampe & Petit 2005) argue that species that would most benefit from connectivity are so called 'rear edge' populations: populations at the low latitude or upper altitude limit of a species. They therefore recommend that conservation efforts should be focused on creating climate gradient corridors and managing the points of colonisations at climate margins.

c) Connectivity as a buffer against climate change for species in topographically diverse areas

Beier (2012) argues that although focusing on range margins the approach can be useful in protecting rare or range-restricted species and in vulnerability assessments (Dawson *et al.* 2011), it is of little use for buffering climate change effects on a large scale due to the massive uncertainties (Beier & Brost 2010) and rough scale inherent to species range shift models.

Elevation and latitude by themselves may not be sufficient to identify favourable climates. For example, contrary to the widespread expectation of uphill range shifts with climate warming, downhill shifts can occur when water availability increases at lower altitude with climate warming. Whilst temperatures increased during 1935– 2005 along mountain slopes in California, 46 of 64 plant species exhibited downslope shifts in their optimum elevations, probably because precipitations also increased (Crimmins *et al.* 2011). Similarly, onshore winds, coastal fog, and rainfall patterns create situations in which the precipitation gradient changes from west to east rather than poleward (Dobrowski 2011).

Such phenomena may explain why coarse-scale models predicted the loss of all suitable climate space for plant species in Europe, and yet, models that considered microclimates linked to landscape topography predicted that most plant species would continue to find suitable climates within short distances of their current habitats (Randin *et al.* 2009; Scherrer & Körner 2011). Randin *et al.* (2009) showed that in the Central Alps, species distribution models based on the commonly used climate data at 16 x16 km resolution predict higher rates of habitat loss than models based on 25 x 25 m cells: they might largely underestimate the persistence of plant species in alpine landscapes with a high topographic variability. Scherrer and Körner (2011) showed that in the Swiss Alpine area, micro-habitat variation in surface and soil temperature has a strong influence on local vegetation composition. They express dire concern that even the most sophisticated climate models predict meteorological rather than actual life conditions. In reality, micro-habitats differ not only in temperature but also in soil type, nutrient and water availability, and wind exposure, and the majority of organisms living in such micro-habitats are strongly decoupled from atmospheric conditions. They use a model taking into account variation in topography at the micro-scale using data from a 2 km^2 area in the Swiss Alps. They predict that in a 2°C warming scenario, only the 10 % of species depending on the very coldest micro-habitats will have to move to higher elevations, while the vast majority of species will find thermally suitable 'escape' habitats within just a few metres. They point out that due to their topographic variability, alpine landscapes are likely to be safer places for most species facing climate warming than lowland terrain. Such findings suggest that connectivity could be very efficient at mitigating climate change impacts where it enables species to move to nearby, more suitable micro-climates.

6.5.2 Strategies for designing corridors for climate change

There are two approaches to designing corridors for climate change: 'coarse filter' conservation planning which aims at protecting most species and targets whole sets of plant communities or geophysical units, and 'fine filter' conservation planning which targets individual species (Beier 2012). Connecting present and future projected suitable habitats based on the predictions of range shift models would entail 'dozens or hundreds' of single species corridors, each up to several hundred kilometres long. Conversely, if climate corridors are designed to link topographically diverse natural landscapes, they only need to be relatively short (1 to 30 km, Beier 2012). We further examine how to design climate corridors for both approaches.

a) 'Coarse filter' conservation corridors: expanding protected areas and enhancing within-area connectivity

Beier & Brost (2010), Davison *et al.* (2012) and Lawton *et al.* (2010) suggest expanding or establishing new protected areas to conserve the diversity of unique topographic settings and climates, and focusing on enhancing connectivity within and between these areas. The protection of large natural landscape blocks supports a wider range of environmental conditions, larger populations with greater evolutionary and demographic potential, and more species. This approach amounts to enhancing resilience to climate change, rather than building a climate corridor based on a temperature gradient shifting poleward. Such an approach is sensible if the magnitude of climate change does not exceed the local variation in micro-climates within a protected area (Beier 2012).

Designing such 'coarse filter' corridors may be a way to bypass the trade-off between investing in connectivity or enlarging protected areas. It makes both ecological and economic sense for these large protected areas to become the focus of a connectivity strategy for adaptation (Beier 2012). Importantly, such coarse climate corridors do not differ from traditional corridors and other traditional forms of connectivity measures: they support range expansion by promoting colonization and gene flow, and we can therefore take advantage of the advances in this field. Although areas for 'coarse filter' approaches are being identified in the US, we are unaware of such approaches in Europe.

b) Long distance climate corridors

To track a 3°C increase in a region lacking topographic micro-climates, a species would need to migrate 400 km poleward (Krosby *et al.* 2010), and unlike in coarse filter corridors in a large protected area, such species would migrate to a previously unoccupied area. Moreover, such a long and narrow corridor would be unlikely to support the poleward transition of a corresponding small population with little genetic diversity (Beier 2012). A suitable strategy may be to promote long distance range shifts via a combination of short shifts within a large protected area, and short corridor-mediated movements between protected areas (Beier 2012). When this approach is unsuitable, the option of translocating a species to a more suitable habitat can be investigated (see below) .

6.5.3 Importance of existing protected areas in Europe as building blocks for ecological networks

In the context of climate change in Europe, the active management of existing protected areas and the establishing or reinforcing of existing corridors between them may form an adequate strategy to help the process of colonisation of migrating species.

The effectiveness of protected areas, both as single sites as well as their functioning as portfolio, has rarely been assessed (Gaston *et al.* 2006), and it is unclear how they will perform under a changing climate. However, while empirical evidence is still scarce, recent studies suggest that protected areas are favoured sites of colonization by six migrating species of birds at range margins in Southern Britain as well as more than 200 invertebrate species (Thomas *et al.* 2012; Hiley *et al.* 2013). Active management is also pivotal so that protected areas may enhance metapopulation expansion under climate change (Lawson *et al.* 2013). An extensive modelling study using climate envelope projections (Araújo *et al.* 2011) suggests, that the majority of the more than 100 000 protected areas sites in Europe are likely to loose climate suitability for a large proportion of the species they host. It has to be noted, though, that a shift of climate envelopes indicates an enhanced exposure to climate change rather than an accurate prediction of actual losses of species, as vulnerability also depends on the climate sensitivity and adaptive capacity of the species (Dawson *et al.* 2011). Nevertheless, in such conditions, improving connectivity between sites will be pivotal to enable species threatened by climatic changes in their current locations to move to more suitable sites.

6.6 Conclusions

Designing and implementing measures to enhance connectivity for climate change adaptation is at its beginning (Hodgson *et al.* 2009). Corridors and other structural connections have been widely advocated, but now require a more refined and evidence-based approach.

It appears clear that a crucial starting point to improving connectivity and species persistence is to create, enlarge and prioritise protected areas that have high environmental heterogeneity, which are more likely to harbour a diversity of micro-climates and hence provide suitable conditions for a range of species even in the face of variable environmental conditions (Beier & Brost 2010; Lawton *et al.* 2010; Beier 2012; Ovaskainen 2012). Such areas should also promote population growth and dispersal and provide conditions for dispersing individuals. This will both optimize the efficiency of connectivity measures and maximize the return on conservation investment, which may otherwise be lost if no connectivity can be established and populations subsequently decline.

Studies also suggest that connectivity is unlikely to be an appropriate measure in some cases, especially for rare, restricted species which are not surrounded by easily accessible micro-climates. In such cases, translocations from within their current range to locations suitable in the future may be an option. This is discussed below.

7 Translocation of species as a climate change adaptation: review of concepts, evidence and recommendations

7.1 Rationale

Many species facing a risk of extinction as a result of climate change are endemics with low dispersal ability. Translocation to habitats with a suitable climate, outside the species natural range, may be the only option to save these endangered populations.

Rapid climatic change has already caused severe range contractions, some species extinctions and changes in the distribution of many plants and animals (Parmesan & Yohe 2003; Parmesan 2006). Various taxa are shifting their habitat range to higher latitudes and altitudes, and species dispersing too slowly or facing dispersal barriers, such as species endemic to mountain tops or living in highly fragmented habitats, might become critically endangered (Thomas *et al.* 2004; Hoegh-Guldberg *et al.* 2008; Ohlemüller *et al.* 2008). For example certain British butterfly species are unable to disperse or adapt swiftly enough to track climate change impacts (Menéndez *et al.* 2006). In such cases, translocation of species to locations within (Hoegh-Guldberg *et al.* 2008) or outside (Thomas 2011) their native range may be the only option to prevent extinction.

7.2 Translocations: an already widespread conservation strategy

Conservation translocation is the deliberate movement of organisms from one site for release in another (IUCN/SCC 2013). Conservation translocations consist of (a) reinforcement and reintroduction within a species' indigenous range, and (b) conservation introductions, comprising assisted colonisation and ecological replacement, outside indigenous range (IUCN/SCC 2013, Ricciardi & Simberloff 2009b). Translocation is already a widespread conservation strategy worldwide (Fischer & Lindenmayer 2000). Seddon, Soorae & Launay (2005) expanded the IUCN Reintroduction Specialist Group records and compiled a database of 699 species of plants and animals targeted by reintroduction projects worldwide, although few case studies have been thoroughly documented in Europe, while there have been over 80 cases worldwide (Fischer & Lindenmayer 2000).

While climate change has stirred renewed interests in translocations as a conservation strategy (Thomas 2011), it is important to note that the introduction of species outside their historical distribution is already a well-established method in some parts of the world (Seddon 2010). In New Zealand for example, many endemic birds, reptiles, and invertebrates threatened by introduced mammalian predators were translocated to offshore islands (Saunders & Norton 2001) that may not be part of their historical ranges. Most of these translocations resulted in new viable populations (Atkinson 2001). Yet, whilst re-introduction of a species within its indigenous range is a commonly accepted conservation method, translocations should always have a comprehensive risk assessment. The IUCN Guidelines (IUCN/SCC 2013) stipulate as a general principle, that, where substantial uncertainty about the risks of a translocation outside indigenous range remain, such a translocation should not be undertaken (IUCN/SCC 2013). Ultimately, the use of documented species distributions is somewhat arbitrary, especially in the context of Europe, which has a long history of human occupation (Seddon, Soorae & Launay 2005).

7.3 Review of successful and unsuccessful translocations and lessons learnt

Translocation is a common method in conservation biology, yet reviews suggest that translocation programmes are only successful in 11 to 26% of cases overall, though this percentage was found higher for certain species (see Table 16, Bajomi 2007; Fischer & Lindenmayer 2000). The IUCN Reintroduction Specialist Group compiled a set of guidelines for planning and carrying out translocation programs (IUCN/SCC 2013).

Fischer & Lindenmayer (2000) reviewed a total of 180 translocations and identified a host of factors influencing the 'success' of a transclocation, i.e. the establishment of a viable population. Notably, biological and ecological factors, such as habitat quality, genetic diversity, and the number of individuals released for translocation (approximately 100 minimum) played an important part in successful programmes. Of 87 re-introductions conducted for conservation purposes, they recorded a success rate of only 29 % and 15% from wild and captive populations respectively, and for more than half the cases outcomes were uncertain at the time of publication.

Fischer & Lindenmayer (2000) concluded that active conservation management and good programme implementation, including public relations and education, good team management, socio-political factors, consideartion of legal issues and litigation costs and crucially long-term commitment to the project were equally important to the success of a translocation programme. To ensure the success of future introductions Fischer & Lindenmayer (2000) recommend for conservation managers to adopt clear definitions of success, including the development of corresponding monitoring protocols. This should include gathering key parameters such as the number of animals, sex ratios, adult and juvenile ratio through time. They also advocate publication of both positive and negative results, as most translocations are poorly documented in the published literature. Bajomi (2007) provides a review of outcomes of different reintrocuction programmes (Table 16) and equally calls for more systematic publication of results as publications are heavily biased towards certain taxa, such as mammals and birds (Bajomi *et al.* 2010).

Table 16: Outcome of reintroduction programmes according to different reviews. Modified with kind permission from Bajomi (2007), using data from Griffith *et al.* (1989); Beck *et al.* (1994); Fischer & Lindenmayer (2000); Singer, Papouchis & Symonds (2000); Matson, Goldizen & Jarman (2004)

	Griffith et al. 1989	Beck et al. 1994	Fischer and Lindenmayer 2000	Singer et al. 2000	Matson et al. 2004
Number of studies considered	198	72	180	100	21
Type of programmes	Translocation of en-dangered species	Reintroduction with captive breeding	Reintroduction (conservation & other purpose mixed)	Reintroduction/Augmentation	Reintro-duction
Taxa	Mammals and Birds	All groups of animals	All groups of animals	Bighorn sheep (*Ovis canadensis*)	Black-faced impala (*Aepyceros melampus*)
Successful (%)	44	11	26	41	62
Uncertain (%)	-	89	47	29	-
Unsuccessful (%)	56	-	27	30	38

7.4 Opportunities for translocations in Europe in the context of climate change

In theory, there are three reasons to consider moving species as a response to climate change:

- Move a species between areas within its historical range, to make overall population larger and more resilient, or to 'rescue' subpopulations reduced by extreme climate events, or to introduce genotypes adapted to changing conditions
- Move a species threatened by changing climatic conditions to a more suitable area outside its historical range, to conserve the *species* being moved

- Introduce a new species as a functional replacement for an existing species thought unlikely to persist under climate change, to maintain *ecosystem function*

Species to be relocated under climate change are likely to be characterized by small and isolated populations with low-dispersal ability, inhabiting highly fragmented landscapes and therefore unable to migrate to more suitable habitats. For example, species inhabiting isolated habitat patches in agricultural or urban areas may be unable to shift their habitat range. Mountain species, including alpine plants (Lenoir *et al.* 2008), butterflies (Wilson *et al.* 2005; Franco *et al.* 2006) and birds (Sekercioglu *et al.* 2008) may become limited in their range shift by the upper altitude limit of the current mountains they inhabit (Thomas, Franco & Hill 2006). In addition, as shown for amphibians, infectious diseases and pathogens may also be able to find suitable climate spaces at higher altitudes and therefore impact on host species range size. In such cases, connectivity measures (see above) or enlargement of protected area of habitats is unlikely to be effective, and translocation may be a favoured strategy to prevent extinction (McLachlan, Hellmann & Schwartz 2007; Hoegh-Guldberg *et al.* 2008).

Especially in the context of climate change, the choice of the species to relocate and the identification of suitable geographical locations will be crucial. When relocating outside the species historical range, Thomas (2011) suggests moving populations to the same biogeographic region that share similar groups of organisms, and replacing extinct species with ecologically equivalent ones to restore biological communities. Thomas (2011) further suggests examples of species under threat of climate change in Europe that may benefit from translocation programmes.

7.5 Barriers to translocation programmes

As highlighted above, translocations are often unsuccessful. We review below a number of factors likely to impede the successful implementation of translocation programmes that are worth noting:

- **Costs**: A non-negligible barrier to translocation programmes implementation is their cost, which can exceed several thousand dollars per year, and sometimes up to one million dollars (Fischer & Lindenmayer 2000; Teixeira *et al.* 2007).
- **Survival of released organisms**: Release of animals and plants for conservation purposes aims to establish a long-term population of the species released. There are usually three critical steps to achieve this objective: survival of the organisms after release; settlement of the organisms into the release area and successful reproduction in the release area (Gosling & Sutherland 2000; Letty *et al.* 2003). For a majority of species, the first step, survival after release, is likely the most critical, as many animals die shortly after having been released (Letty, Marchandeau & Aubineau 2007; Teixeira *et al.* 2007). Studies on translocations of European rabbits (*Oryctolagus cuniculus*) in France all reported mortality rates of over 50% (Letty *et al.* 2003). Hence in many instances, immediate or soon-after-release death is likely to be a major barrier to the success of translocations. Teixeira *et al.* (2007) suggest that stress is one of the main factors associated with early deaths, and advocate better cooperation between animal welfare scientists and conservationists.
- **Disease transmission**: While it is well known that introduced organisms may carry pathogens dangerous for native species, less is known about the risks posed by native pathogens to introduced species. Naïve translocated, introduced hosts may indeed be particularly vulnerable to pathogens they have never encountered before. For example, German red deer stags introduced to the South of Spain were found to be dying from *Theileria* sp. and *Elaeophora elaphi* infections, two parasite strains that are non-harmful to native Iberian deer (Höfle *et al.* 2004). Hence, pathogens that do not present risks for the native fauna may be fatal to introduced species.
- **Lack of suitable endemism cold-spots to act as recipient regions**: A potent barrier to establishing translocation programmes in the context of climate change is

the successful identification of climatically suitable recipient locations (Webber, Scott & Didham 2011). For example, difficulties of matching source and recovery sites have hindered the successful reintroduction of endangered plant species (Lawrence & Kaye 2011). Reintroductions were especially difficult where the target communities within a species historic range had been lost (Possley *et al.* 2009).

- **Uncertainty about the necessary suitable conditions of recipient areas**: even though suitable cold spots might be more easily found in Europe, suitable climatic conditions alone are of course insufficient for the establishment of a new species. For example, Vilà & Hulme (2011) argue that the Iberian Lynx is adapted to living in Mediterranean shrub vegetation, and hence even the presence of its prey (rabbits) and a suitable climate in the UK, a proposed recipient area for translocation (Thomas 2011), would not ensure its survival.
- **Uncertainty about the actual and predicted impacts of climate change**: an important consideration is to assess whether the main cause of the decline of the population of interest is indeed linked to climate change, and cannot be remediated in any other way. Predicting the effects of climate change is an evolving discipline in science that is likely to undergo a strong development in the years to come. Predictions of bioclimatic envelope models have often been seen as predictions of species extinctions, while they may rather provide information on likely population density than population stability and resilience (Oliver *et al.* 2012). Changes in the predictions made are likely to significantly influence the perceived necessary mitigation and adaptation measures. As referred to in section 6 above on connectivity, new climate models incorporating landscape topography in their prediction of micro-climate variations have vastly different outcomes from traditional models (Dawson *et al.* 2011). For example, species from mountain-tops have long been seen as a prime target for translocation measures under climate change for the obvious reason that species endemic to such habitats would be unable to migrate. New models suggest that species of mountain areas might be less affected by climate change impacts, owing to the close proximity of suitable micro-climate space in these highly heterogeneous landscapes (Scherrer & Körner 2011; Beier 2012). Translocation for climate change should apply only when we can both identify a relevant climatic threat in the native habitat as the main driver of decline, and predict with enough accuracy the suitability of climatic conditions as well as other important factors (e.g. prey species) in a proposed recipient area. Finally, it is important to consider the time scale in which climate change takes place: how can we predict at which point in time we should translocate a species, and how to provide a smooth transition to a similar climate (since the endemic and recipient region undergo climate change at the same time)?

7.6 Risks associated with species translocations

There are two prominent risks associated with translocations, namely decline or extinction of native populations caused by introduced species, and hybridisation between native and introduced species.

7.6.1 Risk of decline or extinctions of native species populations

Webber, Scott & Didham (2011) point out that translocations are only likely to be successful for generalist species not reliant on prey mutualists, the characteristic that makes an 'invasive' species most damaging to its recipient ecosystem (Williamson, Fitter & Url 1996). Indeed, the risks brought by translocations are closely associated with the problem of invasive species (Hewitt *et al.* 2012), and whether an introduced species may become invasive must be given extremely high consideration, given that many historically documented species-level extinctions have been linked to invasive alien species (Clavero & García-Berthou 2005).

Some argue that the majority of extinctions by invasive alien species are caused by translocations either to 'island-like environments' such as when a mammal species is introduced to an oceanic island, or a predatory fish to a lake; or to a very different biogeographic region, such as in inter-continental translocations (Thomas 2011). Indeed, gathering data on 204 translocations of 152 mammal species around the world extracted from Long (2003) showed that successful intercontinental and continent-to-remote island translocations were more often associated with a decline in native species populations than intracontinental and continent-to-coastal island translocations. Yet, the risk for the latter category of translocation was not negligible: at least 15% of species successfully translocated within a continent were considered to have had negative impacts on native populations. Hence, even restricting translocation to locations within the same biogeographical area will leave significant risks of damaging native species populations in the recipient location. Besides, whether intracontinental translocations are less likely to cause threats to native species is likely highly case dependent. While Ricciardi & Simberloff (2009b) found that intracontinentally transferred mammals less often caused damage, Mueller & Hellmann (2008) found no correlation between continental origin and degree of invasion severity for a state list of invasive plant species in the United States. They also found that although invasive species from intracontinental origins were far less common, this was not the case for fish and crustaceans. Caution is nonetheless necessary when analysing such data: a species whose native range is on another continent may be more likely to be labelled invasive; similarly, taxa such as fish and crustaceans may be more easily recorded as invasive owing to well-kept fishing records (Mueller & Hellmann 2008).

Regardless, Thomas (2011) argues that not all locations may present the same risks for translocation, and that Britain for example, would be a suitable recipient location for many species from Southern Europe. He points that no native species has been extirpated as a result of non-native species establishing in Britain and that the largest declines of indigenous species in Britain stem from long-distance translocations (Thomas 2011).

7.6.2 Risk of change in ecological interactions

A careful consideration of the plausible negative impacts of translocation on the recipient ecosystem is necessary before taking action. As a starting point, we review below known mechanisms underlying negative impacts on native flora and fauna brought about by introduced species.

a) Alteration of fundamental ecosystem processes and ecological interactions: The introduction of new species may alter fundamental ecosystem processes such as nutrient cycling, primary and secondary production and disturbance regimes (erosion, fire, and sedimentation) (Ricciardi & Simberloff 2009b). For example, pig invasions into forests often trigger the removal or change of the herbaceous understory, which in turn may alter nutrient retention and cause faster decomposition of soil organic matter (Aplet, Anderson & Stone 1991). Introduced or invasive species can also alter the susceptibility of an ecological community to disturbance (Walther *et al.* 2009). Introduced species can further disrupt key ecological interactions such as plant-pollinator mutualism (Traveset & Richardson 2006). For example, invasion by the Asian plant *Impatiens glandulifera* in Central Europe has altered plant-pollinator interaction by competing for bee pollinators with native flowers: its rich nectar attracts pollinators more than the native flora, reducing the seed set in local plants and their overall fitness (Chittka & Schürkens 2001).

b) Release from natural competitors and parasites: Webber, Scott & Didham (2011) warn that releasing a species outside its natural range may separate translocated species from its natural enemies and competitors, and may therefore allow it to spread at fast rates and drive other species to extinction. Torchin *et al.* (2003) similarly point out that the invasion process often ‘filters out’ parasites, i.e. successful introduced species often establish in their new range without their native parasites, and accumulate few new ones relative to the parasite burden of native species. They reviewed a wide range of studies and found that introduced plant species usually escaped more than half of their native parasites. Mitchell & Power (2003) also reviewed studies of 473 European plants introduced to the US and found that they escaped more than 90% of their native fungal and viral pathogens. Similar evidence was found in studies of birds, insects as well as of molluscs, crustaceans, fishes, birds, mammals, amphibians, and reptiles (Torchin *et al.* 2003). The reduced parasitism experienced by most introduced species may partly explain why they can sometimes spread at the expense of native species (Torchin & Mitchell 2004).

c) Spread of parasites and pathogens: Perhaps one of the most serious threats associated with species translocations is the spread of parasites and diseases (Hoegh-Guldberg *et al.* 2008). Even though most invasive species are likely to experience reduced parasitism, when a pathogen or parasite is introduced by an invading species, it can have very severe impacts on the native ecosystems, and sometimes threaten human health. There are numerous examples of diseases spread by invasive species to both similar and new host species (Ricciardi & Simberloff 2009b). The 'blue-tongue disease' for instance, a tropical virus, spread in northern Europe as a result of the combination of climate change and the introduction of infected livestock from Mediterranean countries (Wilson & Mellor 2008). The crayfish plague, transmitted by the fungus-like *Aphanomyces astaci*, was brought by the introduced North American red signal crayfish (*Pacifastacus lenusculus*) and Lousiana crayfish (*Procambarus clarkii),* and devastated native European crayfish populations (Gherardi 2006).

Particular attention must be brought to the fact that introduced new diseases can sometimes be transmitted to new host species. For example, the introduction of the West Nile virus in North America, likely from infected birds from the Middle East, has caused the decline of several species of North American birds, for example, the American crow (*Corvus brachyrhynchos*) that were not immune to the virus (LaDeau, Kilpatrick & Marra 2007). Similarly, the introduction of new diseases is not exclusively restricted to inter-continental or continent-to-coastal/island translocations, and can cause threats to humans. For example Brucellosis was brought to people and domestic animals in Switzerland and France by Hungarian and Czechoslovakian hares introduced for repopulation (Pastoret *et al.* 1988, quoted in (Frölich *et al.* 2002).

d) Predation on native species: Predation by introduced species is one of the most serious impacts of translocations (Simberloff 2010). Many mammals introduced on islands have caused mass extinctions of native species. For example, at least 37 species and subspecies of island birds throughout the world became extinct following the introduction of rats and a global review showed that at least 75 species of seabirds are affected by invasive rats (Jones *et al.* 2008). One of the most famous example of predation by an introduced species is the many cichlid fish species decimated by the Nile perch (*Lates niloticus*) introduced to Lake Victoria (Goudswaard, Witte & Katunzi 2008).

e) Resource competition: Competition for resources can sometimes be a serious threat to native species (Simberloff 2010). A well-known example is the resource competition for food and space of the introduced North American gray squirrel (*Sciurus carolinensis*) to Great Britain which is better at foraging than the native red squirrel (*Sciurus vulgaris*) and therefore drive its population decline (Wauters & Gurnell 1999). In addition a parapox virus, which is highly pathogenic to the red squirrel but has no detectable effect on grey squirrel health, adds significantly to the ecological impact of the introduced species to the native species (Tompkins *et al.* 2002). The North American grey squirrel is currently spreading throughout Europe and the native species can be considered extinct in some regions. This is especially likely to happen when one population is far larger, and hence the species in minority will have more chances of encountering a mate from the distinct population than from its own species. There are many cases where birds, fishes, mammals and plants have been threatened to extinction by hybridisation. For example, the European white-headed duck (*Oxyura leucocephala*) in Spain is threatened by hybridisation with the North American ruddy duck (*Oxycura jamaicensis*) (Muñoz-Fuentes *et al.* 2007), a species which was first introduced to the United Kingdom simply as an ornamental and subsequently spread southward to Spain (Simberloff 2010).

f) Hybridisation: Hybridisation through a native and introduced species can also create a new invasive species (Ricciardi & Simberloff 2009b; Simberloff *et al.* 2013). A well-known example is the hybridization in England between the introduced North American Saltmarsh cordgrass *Spartina alterniflora* and the native grass *Spartina maritima* which produced the new cordgrass *Spartina anglica,* rendered fertile after a spontaneous chromosomal mutation. It subsequently became a globally invasive species (Thompson 1991; Ricciardi & Simberloff 2009b).

Finally, even without dilution of the original genotype or creation of hybrids, hybridisation can threaten a species when it produces infertile hybrids and forestalls successful matings. This is the case for threatened populations of the European mink (*Mustela lutreola*): the North America mink (*Mustela vison*) was introduced in Europe with view to create a fur bearing industry, and subsequently established populations in the wild. North American mink males become sexually mature before the European males, and therefore hybridize with many European female minks. The hybrid embryos resulting from these matings are not viable and are aborted. Female minks cannot breed again following abortion during the same season, a serious threat for these small endangered populations (Maran & Henttonen 1995 cited in Simberloff 2010).

7.7 The translocation debate

Hewitt and colleagues (Hewitt *et al.* 2011) reviewed in detail a total of 50 peer reviewed publications contributing to the debate on translocations. While they found more publications in favour of translocations (30 supporting papers against 10 opposing and 10 neutral), they point out that of all the papers expressing strong concerns most were published after 2007: the debate on translocations appears to be intensifying. Key arguments for and against translocation (Hoegh-Guldberg *et al.* 2008; Fazey & Fischer 2009; Ricciardi & Simberloff 2009b; Ricciardi & Simberloff 2009a; Thomas 2011) can be summarised as follows:

Pro translocation

- High risk of large scale species extinction as current climate envelopes move/disappear and novel climate envelopes emerge
- Low risk if species moved within same biogeographic region and to areas of low endemism
- Cost and effort of translocation might in fact be lower than large scale corridors
- Species ‘natural ranges’ are not static. Current/Historical ranges are only a snapshot of past biogeographic change

Contra translocation

- The risk of introduced species becoming invasive
- The risk of spreading pathogens
- Cost and effort
- Diverting attention from more effective action
- The ethics of creating ‘unnatural’ assemblages

Scholars vastly disagree about the potential risks of using translocation of species as a climate adaptation strategy. While some are advocates of translocation (Hoegh-Guldberg *et al.* 2008) viewing it as the only realistic option to save crucially endangered species from extinction (Thomas 2011), other scientists have warned against any form of ‘assisted colonization’, claiming that associated risks and uncertainties are too high (Ricciardi & Simberloff 2009b; Webber, Scott & Didham 2011). Others call for a careful assessment of the situation before taking action (Schlaepfer *et al.* 2009), and IUCN developed a framework for risk assessment (see the IUCN guidelines, IUCN/SCC 2013).

7.8 Conclusions

Currently, no extensive list of species and populations threatened by climate change has been collated, for whom translocation would be the best and only available conservation strategy. Establishing such a list, along with case-specific associated risks, barriers, and benefits of translocation together with uncertainties would be essential to acquire a more realistic and accurate view on whether translocations are a desirable conservation strategy, and to which extent, and for which species, they should be used. Careful risk assessments are essential tools, especially as climate change may call for more dramatic translocations (Schwartz & Martin 2013). Ultimately, our knowledge is constrained by the uncertainties underlying climate change projections, and of how an introduced population will evolve together with its recipient ecosystem. Ricciardi & Simberloff (2009b) warn of the impossibility of accurate risk assessment, and assert that it is not yet possible to predict with accuracy whether a given species will become extinct due to climate change, and whether a translocated species will endanger native species. Decisions whether or not to translocate a population must therefore be made in the face of uncertainty, and translocation will never be risk free. An exhaustive review of past introductions (for case studies of re-introductions collated by the IUCN/SSC Re-introduction Specialist Group, see Soorae 2010), and proven risks associated with certain taxa, would enhance the evidence base and help to decrease the likelihood of wrongly picking a future invasive species for translocation. The IUCN proposes a simple framework for decision making based on three categories (Hoegh-Guldberg *et al.* 2008):

- Critical extinction threat (How endangered is a particular species?)
- Technical feasibility (Is translocation feasible?)
- Suitability (Do benefits outweigh costs?)

Assessing and evaluating costs and benefits, including the cost of inaction and opportunity costs with regards to other adaptation actions, with the help of decision-making frameworks is eventually needed for developing appropriate translocation policies (Hewitt *et al.* 2011). Further developing such decision frameworks will be crucial to help managers and decision makers to reach appropriate decisions and enable planning and implementation. Finally, translocations by their very nature address isolated cases. While they may be considered a last resort strategy for some rare endemic species, they cannot realistically form the core of adaptation strategies to climate change.

8 Survey - Climate adaptation planning and conservation measures in European conservation projects

8.1 Introduction

To support the findings of the 2011 Edinburgh workshop, to broaden the geographic scope of practical experience and to provide input to the Bonn conference in June 2013, we conducted a survey of conservation projects across Europe with site managers. The survey's goals were to assess how climate adaptation principles are put into action through planning and measures in conservation sites and focussed on the following issues:

- Impacts of climate change and the perceived temporal relevance of climate change for management of the respective conservation sites
- Integration of climate adaptation into conservation goals
- Management actions and monitoring on their sites
- Information sources and barriers to action.

The survey was based on a questionnaire devised by Nick Macgregor and colleagues at Natural England for a study in parts of England (Macgregor & van Dijk 2014). For this survey, the questions were adapted while retaining high compatibility for a future comparison with the Natural England survey (not part of this report). Next to the English version a translated German version was provided to allow easier completion for German speaking participants. A copy of the English version is listed in the Appendix (11.3).

The questionnaire was circulated via email to over 260 contacts from the EU LIFE project database and ENCA members distributed it to their networks. Europarc Germany and the HabitChange project were also instrumental in facilitating input from their members. The survey was open from 15 April to 8 May 2013, a very busy period for site managers. Their efforts in sharing their time and expertise are very much appreciated.

8.2 General characteristics of the conservation sites

8.2.1 Distribution of responding conservation sites

We received feedback of a total of 72 survey responses from 16 European countries, with approximately a third of responses from the UK (25 sites), one third of responses from Germany (26 sites) and 21 sites from 14 other countries across Europe (see Table 17). The feedback reflects in part the focus of the professional networks of the authors of this report, as well as possible language barriers posed by the English and German questionnaire. One might expect the distribution to possibly also reflect to some degree the awareness of, and ongoing activities with regards to, climate adaptation in conservation in some of the countries. However, throughout the analysis of the data, no country specific correlation of results could be established with exception to the extent of completion of vulnerability assessments. Regarding the other counties there was a balanced spatial coverage of responding sites, with six sites in the Northern Europe, four sites in Central Europe, seven sites in South-Eastern Europe.

The term conservation 'site' is used to describe the overall conservation area considered in the questionnaire. While most sites had a formal conservation designation as National Nature Reserve, National Park, Special Area of Conservation (SPA) or Natura 2000 sites, this was not a requirement for the survey. Several responses covered more than one conservation site, for example for Latvia all Natura 2000 sites were assessed, while some Boreal peatland sites were grouped for Finland or several smaller wetland sites for Sweden.

Table 17: Distribution of surveyed conservation sites across Europe

Country	Number of survey responses
Austria	2
Belgium	1
Bulgaria	2
Cyprus	1
Czech Republic	2
Finland	3
Germany	26
Greece	1
Ireland	1
Italy	2
Latvia	1
Poland	1
Romania	2
Sweden	1
Switzerland	1
United Kingdom	25
Total	72

A complete list with names and location of the participating sites can be found in Appendix 11.4 of this report.

8.2.2 Organisation type of the sites

More than half of the respondents were from public authorities (57%, see Fig. 19), 35% from park-reserve authorities and non-governmental organisations (NGOs), while research institutes, businesses and other organisation types played a minor role. In the UK all responding sites were governed by national authorities (25), whereas the respondent sites of Germany and the other countries comprised a mixture of organisation types.

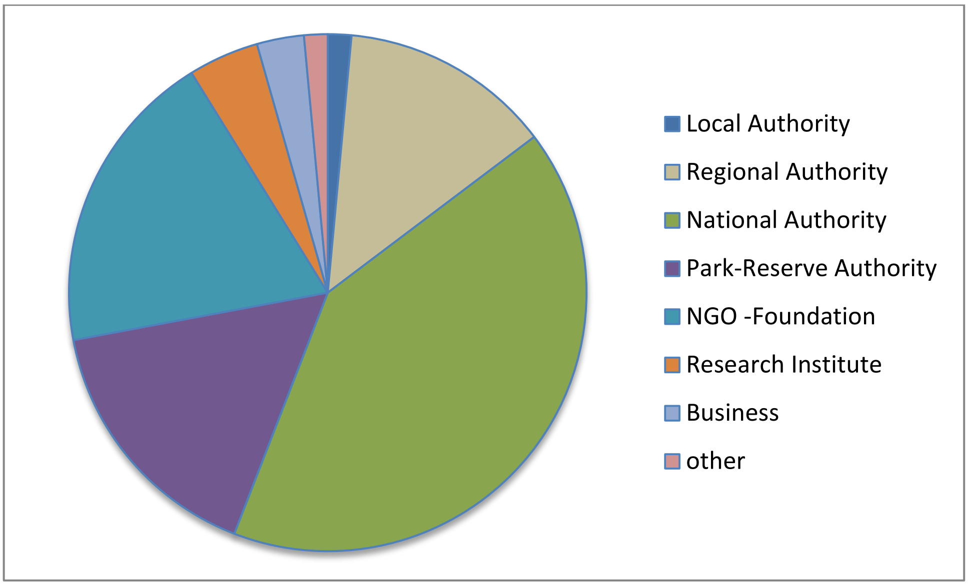

Figure 19: Organisation type of conservation projects

Most respondents were reserve managers, senior reserve managers, LIFE project managers or conservation officers in national and regional authorities. Much of the feedback, especially in the UK, was provided by national authority staff from Natural England, Natural Environment Wales and Scottish Natural Heritage. In Germany feedback was provided by six national parks and six biosphere reserves and across Europe especially from LIFE project managers. Many of the respondents had a scientific background and some are explicitly employed as scientists within their organisation.

8.2.3 Habitat types

Habitat types responded to the Natura 2000 categories and were grouped into 23 habitat type groups. Respondents were asked to indicate the occurrence and proportional distribution of these groups, which were then further grouped into broad ecosystem types for this analysis.

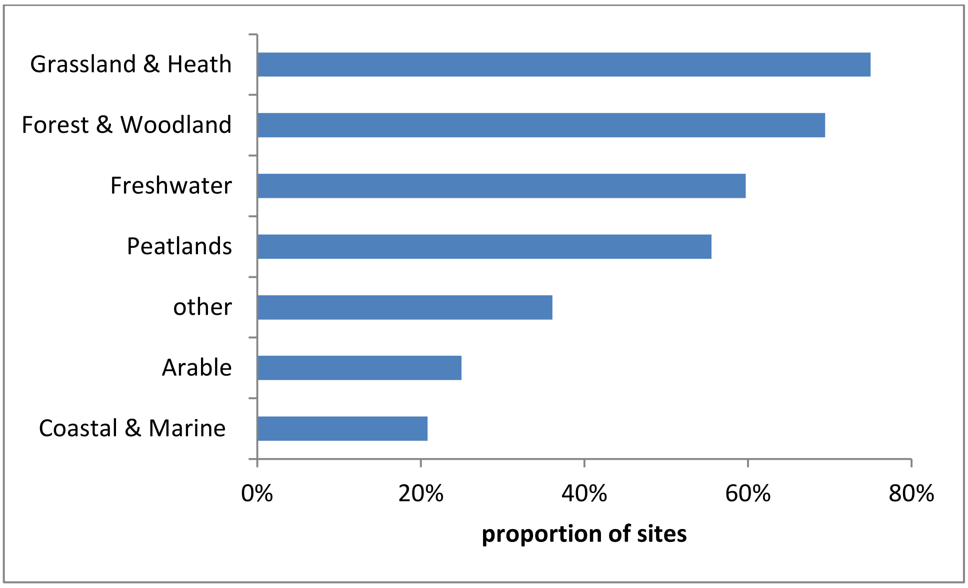

Figure 20: Number of projects with representation of broad ecosystem types across sites (Mountain ecosystems not listed as they may comprise any of these ecosystem types apart from coastal and marine habitats)

Most sites comprised several broad ecosystem types within their range: 52 out of 70 sites included at least 3 broad ecosystem types, while about half of the sites (34) were highly heterogeneous and included at least four ecosystem types evenly spread, each covering less than 50% of the site area.

Grassland and heath as well as forest and woodland ecosystems were the most widely represented ecosystem types and represented in 75% and 69% of sites respectively (Fig. 20). Freshwater and peatland ecosystems were a part of 60% and 56% of sites respectively, whereas arable and coastal and marine ecosystems were least frequently represented.

Mountain regions usually include a mixture of land cover, with a dominance of forest cover across Europe, except for those in southern Greece, Ireland and the UK, and grasslands in Nordic countries, and are mainly defined through their topography (Nordregio 2004). Here we consider only four sites as true mountain regions (with elevations >1000m above sea level) namely the National Park Berchtesgaden in Germany, Snowdonia/Eyriri National Park in Wales, the Greece Ethnikos Drymos Oitis National Park and Creag Meagaidh National Nature Reserve in Scotland. Upland areas (between 600 and 1000 m above sea level) are found in both Czech areas, the Biosphere Reserve Rhön, Germany and the Eifel National Park in Germany, as well as some areas in the UK.

8.2.4 Size of the sites

The area of the sites surveyed widely varied between sites. Several conservation sites for this survey included several sites or areas, that were close to each other and managed in a coordinated way or a number of separate sites that comprised similar ecosystems managed in similar ways and with similar climate issues and adaptation actions.

Out of the 38 sites whose area was specified, the smallest site covered 37 ha whilst the largest covered as much as almost 800,000 ha. The latter encompassed all Natura 2000 sites for Latvia. Other respondents managed for example 50 dispersed small wetlands across Finland others managed several Natura 2000 areas within a national character area or a region. The median area of the sites was 675 ha, and the majority of sites had an area of less than 10,000 ha.

About half the sites belonged to a wider network area, varying between around 100 ha to more than 1 Mio ha belonging to the Trilateral Waddensee area (NL-D-DK) UNESCO world natural heritage site. Statistics of the responses are shown in Table 18.

Table 18: Size of the surveyed sites

	mean	median	min	max
Size of the site under conservation management (ha) (n= 72 respondents)	34,631	675	37	793,265
Size of the wider relevant network area / larger conservation area of which the site is part of (ha) (n=38 respondents)	133,657	3,673	101	1,150,000

8.2.5 Land ownership and management structure

Most sites reported a mixture of ownership across sites, often also within sites. Only a third of the sites are (partly) owned and managed by the responding organisation. Approximately another third is (partly) owned by government or NGOs and managed by the responding organisation or in partnership with public authorities. About half of the land is (partly) privately owned and managed by either the responding organisation or by a mix of agreements with the land owners e.g. Natural Nature Reserve agreements and/or agri-environment agreements.

8.2.6 Primary conservation goals of the sites

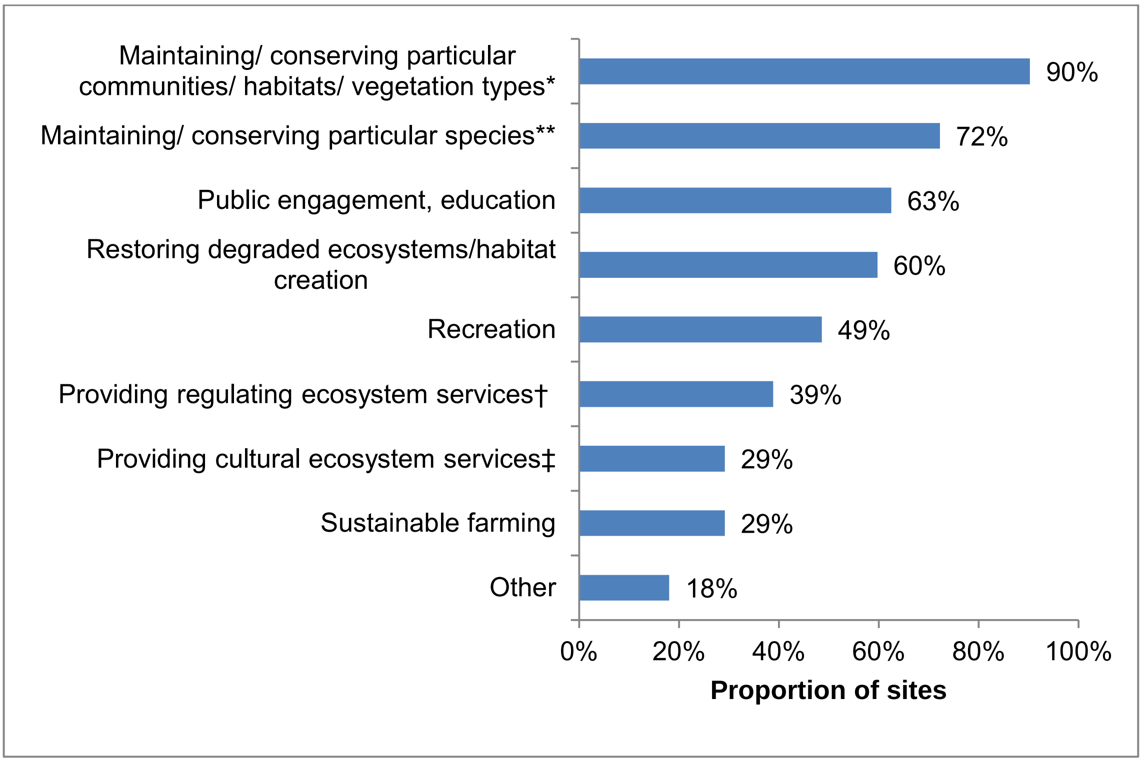

Figure 21: Primary conservation goals of conservation sites
Exact wording was:
* Maintaining/ conserving one or more particular communities/ habitats/ vegetation types
** Maintaining/ conserving one or more particular species
† Providing regulating ecosystem services (e.g. water quality, carbon storage, managing flood risk)
‡ Providing cultural ecosystem services (e.g. historic/cultural landscapes)

As primary conservation goals, most sites mentioned the maintenance and conservation of particular species communities, habitats and vegetation types (90%) or of particular species (72%) (Fig. 21), as discussed in section 4.9.2 of this report. Most respondents indicated that habitat types of special conservation importance on their sites were wetland habitats such as bogs, mires, marsh and saltmarsh, followed by (semi-)aquatic and marine habitat types, such as riparian areas, floodplains, dunes and lakes. Some sites also mentioned rare grassland types or saline habitats, as well as bat roosts within an old mining site. According to the comments regarding particular protected species there was a bias towards bird species, with half of the comments including at least one bird species. The next most important species group mentioned were invertebrates with a focus on butterflies.

Plants were more often mentioned in the community and habitat sense than as protection of single species (often in semiaquatic habitats or bogs). Big mammals were only mentioned in two sites with the Eurasian elk (*Alces alces*) by the Biebrza National Park in Poland and the brown bear (*Ursus arctos)* at the National Forest Park of Mt. Oiti (Ethnikos Drymos Oitis) in Greece.

Conservation of natural processes was an explicit principle conservation goal of three German national parks (Müritz Nationalpark, Nationalpark Hamburgisches Wattenmeer and Nationalpark Unteres Odertal). This conservation concept allows for natural and successional changes within the ecosystem and for focussing on ecosystem functions, alongside species and habitat protection.

Over half of the sites (62%) mentioned public engagement and education as a primary conservation goal. Environmental education, awareness building activities for stakeholders and the general public were part of the task portfolio of sites, while most sites also mentioned cooperation and offers for schools and colleges being part of their work. A few sites also mentioned the running of demonstration events for specialist groups like reserve managers and for research purposes (e.g. Teesmouth NNR and Flanders Moss NNR).

Most of the sites mentioned that their work is at least to some extent connected to habitat restoration. Most pronounced was habitat restoration of aquatic and semiaquatic ecosystems, namely restoration of rivers including their floodplains, lake restoration and peatland restoration through raising of water levels.

Providing regulating ecosystem services in terms of water quality regulation, carbon storage, or flood management was mentioned as primary protection goal by 39% of the sites, of which only three sites were from Southern Europe (Italy, Greece, Romania). Most of these sites named water quality and flood management as important issues, however, only northern and Central European countries provided more detailed comments to this question. According to the respondents' comments the importance of carbon storage, sequestration and reduction of greenhouse gas was mentioned only by sites from the UK and Finland, especially peatland sites, and one site in Germany. Sites including peatland areas from other countries did not mention climate regulation as an issue.

The provision of cultural ecosystem services was important for many sites, as half of the respondents mention the provision of recreation opportunities as a primary conservation goal. Most of them welcome and facilitate 'quiet' recreation including hiking, biking, horse-riding and bird watching by providing open access and trails through the sites. Fewer sites also allow for camping and fishing in their area. One Finish site also referred to the opportinity for hunting as a cultural ecosystem service and reported on associated important recreational activity within their site. Hence, while the enjoyment of wildlife through bird watching was a primary conservation goal at this site, the support of waterfowl populations also provided opportunities for recreational hunting.

The promotion of further cultural ecosystem services and the fostering of sustainable farming were mentioned as important by about one third of the sites. Although some sites had historical cultural and archaeological sites, e.g. Bronze age buildings (Thursley NNR) within their area, most of the cultural heritage conservation activities were related to traditional management of arable land and thus related to sustainable farming. Sustainable farming thereby fosters partly food production and farmers income generation as sustainable provisioning service, while a strong focus is also partly for landscape aesthetic and conservation management reasons as cultural service. Special focus lay on extensive grazing and grassland management, such as the support of rare breeds (Shetland cows, UK 55), the protection of old cultivars of native medicinal plants (Germany, DE 38) or the promotion of traditional haymaking in Poland (Biebrza National Park, PO48). Another example for sustainable farming mentioned was sustainable fishery. The management of the sustainable management of farming and fishing as part of the conservation concept was explicitly mentioned by the coastal site Caerlaverock NNR in the UK.

8.3 Anticipated impacts of climate change

8.3.1 Vulnerability assessments

Site managers were asked if a vulnerability assessment had been conducted to investigate how sensitive the environment of their specific site is to climate change (Fig. 22).

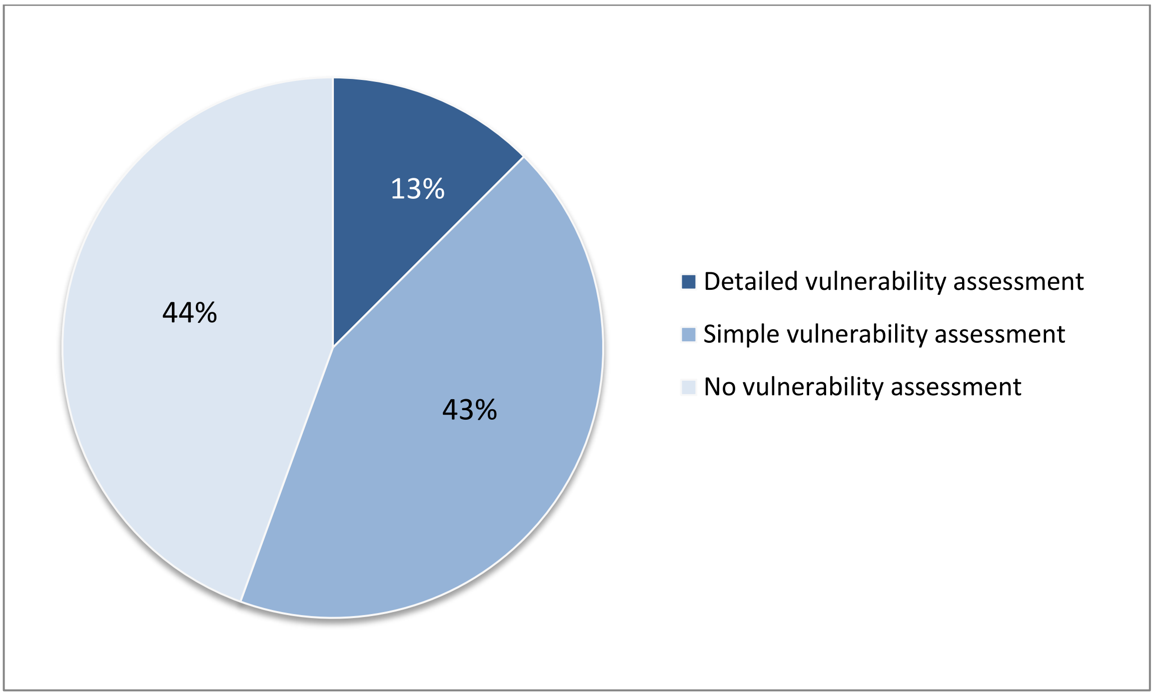

Figure 22: Proportion of sites that have conducted climate change vulnerability assessments

At more than half of the surveyed sites (40 sites), a vulnerability assessment had been conducted; however, for few sites only (9 sites) had the assessment been detailed.

These detailed assessments were carried out in one site in Finland and Poland, two sites in Germany, and five sites in the United Kingdom. While ca 80% of all sites in the UK had a vulnerability assessment, only 25% of sites in Germany had a vulnerability assessment while there were a few assessments in other European countries. In Germany, more than three quarters of the sites had no vulnerability assessment, whereas in the UK only one fifth of the responding sites have not been assessed. Three of the detailed assessed sites were for peatland ecosystems, one for coastal systems and the other sites comprised a mix of ecosystem types. Interestingly, all coastal systems except for one had undergone at least a simple vulnerability assessment. This may be because change has long been accepted as inherent to coastal systems and adaptation to a rise in sea level and associated storm events is seen as a necessity.

Around half of the sites conducted their vulnerability assessment in a wider network in cooperation with other conservation sites. Of the 20 assessed sites in the UK, 12 sites have been assessed in collaboration with other sites. In Wales, all sites have undergone a common general assessment for terrestrial sites (Wilson 2010) and marine sites (Jones *et al.* 2009), and several sites mentioned that assessment boundaries were greater than reserve boundaries. In contrast, most German sites have been assessed independently. Only for the Nationalpark Niedersächsisches Wattenmeer qualitative vulnerability analyses were carried out in the framework of the 1990 trilateral strategy development 'Coastal Protection and Sea Level Rise' (CPSL), with quality assessment reporting and a climate adaptation task group as part of the cooperation of the three Waddensea bordering countries (NL-D-DK). The German Nationalpark Berchtesgaden (DE46) also included the surrounding landscape in the vulnerability study. In Latvia, assessments took into account interaction between different Natura 2000 sites, and in the Biebrza National Park other conservation sites around the reserve were invited for common meetings and discussions aimed at the stakeholder dialogue enhancement, while no common research on vulnerability assessment has been conducted yet.

8.3.2 Expected impacts on species and ecosystems due to consequences of climate change

Survey participants were asked which of the possible consequences of climate change they expect to have the greatest impact on the species and ecosystems within their conservation site. In addition they were asked to estimate in which time range they would expect the impact to happen. More than one impact could be chosen (Fig. 23).

Most important aspects of climate change influencing ecosystems where rising temperature and the change of precipitation patterns and the respective consequences. Two sites, however, mentioned explicitely that for their sites aspects of climate change did not play an important role and thus no sound estimates on possible impacts could be made.

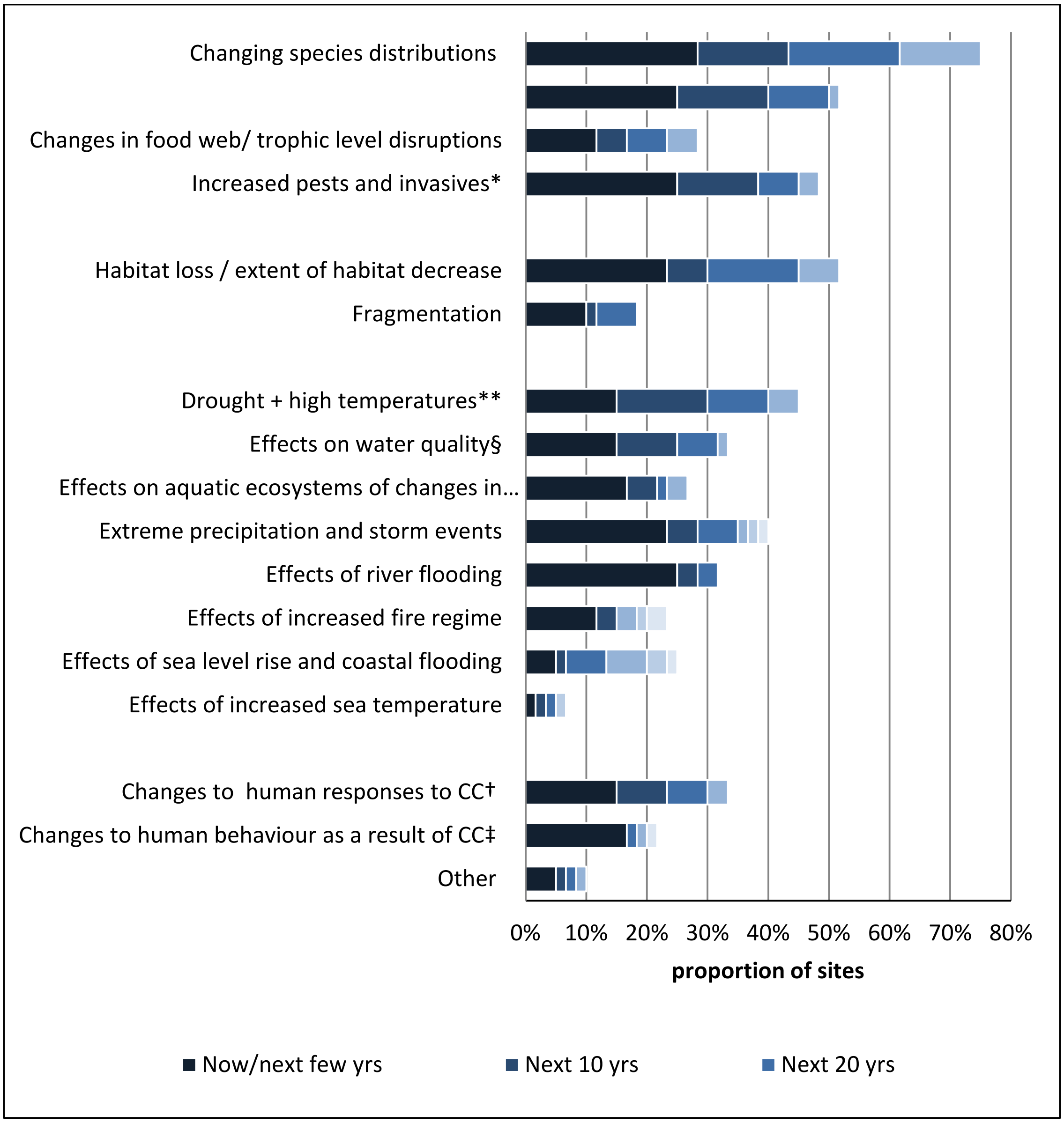

Figure 23: Expected consequences of climate change with greatest impact on the conservation sites
Exact wording was:
* Effects of increased pests and invasives
** Effects of drought + high temperatures (incl. water availability)
§ Effects on water quality of changing rainfall patterns and rising temperatures
† Effects of changes to human responses to CC (e.g. mitigation policies or engineered adaptation responses)
‡ Effects of changes to human behaviour as a result of CC (e.g. changed farming practices, water use, recreation)

Changes in ecosystem and species composition

Spatial changes in species distribution was mentioned by 76% of the sites as main consequence of climate change. Received comments were referring to distributional changes in plant, insect, bird and mammal species. The most frequently mentioned reason for the changes in species distribution was an increase of air temperature, which is expected to lead to a shift of species from warmer climates to originally colder habitats. This was expected to correspond with an upward shift of species from lower elevations and with a northward shift of species from the warmer south, possibly to regions outside the protected areas. Mountain species were mentioned as especially threatened from habitat loss and resulting extinction. For some habitats changes in rainfall patterns was mentioned as important reason for changing species composition. Less rainfall and a corresponding decrease in ground water level is expected to lead to a shift from wetlands to dryer ecosystems, namely for bog to grassland or woodland ecosystems. Besides the possible loss of habitat of wetland species this could also lead to faster decomposition and a decline in carbon storage. For coastal regions the rise in sea level is expected to lead to changes in habitat properties and hence to changes in the distribution of coastal species. Only one of the respondents mentioned that probably succession-caused changes might be stronger than climate related distribution changes.

Half of the sites mentioned changing seasonal events and changes in growing/mating seasons as a main impact of climatic change. Several of these sites already observed the effect of such temporal changes in species distribution and mainly related them to changing temperature regimes and longer vegetation periods. Reported observations refer to an earlier arrival of migrating birds and increase in the number of wintering birds, changes in the spawning seasons of amphibians, and in flowering time of plants. Changing rainfall pattern was mentioned as another possible factor influencing seasonal events. Here for example, the earlier and more frequent occurrence of spring floods is expected to disturb breeding seasons of waders, while an expected general increase of rainfall and cloudiness might lead to less flying and egg-laying time of insects. Dryer summers were also mentioned as limiting factor for plant growth.

Such changes in temporal species distribution will also affect the interaction between species and thus lead to disruptions in food web and trophic interactions. This impact on the site's ecosystem was mentioned as important by over one third (34%) of the sites. However, due to ecosystem complexity a prediction of concrete effects was seen as difficult and largely unpredictable. Examples for possibly affected ecosystems were the interaction within marine food webs between plankton bloom, fish growth and breeding times of predatory birds.

Increase of pest and invasive species

The increase of pest and invasive species was mentioned by almost half of the sites as important climate induced impact on their sites' ecosystems. Many sites already experienced that climate change creates better opportunities for invasive plant and animal species, which outcompete existing species within their habitat or spread of plant pathogens, such as *Phytophthora pseudosyringae*.

Habitat loss and fragmentation

Habitat loss was mentioned by 62% of the sites as an important climate induced impact on the site. Habitat loss may have several reasons, often attributed as a consequence of shifting species distribution especially for populations on the edges of distribution areas. For many wetland habitats a lowering of groundwater levels with changing rainfall patterns and increased summer temperatures may favor the development of dryer ecosystems. In addition higher temperatures in lakes were exepected to lead to eutrophication and therefore deterioration and overgrowth of more sensitive microhabitats. For coastal regions anticipated losses of saltmarsh and mudflats or shingle habitats were linked to erosion due expected higher frequency or intensity of storm floods. Furthermore, salt water inflow due to sea level rise was expected to lead to changes in water quality in the sites and respective losses of freshwater and hypersaline habitats.

In contrast to habitat loss only 22% of the respondents see habitat fragmentation as a direct consequence of climate change. Existing fragmentation through land use pressures was seen as clearly impacting on species already, so likely to be exacerbated by climate change.

Effects due to changing weather pattern

Consequences of extreme weather events, such as drought and high temperatures, were mentioned by almost half of the respondents (47%) to have an important effect on the sites' ecosystems. The most frequently named effects were a shift from wet to dryer ecosystems due to decrease of the ground water table and reduced precipitation mainly affecting peatland and grassland ecosystems, and a decline in quantity and quality of water in lakes and rivers due to drying and deoxygenation of surface water. Consequently, about one third of the respondents also named the effects on water quality due to changes in precipitation and rising temperature as important impact to the ecosystem. Besides higher temperatures an increased erosion of sediment and nutrients into the rivers and water bodies was supposed to enhance the deoxygenation of surface water. Effects on aquatic ecosystems due to changes in stream flow were mentioned by 25% of the respondents, again naming increasing eutrophication and reduced base flow especially in the dry summer months as main reasons.

One third of the respondents expected higher frequency and intensity of extreme precipitation and storm events to impact on ecosystems, with respondents mentioning breach of shingle ridges and dams protecting a lagoon as major impacts as well as coastal erosion. One respondent also mentioned the positive impact of storms and floods to the ecosystem and succession dynamic of dune beaches.

Respondents observed both an increase in intensity or frequency of river flooding, alongside a shift in timing of flood events. Such time shifts of floods may impact e.g. on the breeding success of birds, or cause habitat changes due to different management practices for e.g. vegetation cutting and grazing which have to be adapted to new flooding seasons. One respondent from Finland observed a decreasing trend in flooding and another mentioned positive effects for conservation from the increase of river flooding for the floodplains.

An increased fire regime was expected as important consequence of climate change by 25% of the respondents, mostly for heathland and forest ecosystems. Especially increasing temperatures and dry periods during the summer season were expected to increase fire frequency during summer months. This effect has already been observed during the last years in parts of the sites.

Increased sea temperature as a consequence of higher air temperature was mentioned as important impact on coastal and marine ecosystems by about 50% of all participating marine sites. The expected or observed effects were comparable to effects on terrestrial ecosystems, namely the spatial and temporal change of species distribution and increased eutrophication of sea water.

For coastal ecosystems sea level rise and coastal flooding were mentioned as an important consequence of climate change by one fourth of the respondents. Especially, the reduction of coastal habitat due to increased erosion following storm events and flooding, and the retreat of the coastline was an important issue. Another effect of sea level rise and increased coastal flooding mentioned by the respondents was the breach of the shoreline and the ingress of saltwater into low lying areas, leading to increased salinity of these ecosystems.

Effects due to changes of human behaviour

Climate change may not only directly impact on ecosystems, but also lead to indirect effects through changes to individual human behaviour as a result of climate change, as mentioned by 37% of the respondents. Two aspects of human behaviour were seen as most pronounced: On the one hand, respondents expected to see the effects of a change in recreation pattern to lead to an increase of human pressure on the ecosystems. For example, a longer summer season could prolong the season for outdoor activities, such as bathing in rivers or lakes or other terrestrial activities, leading to recreational disturbance of wildlife sites, as partly observed already. At the same time the tourism industry may benefit from this. On the other hand land management practices will have to adapt to changing environmental conditions, such as increased wetness of sites, changes in plant species composition, or longer growing season due to warmer winter temperatures. Some special forms of land use like salt marsh grazing or salt production might also become rare or to be abandoned in specific regions.

In addition climate mitigation policies or engineered adaptation responses may affect ecosystems. However, only about 20% of the respondents chose these as relevant for their sites. Of these, almost all respondents expect effects of mitigation and adaptation policies to be in effect already or within the next few years. Sites in Germany seem to already experience effects in land use and land use change, with regards to a change in forestry practice with increased planting of Douglas fir or increased production of maize as bioenergy crop, as well as increased drainage of sites. Respondents from the UK and Poland expressed their expectance of developments both positive for increased support for ecosystem based adaptation as well as negative through increased drainage measures and engineered coastal defence measures.

Overall, it is notable that between 50 – 89% of the respondents expect almost all of the mentioned climate impacts to happen within the next 10 years. Only for the effects of sea level rise, the majority of respondents expected changes to occur within the next 20 - 50 years or longer. Many effects especially extreme events like river flooding, extreme precipitation and storm events have already been observed in many sites or are expected to happen within the next few years. Effects of private human behavior and management practices are expected to occur slower than the human response in form of mitigation and adaptation policies.

8.4 Integration of climate adaptation into conservation goals

8.4.1 Adaptation to climate change as factor in the design, planning and management of conservation sites

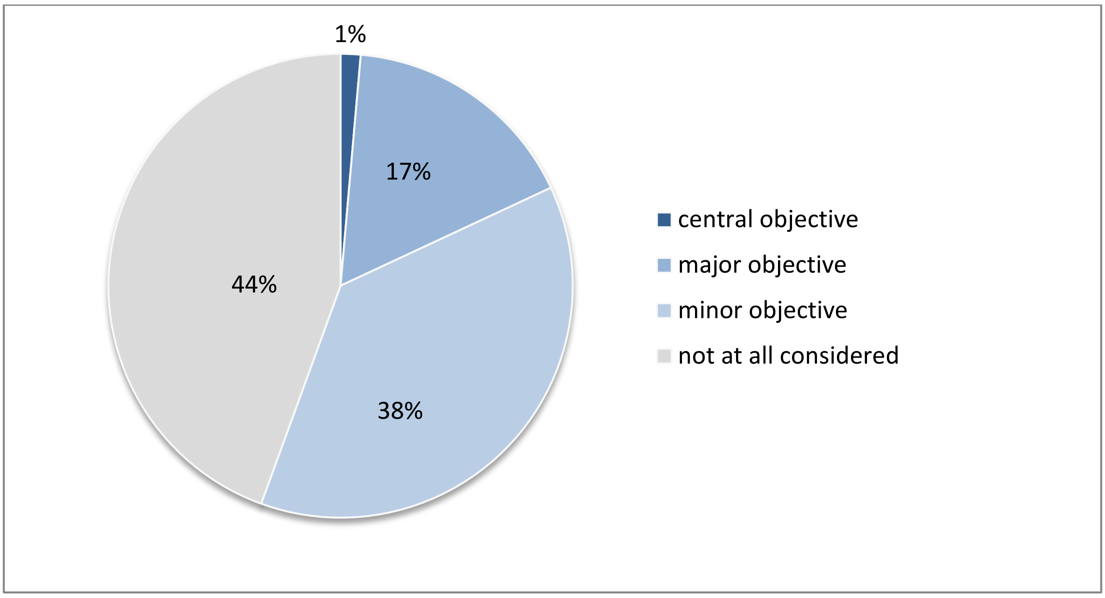

Figure 24: Climate change adaptation as a factor in the design, planning and management of the site (regardless of whether it has led to changes in previous management; n = 72 sites)

Adaptation measures have been included into the management plans for about half of the surveyed sites (40 sites, Fig. 24). Only the German national park 'Hamburgisches Wattenmeer' determined adaptation to climate change as central objective in their site management. Another 17% of all sites mentioned climate change adaptation to be a major objective, especially peatland sites, and for 38% of all sites it was a minor objective. In the UK, more than two thirds of the sites had adaptation measures included into their management plans and in Germany less than half of all sites. Throughout Europe (excluding UK and Germany) more sites in the South had adaptation measures included compared to the North. However, as the sampling density for these countries was much lower with one or two respondents per country, conclusions are hard to draw.

8.4.2 Time since explicit inclusion of climate change adaptation into site planning and management

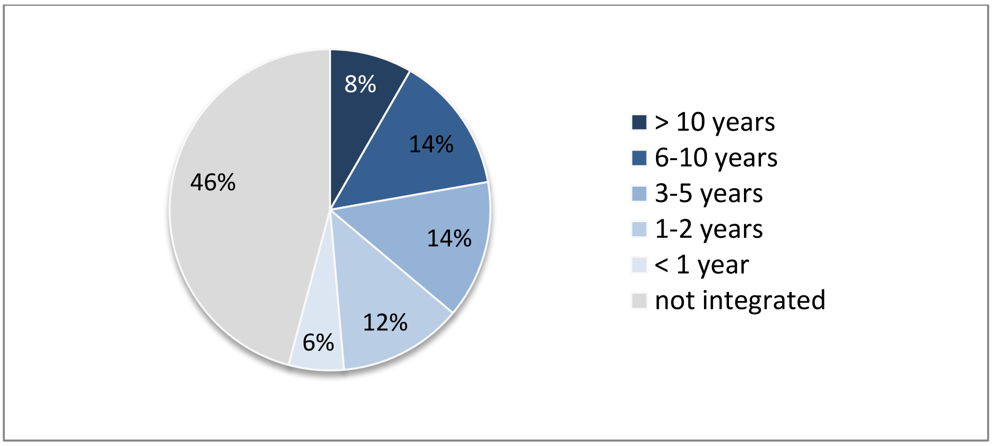

Figure 25: Time since adaptation to climate change has been a factor in the design, planning and management of the site (regardless of whether it has led to changes in previous management; n = 72 sites)

More than half of the sites that mentioned to have climate change adaptation measures included in their site design or management plans included these measures within the last 5 years (Fig. 25). Less than one fourth of the sites had climate change adaptation included for six years or longer. Sites with the longest integration time were three sites in the UK, three sites in Germany and one site in Poland with one coastal ecosystem, one grassland site and the others as mixed ecosystem sites.

8.4.3 Main goals in relation to adaptation

All participants who had adaptation measures integrated in their management plan were asked about their main goals in relation to adaptation. Five possible statements and the option for other answers were given. Multiple answers were possible.

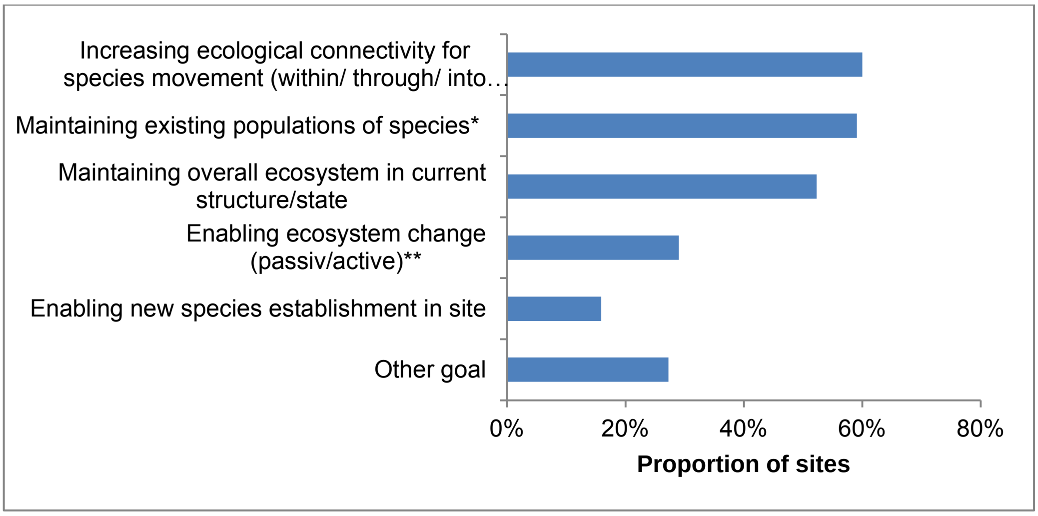

Figure 26: Main climate change adaptation goals (several goals possible per site; n = 45 sites)
Exact wording was:
* Maintaining existing populations of particular species or groups of species in spite of climate pressures
** Letting the ecosystem change, or actively helping it to do so (e.g. letting a freshwater wetland change to brackish/saline)

For two thirds of the respondents one main goal of undertaken adaptation measures was to increase the ecological connectivity between sites (Fig. 26, for discussion see also section 6). A major part of the sites determined the maintenance of the actual status in terms of both species distribution and ecosystem status as main goal of the included adaptation measures (59% and 52% respectively), thereby having resistance to change as a main objective. Enabling changes within the ecosystems regarding overall ecosystem change and species distribution change was goal of only one third and one fifth of the sites, respectively.

In the UK, over two thirds of the sites applied adaptation measures in practice, and of these only two sites had passive or active enabling of changes as main goal. Three sites mentioned both maintenance and enabling changes as goals, whereas the majority of sites (13 sites) mentioned the maintenance of the existing status. In Germany, less than half of the sites mentioned adaptation measures in practice (12 sites). Of these, however, nine sites indicated enabling changes or both enabling changes and maintenance of the status as goals, whereas the other three sites mentioned status maintenance as the only goal.

Maintenance of existing species and habitats was mostly mentioned in relation to mitigation of local species extinction. Besides several sites in Germany and the UK only sites from Switzerland, Italy and Belgium named active or passive enabling of ecosystem and species changes as main goals. Several sites also mentioned both maintaining the existing status and enabling for changes as goals. Respondents interpreted the term ‘enabling changes’ in two ways: first, promotion of active environmental change in the sense of restoration of the habitat, e.g. restoration of peatland and enhancing biodiversity within the habitat to restore original biodiversity. The second interpretation of enabling changes was in the sense of allowing for natural processes e.g. to allow the ecosystem to undergo natural succession and change. The second interpretation was explicitly mentioned by three German national parks (Müritz-Nationalpark, Nationalpark Unteres Odertal and Nationalpark Kellerwald-Edersee).

Half of the UK’s maintenance only sites were single ecosystem sites, including two coastal, three grassland and three peatland sites, the others comprise mixed habitats. One peatland site mentioned the allowance for changes as specific adaptation goal (Humberhead Peatlands National Nature Reserve). The maintenance only sites across other countries were all mixed sites. Three coastal sites were mentioned for both maintenance and change.

Other goals mentioned were the adjustment of water and land management to climate change and providing advice to land owners in regard to adapted land use management (Biosphärenreservat Rhön and Spreewald Biosphere reserve). The Nationalpark Berchtesgaden determined part of the conservation area as scientific reference area for understanding climate change.

8.5 Existing qualitative or quantitative targets to measure the progress towards their specific goals

Half of the sites who defined adaptation goals also set qualitative or quantitative targets to measure the progress towards their specific goals. Measures to prove targets were for example measuring of water flow and water dynamics in peat land, counting of breeding pairs and species numbers, vegetation monitoring and the active renaturation of ecosystems by removal of river bank stabilization or introduction of dead wood into forests.

8.5.1 Adaptation measures as contribution to ecological networks

About two thirds of the projects with adaptation measures confirmed that the adaptation work was intended to make a specific contribution to enhancing ecological networks and connectivity.

8.5.2 Spatial scales of ecological networks

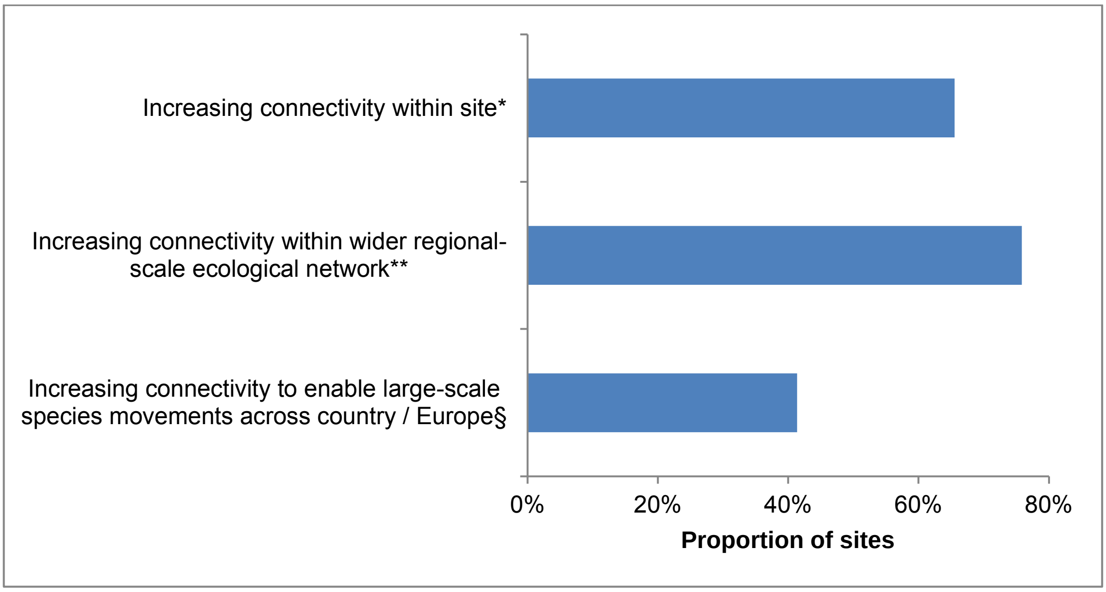

Figure 27: Spatial consideration of connectivity measures of sites (several goals possible per site; n = 30 sites)
Exact wording was:
* Increasing connectivity within the site itself
** Management of the site is being planned as part of a wider regional-scale ecological network

§ Management of the site is being planned with reference to large-scale species movements across your country, or across Europe (e.g. as a site to accommodate new species arriving from southern countries)

Most sites intended to contribute to enhancing ecological networks and connectivity at small and intermediate spatial scales: 67% and 77% of the respondents mentioned that they intend to increase connectivity *within sites* or connectivity *within regional scales*. Less than half of the sites aimed for the establishment of ecological networks *across the countries or within Europe* (Fig. 27).

Eight out of the twelve sites who responded to be active at international scale were sites in Germany and one site each from Finland, Belgium, UK and Poland. That also means that eight out of the twelve sites in Germany having adaptation measures included in their site's monitoring plans did not yet work at international levels. Two of the sites working within international networks were coastal only sites (Nationalpark Niedersächsisches Wattenmeer and Nationalpark Hamburgisches Wattenmeer), all other sites were mixed ecosystem sites.

Aims of within site activities were an establishment of continuous networks especially regarding waterways and wetlands as well as general mitigation of habitat fragmentation.

There are a variety of regional, national and international networks in which sites were organised including e.g. two UK *Nature Improvement Areas* (large contiguous areas instigated by the Lawton review, see Lawton *et al.* 2010), The Walloon network in Belgium, the Nationaler Biotopverbund in Germany (national habitat network), the trilateral Waddensea cooperation as well as collaborations under the European Water Framework Directive.

8.5.3 Design of ecological networks designed for particular species or groups of species

Two thirds of the sites with ecological networks were designed with the movement of a particular species or group of species in mind (half of the sites from the UK and two thirds of the German sites). The other sites, who confirmed specially designed networks, were distributed across Europe without focus on any special region. Four of the seven coastal sites and two grassland sites were mentioned to have specifically designed networks; all other sites comprised more than one ecosystem type.

Many of these networks were established to protect and enhance the distribution of particular mammal or bird species like red deer, wild cat, waterfowl and migrating birds. But also freshwater and marine species (marine mammals, water voles, European river lamprey and fish, such as salmonids) were a focal group for cooperative protection. For plant species communities the need for large scale woodland networks and peatland communities was mentioned.

8.5.4 Assessment of physical network structure

In order to determine the physical structure of these networks, about half of the respondents (14 sites) confirmed that particular tools or methods have been used, including half of the sites in Germany and the UK. Two of the coastal only sites and two of the grassland only sites have used such measures; all other sites were mixes ecosystems. Examples for employed measures are the size and shape of core areas, length of corridors, landscape-scale analysis of the extent of habitats and determination of stepping stones. Methods used to measure these tools were habitat mapping, aerial photograph analysis and GIS modelling of opportunities for habitat creation and linkages.

8.5.5 Ecological networks planning in cooperation with other conservation sites

About two thirds of the respondents confirmed that planning of ecological networks involved cooperation with other conservation sites in the respective area (all sites in the UK, two thirds in Germany). Three other sites from Romania, Belgium and Italy confirmed their cooperation with other conservation sites. Five out of the seven coastal only sites, two grassland only and two peat land only sites collaborated with other sites during network planning. Cooperation was often established between adjacent sites, e.g. sites within wider Special Areas of Conservation (UK), between sites of similar ecosystems like dune sites along the Welsh coast, Waddensea cooperation or peatland and wetland restoration, in collaboration with the Wildlife Trusts in the UK or within international networks, e.g. across Natura 2000 sites.

8.6 Management actions and monitoring

8.6.1 Adaption of management actions

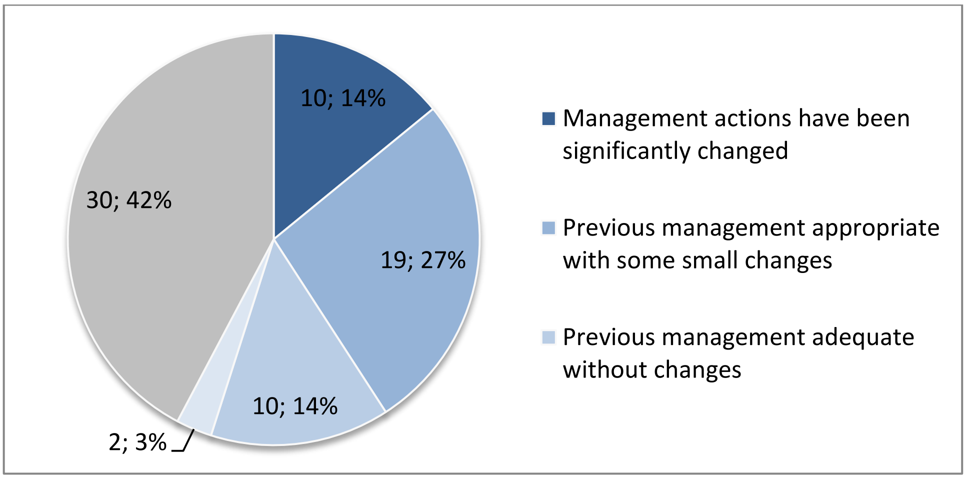

Figure 28: Change in management in response to climate adaptation (n = 72 sites)

Survey participants were asked if they changed their management actions on the basis of the projected climate impacts and adaptation goals above (Fig. 28).

Only 14% of the respondents mentioned, that the monitoring plans of their sites have been significantly altered to meet the requirements of climate change adaptation, whereas in 44% of the sites no or only slight changes were included. Some sites mentioned, that they hoped that existing measures to strengthen resilience or to allow for natural processes were sufficient for climate adaptation. Only two sites (Exmoor Mires Project in the UK and the

Nationalpark Eifel in Germany) confirmed that the management addressed climate change adaptation from the outset of the site's planning. The German Nationalpark Eifel exists since 2004.

These changes in the management plans stood in context of more active restoration e.g. of waterways and wetlands, newly introduced or intensified control of either threats such as fire or ecosystem properties such as water levels, as well as a shift from strict conservation and protection of ecosystems towards more dynamic approaches and allowing for change.

8.6.2 Important specific actions towards natural environment adaptation

Survey participants were asked which, in their opinion, were the most important specific actions taken at the conservation sites to help the natural environment adapt to climate change. Multiple answers were possible (Fig. 29).

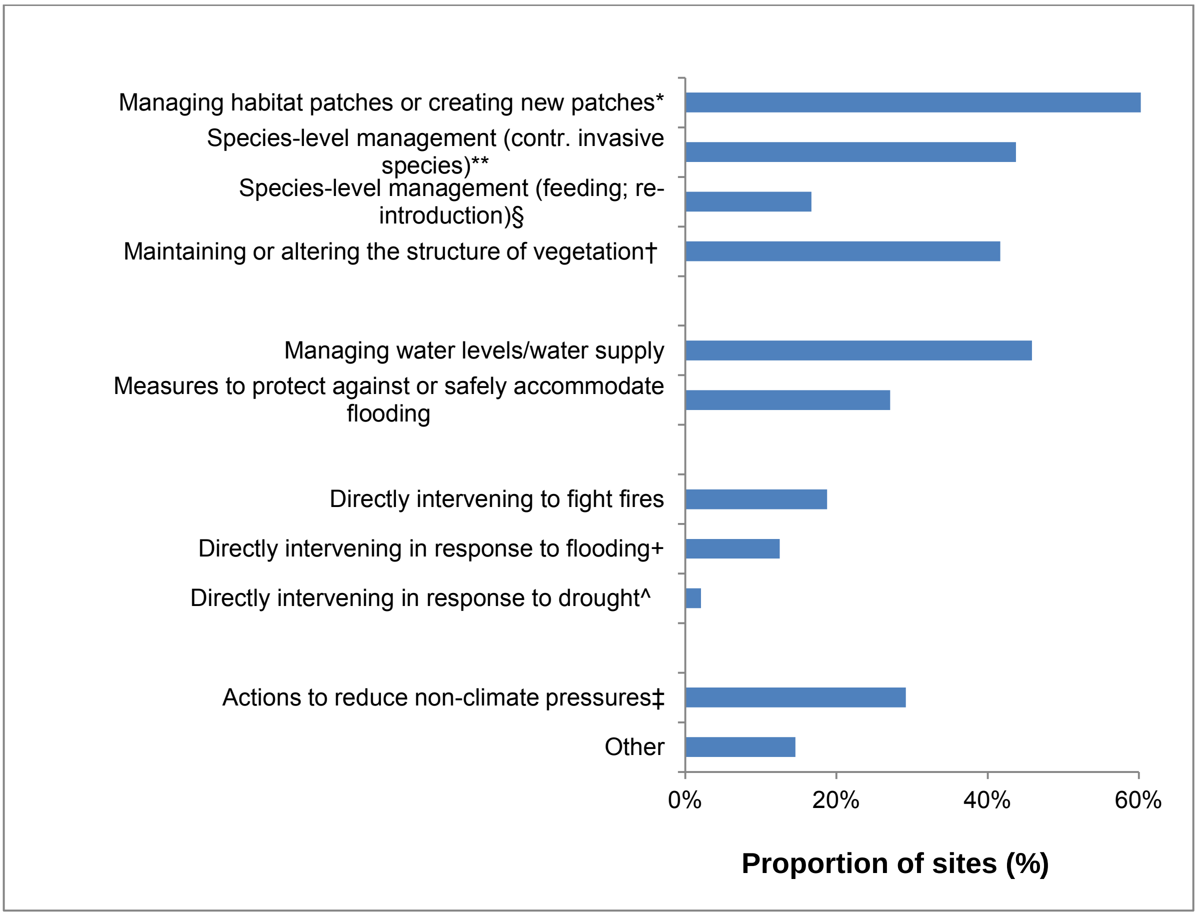

Figure 29: Most important specific actions of site management to adapt to climate change (n=48)
Exact wording was:
* Enlarging, buffering and linking habitat patches or creating new patches
** Species-level management (e.g. controlling invasive species)
§ Species-level management (e.g. supplementary feeding; re-introduction)
†Maintaining or altering the structure of vegetation (e.g. heterogeneity/height)
+Directly intervening in response to flooding after it occurs (e.g. pumping out floodwater)
^Directly intervening in response to drought after it occurs (e.g. pumping water into the site)
‡Actions to reduce non-climate pressures on the environment (e.g. water pollution)

Two thirds of the respondents mentioned habitat management as important in form of enlarging, buffering or linking habitat patches, or in form of creating new habitats as important management action towards adaptation. The main aim was first the securing of existing habitats through restoration, especially of wetlands and saltmarshes, and secondly reduction of fragmentation and increase of ecosystem connectivity through creation of stepping stones. Regarding species level management, most sites focussed on control and removal of invasive species rather than in manipulation of the existing natural species composition (17%). Active support for species was mentioned by two coastal sites via translocation of species and special treatment of orchid species (UK 10 and DE 26). One grassland site mentioned seed collection by the National Seed Bank as active species level management (UK11). The management of vegetation was mentioned by 42% of the respondents. In grassland ecosystems this management occurred in form of grazing management (UK13), whereas in peatland and dune systems often control of shrub and tree growth was necessary (UK53, UK55, DE26). Another type of vegetation management mentioned was vegetation planting as initial planting in floodplains or forest creation and improvement.

Water supply and water levels were managed in almost half of the sites. Almost all comments were related to the reconstruction of natural water levels and the restoration of artificially drained sites in wetlands and coastal systems.

Measures to safely accommodate flooding was mentioned as important action towards environmental adaptation by about one third of the sites. Especially the restoration of wetlands as buffer regions or retention sites was mentioned to be most important for flood regulation (it should be noted, though, that topography, soil and vegetation properties and drainage network properties will be crucial determinants, whether wetlands can contribute to water retention). Two riverine sites also mentioned the increase of the dam heights at one special location within their site as adaptation measure, whereas the other considered dike relocation to alow for greater flooplain area.

Direct intervention during or after flooding or drought events was mentioned only by 2% and 17% of the respondents respectively. Direct intervention during fire events was important for one fifth of the respondents. Especially peat and grassland sites in the UK mentioned the necessity to manage vegetation by cutting to reduce the probability of wildfires (UK54, UK65, UK55). In general, long-term measures were seen as more important than direct intervention during or after extreme events. But, direct intervention was always considered in the case of extreme events and if human lives or infrastructure was endangered.

Measures against non-climate pressures were taken by a third of the sites, mainly in the form of reduction of eutrophication at coastal, freshwater and peat land sites (LA66, UK54, UK40, DE26), but also via maintenance of traditional land management (RO37).

Other actions undertaken towards climate adaptation were for example renewable energy generation from a micro hydro plant inside the site (Creag Meagaidh NNR), as well as monitoring of change with an emphasis to differentiate between effects of land use change and climatic change. Furthermore, stakeholder dialogue and awareness raising was seen as important by the Briebza Nationalpark to generate acceptance and support for climate change related approaches in order to properly implement adaptation actions.

8.6.3 Management actions as climate adaptation benefits for people

Site management can serve as ecosystem based adaptation (EbA, section 5) to also benefit local and regional communities. Climate adaptation benefits for people was important for 45% of all sites. Most frequently named benefits for people were drought and flooding mitigation to protect productivity of arable land and grazing sites as well as site contribution to recreation opportunities and tourism. Coastal and freshwater sites especially from Northern and Central Europe mentioned their contribution to flood regulation (Germany, Ireland, Poland, Latvia and the UK), while peatlands emphasised their importance to carbon storage and climate regulation (DE47 and UK67).

8.6.4 Costs of climate adaptation management

Costs for climate adaptation managements varied widely between projects, with responses from half of all sites (35 respondents, Fig. 30). Many of the responding site managers (43%) indicated, that they had not estimated costs, partly due to difficulties to disentangle these from other costs. Some sites indicated these expenses occured for surveys and information events. The range of the costs estimated from the remaining 20 sites varied widely between sites, with about a fifth of the responding sites estimating 10,000-50,000 Euros and almost equal number of sites (4 each) estimating 5,000-10,000 and 50,000-500,000 Euro. About half of the German and UK sites that responded to the question said that costs of the adapation actions had not been estimated. Only one out of the 10 German sites estimated its costs to be in the higher sector (50,000-500,000 Euro), while four of the German sites estimated their costs to about 5,000-10,000 Euro. None of the German sites lay in the 'intermediate' (10,000-50,000 Euro) sector. In contrast, the 17 responding sites in the UK were equally distributed throughout the cost range. From the other responding countries sites were distributed across all cost ranges. Sites within the lower price sector were mainly composite ecosystems of grassland, forest and arable land. All responding ecosystems containing coastal components (3 sites) were found within the intermediate sector (10,000-50,000 Euro), alongside several peatland sites and two other sites. Almost all ecosystems within the higher price sector (50,000-500,000 Euro) contained a peatland component alongside one grassland mountainous site. Mountains or mountainous regions were present in all price sectors.

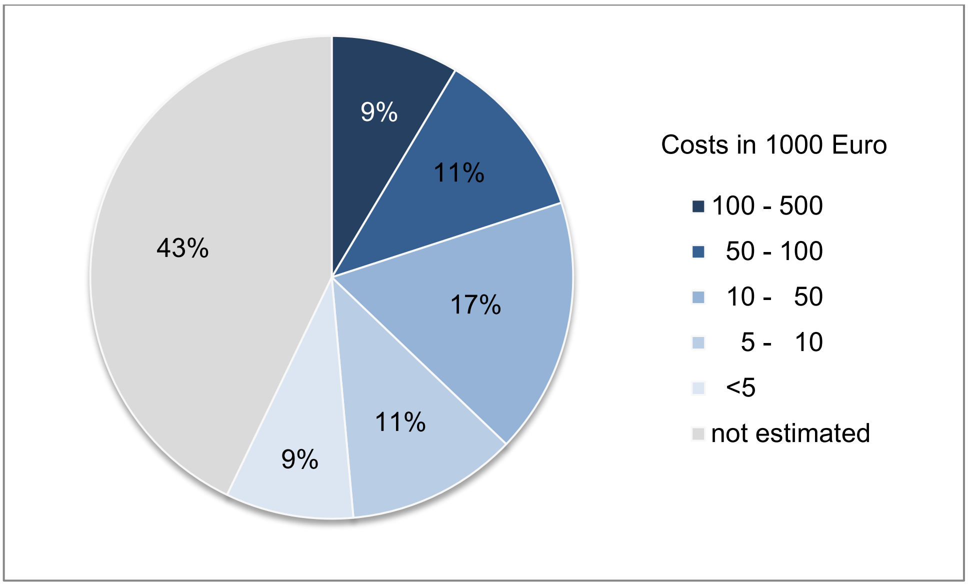

Figure 30: Costs for climate adaptation measures in 1000 Euro (n=35)

Some sites indicated these expenses occurred for surveys and information events. Many indicated that they had not estimated costs, partly due to difficulties to disentangle these from other costs. One of the sites, who estimated their costs within the higher price sector mentioned that their costs included land leasing costs (Flanders Moss NNR, UK55).

8.6.5 Management actions coordinated with other nature reserves or sites

About half of the survey participants answered the question whether management actions were coordinated with other nature reserves or sites (Fig. 31). About half of the respondents answered with 'yes'. From the sites that responded, about 50% of the sites in the UK (9 sites) and Germany (6 sites) confirmed cooperation with other sites, whereas two thirds of the other responding European sites (7 out of 10 sites) did not coordinate their management actions with other conservation sites. Overall, only 19 out of 72 sites indicated a coordination, which accounts to 25% of all sites if non-responses are interpreted as no coordination.

Over three quarters of all the ecosystems containing a coastal component mentioned a cooperation with other sites, eg. through the trilateral Waddensea cooperation or the Welsh dune strategy, and there was collaboration between sites regarding fire management. Interestingly, all sites containing arable land did not mention any coordination of their climate adaptation measures. This difference could possibly be due to preoccupation with other land use pressures or site specific issues in composite sites, as well as a greater awareness of climate issues among coastal sites or possibly a better existing networks to share and coodinate best practice.

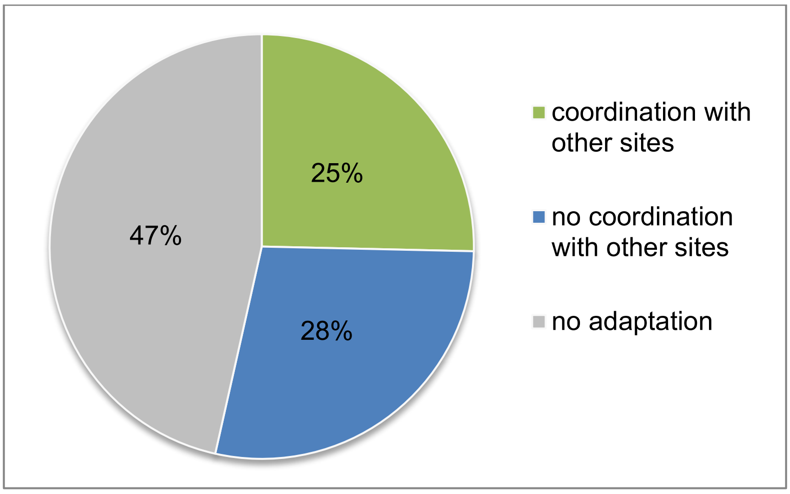

Figure 31: Coordination of climate adaptation within wider network (n=72)

8.6.6 Environmental monitoring

Out of the 72 respondents of the survey 43 sites confirmed to have monitoring programmes in place for different environmental parameters on their sites (Fig. 32). Almost all of the sites mentioned the monitoring of fauna (93%) and/or flora (91%). The majority of sites (88%) also monitored habitat and vegetation types. Floral monitoring and habitat monitoring was most frequently done in transects or permanent monitoring quadrats, also according to SAC (Special Area of Conservation) condition monitoring and /or UK national site condition monitoring programmes. Some sites only monitored special key species or species of interest, like orchid species or montane species of the subalpine and alpine zones. Fauna monitoring was more species specific, with most of the sites monitoring bird species, including population size, nesting and breeding behaviour. Other frequently mentioned animal groups were invertebrates, with a focus on butterflies. Fish, reptiles, amphibians and mammals were less often mentioned.

Physical processes were monitored by 67% of the sites. Here, especially the monitoring of the water table was mentioned by most coastal and freshwater ecosystems as well as some peatland sites. Additionally, hydromorphological and metereological parameters, greenhouse gas emissions and carbon sequestration as well as nutrient levels were measured by some sites, often in collaboration with universities. In addition, erosion processes also of trails, were assessed.

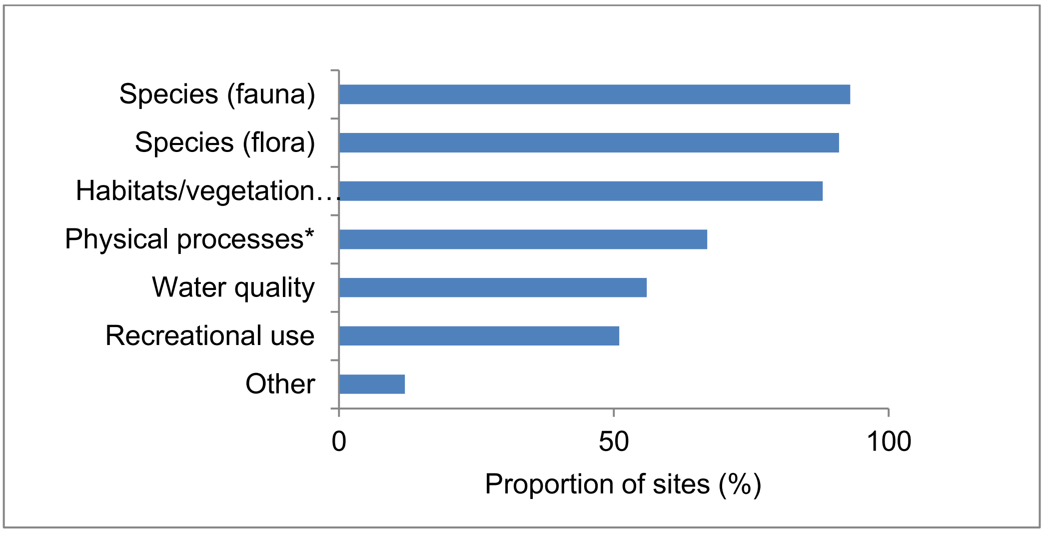

Figure 32: Monitoring of different environmental parameters in conservation sites (n=43)
Exact wording:
* Physical processes (erosion, GHG emissions, water table/flow etc)

Water quality of lakes, ground water and wetland sites was measured by more than half of the sites, with a focus on dissolved organic carbon (DOC) and nutrient input. Recreational use was mainly monitored by counting visitors (12 sites). Two sites also mentioned that visitor surveys are conducted about profiles and expectations of the visitors (FI28 and UK55). In a Finish site hunting bags are monitored, since the most important recreational use of the site was hunting. Other factors monitored by responding sites included fishing activities.

8.6.7 Experimental approach to adaptation management

Survey participants were asked if any of their management actions are carried out in an explicitly experimental way, with the results recorded, analysed and used to modify future management.

43 out of the 72 participants answered this question and about half of them responded with 'yes'. About half of the German sites and the sites of the UK confirmed that at least some of their management actions are carried out in an explicitly experimental way. Out of the seven sites from the high priced sector (section 8.6.4) only one site conducted experimental management actions (Flanders Moss NNR). There was no obvious focus on any ecosystem type regarding the conduction of experimental management actions, since most of them where mixed sites. However, the description of experimental setups and purposes indicates, that most of them were carried out on grassland, peatland and heather ecosystems, but also woodland and marine sites. The described experimental approaches most frequently included the response of ecosystems to change in managment, e.g. the effects of grazing or livestock exclusion, controlled burning on peatland or restoration trials. Two respondents mentioned that setup and results of the experiments are published on their website.

8.7 Information sources and barriers to action

8.7.1 Importance of own experience from past changes

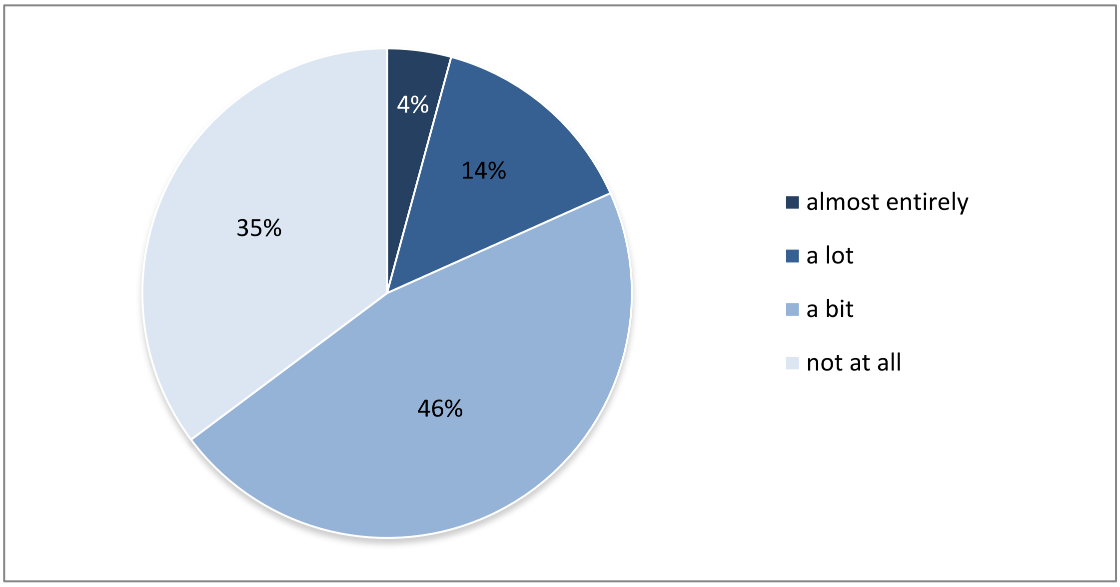

Figure 33: Importance of own past experience influencing climate adaptation conservation measures by site managers (n=72)

More than 80% of all respondents indicated that the management approach to climate adaptation was not or only slightly informed by past own experience (Fig. 33). Only three sites reported that the approach to managing the site to cope with future environmental change was almost entirely based on their experience of past changes in the area.

Already implemented measures developed from own experience in the sites where mainly related to water management e.g. of past extreme flooding events (e.g. DE18, DE 61), of digging additional waterholes for cattle and watering saplings due to more frequent summer droughts (UK2, CY15), or adaptation of drainage systems due to alteration between droughts and flooding events (UK21). Other adaptation measures were e.g. a greater temporal flexibility that was given to landowners concerning their land management due to the seasonal variability of the last years (UK12) and the development of forest edges as protection against accidental tree fall due to stronger and more frequent storms (BE24).

8.7.2 Important sources of information to understand climate impacts

The survey assessed the importance of information sources to understand climatic impacts, both through personal expertise and exchange as well as through publications (Fig. 34). It is important to note, that the majority (86%) of the respondents agreed, that the ecological knowledge and experience of their site staff was a very important or important source of information in helping to understand possible climate impacts, to incorporate adaptation into their conservation goals, and to identify the necessary management actions. Second and third most important information sources were other scientists, with particular emphasis on good exchange and collaboration with external scientists (71%), e.g. from universities or through the EU funded project 'Adaptive Management of Climate-induced Changes of Habitat Diversity in Protected Areas' (HABIT-CHANGE, www.habit-change.eu) or the EU funded project 'Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region' (BaltCICA www.baltcica.org). Other colleagues, conservation managers of other sites and other experts were considered as important information source by less than a third of the respondents and as very important by about 10%. These include the expertise of local stakeholders, land owners and farmers.

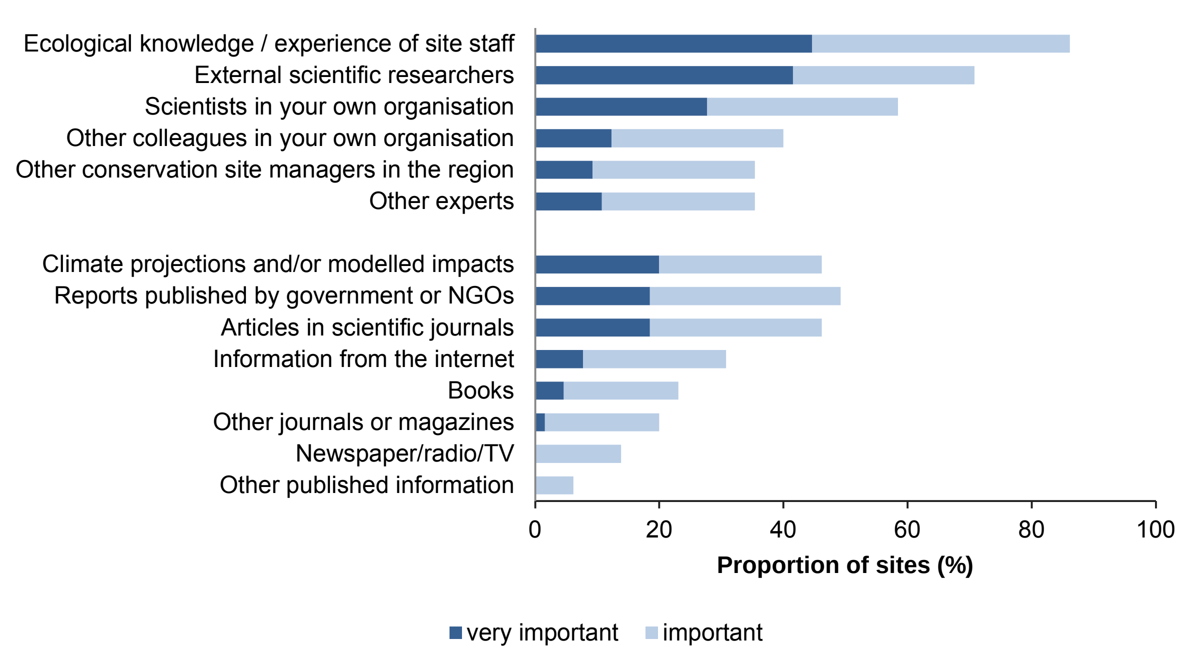

Figure 34: Sources of information perceived as most useful to inform climate adaptation planning (n=65)

In contrast, published reports and articles in scientific journals, by governmental or non-governmental organizations were found to be important or very important to a lesser extent, by only about half of the respondents. Information from the internet, books and other magazines and journals were considered as important by about 20-30% of the respondents, and as very important by less than 10%. Public information channels like newspapers, radio and TV were not considered to be an important source of information for helping to understand possible climate impacts at all and were only considered important by less than one fifth of the respondents.

Most important or very important information sources developed from personal cooperation and the establishment of networks with other conservation sites, universities or other governmental and non-governmental authorities, during corporate planning of future management measures.

8.7.3 Barriers to taking action to adapt to climate change

Participants of the survey were asked to comment on the currently greatest barriers to taking action to adapt to climate change on their conservation site and to rank potential barriers on a scale from 1 to 9, with 9 being the most important (Fig. 35).

About 90% of the respondents perceived the uncertainty of climate impacts and how they will affect complex ecosystem processes and species interactions on their sites as currently one of the greatest barriers to taking action to adapt to climate change. Consequently, a lack of knowledge of appropriate actions to take in response to climate impacts was identified as another important barrier, and advice was sought on how to break down general adaptation principles to site specific action. As common in conservation, a lack of resources with respect to finance and staff was identifed as key barrier (76%), already reflected in the fact that many sites had no vulnerability assessment or only little detailed adaptation plans. About two thirds of the respondents considered public opinion as a barrier to change management. The unpredictability of change and sometimes slow speed of change make it difficult to raise awareness and support for the need for change in management until drastic change occurs. However, as users or possibly owners of the sites, early involvement of the general public and stakeholders is seen as crucial to success.

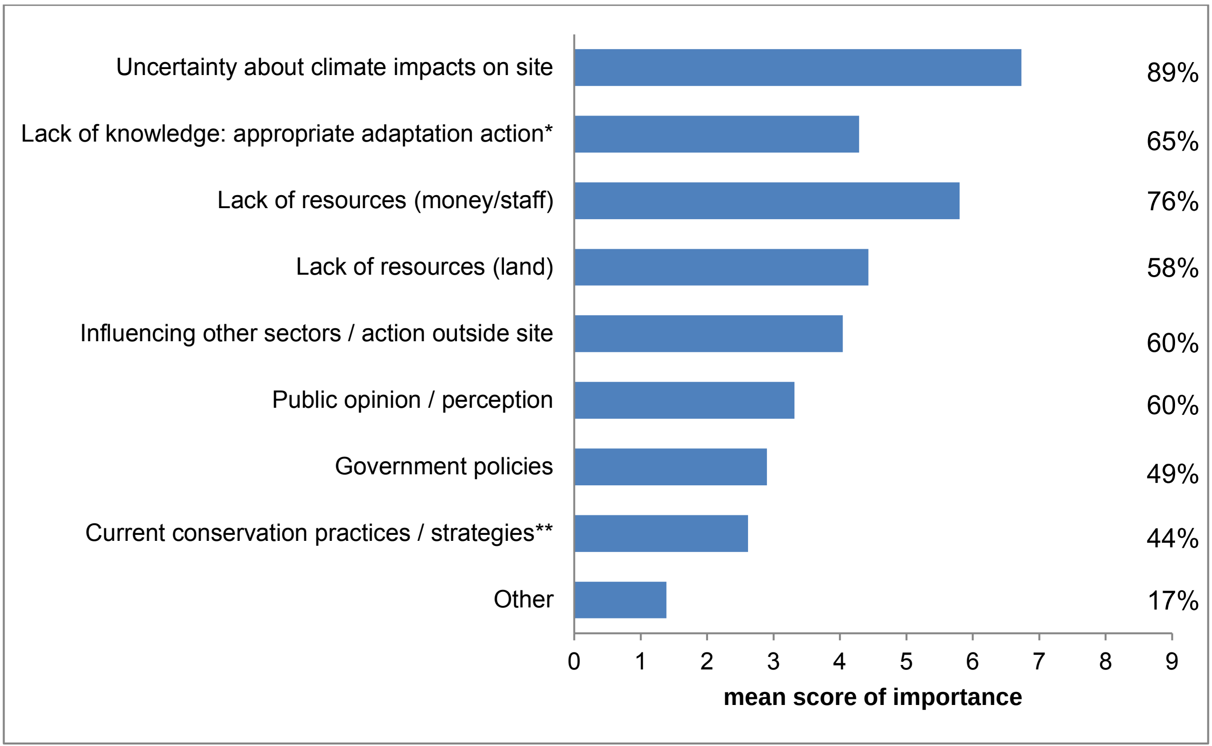

Figure 35: Mean score of importance of barriers to implementing climate action (n= 72, highest score 9 being most important, percentages of respondents who identified issue as a barrier)
Exact wording:
* Lack of knowledge about appropriate actions to take in response
** Current conservation practices and strategies (e.g. designations)

In addition, influencing other sectors and taking necessary action outside the reserve site to address offsite effects or impacts were considered as a key difficulty. Repondents reported on the frequent lack of interlinkage between sectors and lack of clear understanding of climate change impacts, as well as a lack of consensus on management priorities for e.g. food security or conservation. In addition, the limited availability to land or lack of funds to acquire land for enhancing buffering capacity around sites and reducing fragmentation was seen as an important barrier. Agricultural usage around the sites constrained in parts action on site, such as rewetting.

Interestingly, government policy was perceived by some sites as a very important barrier, while it did not matter to other sites. In some countries, sites reported on a lack of government policies dealing explicitly with climate change, whereas in other countries climate mitigation policy and subsequent promotion of renewable energy production can at times be in conflict with conservation goals, e.g. for the production of bioenergy from maize crops on drained peatland sites. Other sector policies such as the Common Agricultural Policy (CAP) or forestry policies in some countries and their subsidy schemes or the declaration of peat as renewable energy, e.g. in Finland, lead to unsustainable exploitation of habitats (Note: as authors we define peat as non-renewable sub-surface assett, that is similar to coal not renewable in short time scales. In addition, once peatlands have been drained for extraction, peat oxidation continues even if extraction is stopped, if no rewetting is taking place, and thereby continuing to emit greenhouse gases). Respondents felt, that governments were not considering ecosystem based adaptation through e.g. restoration of habitats for climate regulation or flood water retention as a viable and efficient option to adapt to climate change (see section 5).

Also, for some respondents current static conservation practices and strategies can lead to stifled adaptation action allowing for little flexibility and adaptive change. In the face of uncertainty of climatic effects, however, this may be justified in order to retain the current set of species in many cases, while some efforts could be made to also allow for shifts in species distribution and welcoming new species.

8.7.4 Opportunities for conservation in a changing climate

Half of all survey participants (49%) considered climate change also as an opportunity for conservation on their site, while 38% could not see any opportunities with a changing climate for conservation (no response for 16 sites). About half of the sites from Germany and the UK as well as two thirds of the sites from the other European countries responded that climate change may create chances for the conservation site while there was no correlation to a particular ecosystem type. Greatest chances were seen in awareness raising in the public and in greater acceptance of conservation measures as part of ecosystem based adaptation. The inevitability of change, e.g. for marine shorelines, may force a re-think of conservation policy and the adoption of an adaptive strategy to roll the features inland and restore flexibility to the system. In addition, it was seen as an opportunity for policy to take further strategic and long-term steps towards climate adaptation, and include closer cross-sector working focussing on synergies between conservation and other sectors. In practice, a rise in sea level or more frequent inundation of farmland in floodplains may lead to abandonment of unsustainable farming practices with benefits to conservation. Further opportunities mentioned by several respondents were the increased potential for restoration of wetlands and peatlands to contribute to flood mitigation and climate regulation. In addition, an increase in dry grassland sites alongside range expansion or shifts of southern species may create opportunities to welcome more thermophilic and southern species, while this might be at the cost of other species and is therefore a multifacetted issue.

8.8 Survey Conclusions

This webbased survey on ‘Climate adaptation planning and conservation measures in European conservation projects’ was extremely informative and useful to assess the state of current conservation planning and actions with regards to climate change adaptation and to complement the Edinburgh workshop results. We would like to thank all survey participants very much for offering their time and expertise.

It was clear that most site managers were well aware of general impacts of climate change. In reality, they have to manage a mix of ecosystem types on their sites, and therefore impacts are complex and cannot be assessed in a simple framework. Indeed, most conservation managers mentioned the uncertainty and high unpredictability of climatic changes as a key difficulty, especially when applying this to their specific sites.

It is notable, that most site managers perceive climatic changes to have an imminent impact on their sites (within next 10 years, see section 8.3.2). This is in stark contrast to the fact, that almost half of the sites have not yet prepared vulnerability assessments or included climate adaptation in site management plans. Only 13 out of 72 sites, considered climate change adapation as a major or central objective in their conservation management plans.

This can partly be explained by either lack of awareness, lack of knowledge or lack of capacity or difference in priority setting, as other current land use pressures as well as successional processes may be seen as more prevalent. Several respondents mentioned that there is a shortage of resources for planning or that at the time when the management plans were written, e.g. 5 years ago, climate change was not perceived as a major issue for the site, yet. In addition, the intensity and direction of change is perceived as highly unpredictable with high uncertainty of local impacts of changing climate, and that general trends are difficult to apply for site level planning. There is accordingly a high uncertainty for the direction of responsive management appropriate to increase resilience for the specific sites.

Many of the tools that can be used to address climate change effects are already available to natural resource managers, but as Mawdsley, O'Malley & Ojima (2009) state, they will likely need to apply these tools in novel and innovative ways to meet the unprecedented challenges posed by climate change. Most of the surveyed sites focussed their adaptation goals on resistance of existing species communities to change, with management goals still centered on species and habitat protection for a majority of sites, by securing good habitat quality. As discussed in section 4.9.3, this can be a good strategy, especially if heterogeneity of microhabitats within sites can be fostered to buffer for extreme weather events or periods of water or temperature stress. Many sites also included aspects of increasing resilience, especially through increasing ecological connectivity with other sites. Transformational goals, however, by facilitating change through passive or active ecosystem change or actively managing change by enabling new species establishment at sites was considered by less than 30% and 20% of all sites, whereby coastal sites were more open towards this strategy. Accordingly most adaptation management focussed on species and habitat specific actions (restoration, habitat creation, control of invasive species) and to some extent on maintaining ecosystem processes, with around half of all sites focussing on water level management as key determinant for ecosystem functioning. Intervention measures, such as fire control were seen as last resort, while several sites also emphasised the need to reduce non-climatic pressures, too.

Interestingly, collaboration between sites, even for increasing connectivity between sites was relatively low, with only 19 out of 72 sites actively engaged in coordination with other sites. This is surprising, as expertise of colleagues was mentioned as the main source of information. While most respondents declared that they cannot rely on past own experience, such as past extreme weather events, to inform their approach to managing the site to cope with future environmental change, the main source of information for understanding climate change impcats were site staff and scientists within and outside organisations. Published literature (online and print) was not seen as useful as personal expertise.

Barriers to action were both knowledge barriers and institutional barriers. Knoweldge barriers included uncertainty about how to apply general principles of climate change to specific sites and further translate this into concrete adaptation management actions. In addition, respondents mentioned little awareness and acceptance of the general public of the need for change. Institutional barriers included the lack of cross-sector working across policy goals. Embracing an ecosystem based adaptation and mitigation approach especially by allowing for water retention in floodplains for flood mitigation or rewetting peatlands for climate change mitigation by reducing greenhouse gas emissions, can create synergies with other sectors. At times climate policy, especially with regards to bioenergy production, can lead to conflicts with conservation goals. Current conservation strategies may also be inflexible to integrate climate adaptation, and may need some adjustment, while taking care to conform to the Habitats Directive.

One respondent also suggested a bit mockingly that the consideration of climate change was an ‘irrelevant distraction’ to conservation. In a further email they explained that e.g. land use and land use change alongside pollution were more pronounced and pressing issues in their country, that cannot be ignored and have to be dealt with first. This may on the one hand reflect on priority setting, but probably also reflects on the scarcity of available resources in conservation management and planning across Europe. It is acknowledged that especially in Southern and Eastern Europe capacities of conservation staff teams may currently not be sufficient to address climate adaptation in the face of imminent other pressures.

The capacity to include climate change adaptation planning in site management may need to be fostered by ENCA through sharing of good practice across countries, and e.g. providing for meeting opportunities also in Southern and Eastern countries, that impact less on staff time and budget. Overall, it seems useful to promote more active knowledge exchange of site managers between sites across Europe, ideally with face-to-face meetings and workshops to share experience and best practice. This should also include scientists from the organisations and universities, as individual contact to experts from practice and science was seen as the best way to promote understanding of climate change adaptation.

9 Conclusions

The 2011 ENCA Edinburgh workshop and the 2011 and 2013 Bfn/ENCA Bonn conferences identified climate impacts for a range of ecosystems across Europe, focussing in particular on mountain and sub-arctic ecosystems, peatland ecosytems, coastal ecosystems, freshwater and riparian ecosystems and forest ecosystems. The report summarises discussion results how to set adaptation objectives and how they can result in adaptation actions, points out information and monitoring needs as well as potential barriers and opportunities, summarised in section 4.9. It is clear that climate impacts are already being felt, especially in mountain and coastal ecosystems, and opportunities for adaptation vary between ecosystems. For grassland ecosystems the type and intensity of pressure from land use and land use change are of particular importance and addressing these may be key to enhance resilience to climatic effects. Urban ecosystems were only discussed at a workshop session at the 2013 conference, although these form very species rich ecosystems, including a range of non-native species. Urban ecoystems are possibly those that people most relate to and may depend on for daily life. Especially with rising urbanisation, urban ecosystems therefore become more and more important from a socio-ecological perspective, and with their hotter micro-climates may also serve as demonstration systems for ecosystem-based mitigation and adaptation potential of nature conservation, as discussed in section 5. It might therefore be useful to consider climate adaptation in cities in more depth at further meetings.

The review of concepts and evidence for increasing connectivity and translocation as climate change adaptation measures led to the following conclusions. Enhancing connectivity for climate change adaptation has been widely advocated, but now requires a more refined and evidence-based approach. A crucial starting point to improve connectivity and species persistence is to create, enlarge and prioritise protected areas that have high environmental heterogeneity. Such areas should promote population growth and dispersal and provide good conditions for dispersing individuals. This will both optimize the efficiency of connectivity measures and maximize the return on conservation investment, which may otherwise be lost if no connectivity can be established and populations subsequently decline. Risks of connectivity may include the loss of resilience against environmental stochasticity, the spread of antagonistic species and diseases as well as potential homogenisation of the gen pool, while overall the benefits appear to prevail. In some cases, connectivity may not be sufficient for rare, restricted species in ‘island’ situations, that are not surrounded by easily accessible micro-climates, and translocation may be considered as an option.

Translocations by their very nature address isolated cases. Here, costs and benefits need to be closely evaluated, e.g. whether a species might become invasive or fail to establish, including the cost of inaction and opportunity costs with regards to other adaptation actions. While translocations may be considered a last resort strategy for some rare endemic species, they cannot realistically form the core of adaptation strategies to climate change.

The online survey of climate adaptation planning and conservation measures in European conservation projects revealed, that while most site managers expect climatic changes to have imminent impact in their conservation areas, there is too little knowledge on potential effects and forward planning. Almost half of the sites have not yet prepared vulnerability assessments or included climate adaptation in site management plans. Here, the experience on vulnerability assessments from some countries, such as the UK, or particular ecosystems, such as marine and coastal ecoystems, could be shared as good practice across Europe.

Barriers to planning and preparatory action include lack of knowledge on specific impact of climatic changes on protected areas, as climate projections are often at a too large spatial and temporal scale to be translated into specific management. In addition, both a lack of resources and institutional barriers, especially a lack of cross-sector working, prevented change management. Interestingly, ressource managers stated that personal interaction with ecologist and scientists within and across organsiations was seen as the most helpful source of information on climate adaptation management, rather than written material (publications, online resources). Therefore, a greater exchange of resource managers across sectors with e.g. workshops seems desirable to foster concerted climate adaptation action across Europe.

Overall it is recommended to share and implement the ENCA recommendations on climate adaptation across Europe (section 3). This can be achieved through a) enhancing communication and cross-sectoral collaboration for integrated adaptation management and planning, b) raising greater awareness of effects of climatic changes on biodiversity but also human well-being, c) fostering action and optimizing investments into Green Infrastructure, as well as d) monitoring and increasing understanding of climate change impacts, in order to enhance resilience of biodiversity in the different ecosystems. Here, the potential of focussing on multifunctionality of nature conservation by enhancing ecosystem services through ecosystem based adapation and mitigation can foster strong synergies with other policy goals across Europe.

10 Literature

ADRIAN, R., O'REILLY, C.M., ZAGARESE, H., BAINES, S.B., HESSEN, D.O., KELLER, W., LIVINGSTONE, D.M., SOMMARUGA, R., STRAILE, D. & VAN DONK, E. (2009) Lakes as sentinels of climate change. *Limnology and Oceanography,* 54, 2283-2297.

AKÇAKAYA, H.R. & BAUR, B. (1996) Effects of Population Subdivision and Catastrophes on the Persistence of a Land Snail Metapopulation. *Oecologia,* 105, 475-483.

ALLEN, C.D., MACALADY, A.K., CHENCHOUNI, H., BACHELET, D., MCDOWELL, N., VENNETIER, M., KITZBERGER, T., RIGLING, A., BRESHEARS, D.D. & HOGG, E. (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management,* 259, 660-684.

ALOFS, K.M. & FOWLER, N.L. (2010) Habitat fragmentation caused by woody plant encroachment inhibits the spread of an invasive grass. *Journal of Applied Ecology,* 47, 338-347.

ALTIZER, S., HARVELL, D. & FRIEDLE, E. (2003) Rapid evolutionary dynamics and disease threats to biodiversity. *Trends in Ecology & Evolution,* 18, 589-596.

APLET, A.G.H., ANDERSON, S.J. & STONE, C.P. (1991) Association between Feral Pig Disturbance and the Composition of Some Alien Plant Assemblages in Hawaii Volcanoes National Park. *Vegetatio,* 95, 55-62.

ARAÚJO, M.B., ALAGADOR, D., CABEZA, M., NOGUÉS-BRAVO, D. & THUILLER, W. (2011) Climate change threatens European conservation areas. *Ecology Letters,* 14, 484-492.

ATKINSON, I.A.E. (2001) Introduced mammals and models for restoration. *Biological Conservation,* 99, 81-96.

AUSDEN, M. (2013) Climate change adaptation: Putting principles into practice. *Environmental management*, DOI 10.1007/s00267-00013-00217-00263.

BAIN, C., BONN, A., STONEMAN, R., CHAPMAN, S., COUPAR, A., EVANS, M., GEARY, B., HOWAT, M., JOOSTEN, H., KEENLEYSIDE, C., LINDSAY, R., LABADZ, J., LITTLEWOOD, N., LUNT, P., MILLER, C., MOXEY, A., ORR, H., REED, M.S., SMITH, P., SWALES, V., THOMPSON, D.B.A., VAN DE NOORT, R., WILSON, J.D. & WORRALL, F. (2011) *Commission of Inquiry on UK Peatlands.* IUCN UK Peatland Programme, Edinburgh. http://www.iucn-uk-peatlandprogramme.org/sites/all/files/IUCN%20UK%20Commission%20of%20Inquiry%20on%20Peatlands%20Full%20Report%20spv%20web.pdf

BAJOMI, B. (2007) *Factors Influencing the Success Rate of Reintroduction of Endangered Animal Species. Systematic Review No. 29.* Centre for Evidence-based Conservation, Bangor, UK. www.environmentalevidence.org/Documents/Protocol29.pdf

BAJOMI, B., PULLIN, A.S., STEWART, G.B. & TAKÁCS-SÁNTA, A. (2010) Bias and dispersal in the animal reintroduction literature. *Oryx,* 44, 358-365.

BASILICO, L., MOJAÏSKY, M. & IMBARD, M. (2013) *Climate Change and Mediterranean Coastal Areas: Understanding the Impacts and Developing Adaptation Strategies. An overview of the CIRCLE-Med Research Projects 2008-2011.* VERSeau Développement Editions. http://www.circle-era.eu/np4/513.html

BECK, B.B., RAPAPORT, L.G., STANLEY-PRICE, M.R. & WILSON, A.C. (1994) Reintroduction of captive-born animals. C *Creative conservation: interactive management of wild and captive animals* (eds P.J.S. Olney, G.M. Mace & A.T.C. Feister), pp. 265-286. Chapman & Hall, London.

BEIER, P. (2012) Conceptualizing and Designing Corridors for Climate Change. *Ecological Restoration,* 30, 312-319.

BEIER, P. & BROST, B. (2010) Use of land facets to plan for climate change: conserving the arenas, not the actors. *Conservation Biology,* 24, 701-710.

BENISTON, M. (2000) *Environmental change in mountains and uplands*. Arnold Publishers, London.

BENISTON, M. (2003) Climatic Change in Mountain Regions: A Review of Possible Impacts. In: *Climate Variability and Change in High Elevation Regions: Past, Present & Future* (ed. H.F. Diaz), pp. 5-31. Springer Netherlands.

BENNETT, G. (2004) *Linkages in practice: a review of their conservation value*. IUCN, Gland, Cambridge.

BENNETT, G. & MULONGOY, K.J. (2006) *Review of experience with ecological networks, corridors and buffer zones.,* Technical Series No. 23. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

BIANCHI, F.J.J.A., BOOIJ, C.J.H. & TSCHARNTKE, T. (2006) Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B,* 273, 1715-1727.

BJÖRK, R.G. & MOLAU, U. (2007) Ecology of Alpine Snowbeds and the Impact of Global Change. *Arctic, Antarctic, and Alpine Research,* 39, 34-43.

BONN, A., ALLOTT, T., HUBACEK, K. & STEWART, J. (2009) *Drivers of environmental change in uplands.* Routledge, London and New York.

BONN, A., REBANE, M. & REID, C. (2009) Ecosystem services: a new rationale for conservation of upland environments. In: *Drivers of environmental change in uplands* (eds A. Bonn, T. Allott, K. Hubacek & J. Stewart), pp. 448-474. Routledge, London and New York.

BONN, A., ALLOTT, T., EVANS, M., JOOSTEN, H. & STONEMAN, R. (in press) *Peatland restoration and ecosystem services - science, policy and practice.* Cambridge University Press, Cambridge.

BOUWMA, I.M., VOS, C.C., BIEMANS, M., MCINTOSH, N., VAN APELDOORN, R. & VERDONSCHOT, P. (2012) *Guidelines on dealing with the impact of climate change on the management of Natura 2000*. Publications Office of the European Union, Luxembourg http://ec.europa.eu/environment/nature/climatechange/pdf/N2_CC_guidelines.pdf

BOWLER, D.E., BUYUNG-ALI, L.M., KNIGHT, T.M. & PULLIN, A.S. (2010) A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health,* 10, 456.

BRANTON, M. & RICHARDSON, J.S. (2011) Assessing the Value of the Umbrella-Species Concept for Conservation Planning with Meta-Analysis. *Conservation Biology,* 25, 9-20.

BRASIER, C., DENMAN, S., BROWN, A. & WEBBER, J. (2004) Sudden Oak Death (*Phytophthora ramorum*) discovered on trees in Europe. *Mycological Research,* 108, 1108-1110.

BROOKER, R.W., BRITTON, A.J., GIMONA, A., LENNON, J.J. & LITTLEWOOD, N.A. (2011) *Literature review: species translocations as a tool for biodiversity conservation during climate change.* Scottish Natural Heritage Commissioned Report, Inverness.

CALLAGHAN, T.V., BJÖRN, L.O., CHERNOV, Y., CHAPIN, T., CHRISTENSEN, T.R., HUNTLEY, B., IMS, R.A., JOHANSSON, M., JOLLY, D., JONASSON, S., MATVEYEVA, N., PANIKOV, N., OECHEL, W., SHAVER, G., ELSTER, J., HENTTONEN, H., LAINE, K., TAULAVUORI, K., TAULAVUORI, E. & ZÖCKLER, C. (2004) Biodiversity, Distributions and Adaptations of Arctic Species in the Context of Environmental Change. *Ambio,* 33, 404-417.

CARROLL, C., NOSS, R.F., PAQUET, P.C. & SCHUMAKER, N.H. (2004) Extinction Debt of Protected Areas in Developing Landscapes. *Conservation Biology,* 18, 1110-1120.

CARROLL, M.J., DENNIS, P., PEARCE-HIGGINS, J.W. & THOMAS, C.D. (2011) Maintaining northern peatland ecosystems in a changing climate: effects of soil moisture, drainage and drain blocking on craneflies. *Global Change Biology,* 17, 2991-3001.

CASTRIC, V. & BERNATCHEZ, L. (2003) The rise and fall of isolation by distance in the anadromous brook charr (*Salvelinus fontinalis* Mitchill). *Genetics,* 163, 983-996.

CBD (2009) *Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Montreal.* Technical Series No. 41. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

CHANG, C.-S., KIM, H., PARK, T.-Y. & MAUNDER, M. (2004) Low levels of genetic variation among southern peripheral populations of the threatened herb *Leontice microrhyncha* (Berberidaceae) in Korea. *Biological Conservation,* 119, 387-396.

CHARMAN, D.J., BEILMAN, D.W., BLAAUW, M., BOOTH, R.K., BREWER, S., CHAMBERS, F.M., CHRISTEN, J.A., GALLEGO-SALA, A., HARRISON, S.P., HUGHES, P.D.M., JACKSON, S.T., KORHOLA, A., MAUQUOY, D., MITCHELL, F.J.G., PRENTICE, I.C., VAN DER LINDEN, M., DE VLEESCHOUWER, F., YU, Z.C., ALM, J., BAUER, I.E., CORISH, Y.M.C., GARNEAU, M., HOHL, V., HUANG, Y., KAROFELD, E., LE ROUX, G., LOISEL, J., MOSCHEN, R., NICHOLS, J.E., NIEMINEN, T.M., MACDONALD, G.M., PHADTARE, N.R., RAUSCH, N., SILLASOO, Ü., SWINDLES, G.T., TUITTILA, E.S., UKONMAANAHO, L., VÄLIRANTA, M., VAN BELLEN, S., VAN GEEL, B., VITT, D.H. & ZHAO, Y. (2012) Climate-related changes in peatland carbon accumulation during the last millennium. *Biogeosciences Discussions,* 9, 14327-14364.

CHEN, I.-C., HILL, J.K., OHLEMÜLLER, R., ROY, D.B. & THOMAS, C.D. (2011) Rapid Range Shifts of Species Associated with High Levels of Climate Warming. *Science,* 333, 1024-1026.

CHITTKA, L. & SCHÜRKENS, S. (2001) Successful invasion of a floral market. *Nature,* 411, 653-653.

CLARK, J.M., GALLEGO-SALA, A.V., ALLOTT, T.E.H., CHAPMAN, S.J., FAREWELL, T., FREEMAN, C., HOUSE, J.I., ORR, H.G., PRENTICE, I.C. & SMITH, P. (2010) Assessing the vulnerability of blanket peat to climate change using an ensemble of statistical bioclimatic envelope models. *Climate Research,* 45, 131-150.

CLARKE, S.J. (2009) Adapting to Climate Change: Implications for Freshwater Biodiversity and Management in the UK. *Freshwater Reviews,* 2, 51-64.

CLAVERO, M. & GARCÍA-BERTHOU, E. (2005) Invasive species are a leading cause of animal extinctions. *Trends in Ecology & Evolution,* 20, 110.

CLEVENGER, A.P. & SAWAYA, M.A. (2010) Piloting a Non-Invasive Genetic Sampling Method for Evaluating Population-Level Benefits of Wildlife Crossing Structures. *Ecology & Society,* 15.

COLE, C.T., ANDERSON, J.E., LINDROTH, R.L. & WALLER, D.M. (2010) Rising concentrations of atmospheric CO2 have increased growth in natural stands of quaking aspen (*Populus tremuloides*). *Global Change Biology,* 16, 2186-2197.

CORLATTI, L., HACKLÄNDER, K. & FREY-ROOS, F. (2009) Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. *Conservation Biology,* 23, 548-556.

COUNCIL OF EUROPE (1996) *Pan-European biological and landscape diversity strategy,* Nature and Environment. Council of Europe Press, Strasbourg.

COUWENBERG, J., THIELE, A., TANNEBERGER, F., AUGUSTIN, J., BÄRISCH, S., DUBOVIK, D., LIASHCHYNSKAYA, N., MICHAELIS, D., MINKE, M., SKURATOVICH, A. & JOOSTEN, H. (2011) Assessing greenhouse gas emissions from peatlands using vegetation as a proxy. *Hydrobiologia,* 674, 67-89.

CRABTREE, D. & ELLIS, C.J. (2010) Species interaction and response to wind speed alter the impact of projected temperature change in a montane ecosystem. *Journal of Vegetation Science,* 21, 744-760.

CRIMMINS, S.M., DOBROWSKI, S.Z., GREENBERG, J.A., ABATZOGLOU, J.T. & MYNSBERGE, A.R. (2011) Changes in climatic water balance drive downhill shifts in plant species' optimum elevations. *Science,* 331, 324-327.

CROOKS, K.R. & SANJAYAN, M. (2006) *Connectivity conservation*. Cambridge University Press, Cambridge.

CUSHMAN, S.A. (2006) Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation,* 128, 231-240.

DA FONSECA, G.A.B., SECHREST, W. & OGLETHORPE, J. (2005) Managing the matrix. In: *Climate Change and Biodiversity* (eds T.E. Lovejoy & L. Hannah), pp. 346 – 358. Yale University Press, New Haven.

DASZAK, P., CUNNINGHAM, A.A. & HYATT, A.D. (2000) Wildlife ecology - Emerging infectious diseases of wildlife - Threats to biodiversity and human health. *Science,* 287, 443-449.

DAVID, A.S., SANDRA, C.C. & NICHOLAS, W.W. (2013) Mapping climate change in European temperature distributions. *Environmental Research Letters,* 8, 034031.

DAVIES, Z.G., EDMONDSON, J.L., HEINEMEYER, A., LEAKE, J.R. & GASTON, K.J. (2011) Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology,* 48, 1125-1134.

DAVIES, Z.G., WILSON, R.J., BRERETON, T.M. & THOMAS, C.D. (2005) The re-expansion and improving status of the silver-spotted skipper butterfly (*Hesperia comma*) in Britain: a metapopulation success story. *Biological Conservation,* 124, 189-198.

DAVIS, M.B. & SHAW, R.G. (2001) Range shifts and adaptive responses to Quaternary climate change. *Science,* 292, 673-679.

DAVIS, T.W., BERRY, D.L., BOYER, G.L. & GOBLER, C.J. (2009) The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of *Microcystis* during cyanobacteria blooms. *Harmful algae,* 8, 715-725.

DAVISON, J.E., GRAUMLICH, L.J., ROWLAND, E.L., PEDERSON, G.T. & BRESHEARS, D.D. (2012) Leveraging modern climatology to increase adaptive capacity across protected area networks. *Global Environmental Change,* 22, 268-274.

DAWES, M.A., HÄTTENSCHWILER, S., BEBI, P., HAGEDORN, F., HANDA, I.T., KÖRNER, C. & RIXEN, C. (2011) Species-specific tree growth responses to 9 years of CO2 enrichment at the alpine treeline. *Journal of Ecology,* 99, 383-394.

DAWSON, T.P., JACKSON, S.T., HOUSE, J.I., PRENTICE, I.C. & MACE, G.M. (2011) Beyond predictions: biodiversity conservation in a changing climate. *Science,* 332, 53-58.

DESCIMON, H., BACHELARD, P., BOITIER, E. & PIERRAT, V. (2006) Decline and extinction of Parnassius apollo populations in France - continued. In: *Studies on the Ecology and Conservation of Butterflies in Europe (EBIE)* (eds E. Kühn, R. Feldmann & J. Settele), pp. 114–115. Pensoft, Bulgaria.

DOBROWSKI, S.Z. (2011) A climatic basis for microrefugia: the influence of terrain on climate. *Global Change Biology,* 17, 1022-1035.

DÖLL, P. & ZHANG, J. (2010) Impact of climate change on freshwater ecosystems: a global-scale analysis of ecologically relevant river flow alterations. *Hydrology & Earth System Sciences Discussions,* 7, 1305-1342.

DOMISCH, S., ARAÚJO, M.B., BONADA, N., PAULS, S.U., JÄHNIG, S.C. & HAASE, P. (2013) Modelling distribution in European stream macroinvertebrates under future climates. *Global Change Biology,* 19, 752-762.

DONALD, P.F. & EVANS, A.D. (2006) Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. *Journal of Applied Ecology,* 43, 209-218.

DORP, D. & OPDAM, P.F.M. (1987) Effects of patch size, isolation and regional abundance on forest bird communities. *Landscape Ecology,* 1, 59-73.

DOSWALD, N. & OSTI, M. (2011) *Ecosystem-based Approaches to Adaptation and Mitigation: Good Practice Examples and Lessons Learned in Europe*. BfN-Skripten, 306. Federal Agency for Nature Conservation, Bonn.

DURIEZ, O., SACHET, J.-M., MÉNONI, E., PIDANCIER, N., MIQUEL, C. & TABERLET, P. (2007) Phylogeography of the capercaillie in Eurasia: what is the conservation status in the Pyrenees and Cantabrian Mounts? *Conservation Genetics,* 8, 513-526.

ECKERT, N., BAYA, H. & DESCHATRES, M. (2010) Assessing the Response of Snow Avalanche Runout Altitudes to Climate Fluctuations Using Hierarchical Modeling: Application to 61 Winters of Data in France. *Journal of Climate,* 23, 3157-3180.

EEA (2009) *Regional climate change and adaptation. The Alps facing the challenge of changing water resources*. European Environment Agency, Copenhagen http://www.eea.europa.eu/publications/alps-climate-change-and-adaptation-2009

EEA (2010) *The European environment. State and outlook 2010. Land use.* European Environment Agency, Copenhagen. http://www.eea.europa.eu/soer

EEA (2012) *Climate change, impacts and vulnerability in Europe 2012. An indicator-based report*. European Environment Agency, Copenhagen. http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012

ELSASSER, P., MEYERHOFF, J., MONTAGNÉ, C. & STENGER, A. (2009) A bibliography and database on forest benefit valuation studies from Austria, France, Germany, and Switzerland – A possible base for a concerted European approach. *Journal of Forest Economics,* 15, 93-107.

EPSTEIN, P.R. (2001) Climate change and emerging infectious diseases. *Microbes and Infection,* 3, 747-754.

ESSL, F., DULLINGER, S., MOSER, D., RABITSCH, W. & KLEINBAUER, I. (2012) Vulnerability of mires under climate change: implications for nature conservation and climate change adaptation. *Biodiversity and Conservation,* 21, 655-669.

ESSL, F. & RABITSCH, W. (2013) *Biodiversität und Klimawandel. Auswirkungen und Handlungsoptionen für den Naturschutz in Mitteleuropa*. Springer, Berlin, Heidelberg.

ETHERIDGE, E.C., BEAN, C.W., MAITLAND, P.S. & ADAMS, C.E. (2010) Morphological and ecological responses to a conservation translocation of powan (*Coregonus lavaretus*) in Scotland. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 20, 274-281.

EUROPEAN COMMISSION (2010) *Soil biodiversity: functions, threats and tools for policy makers*. European Commission DG ENV [Contract 07.0307/2008/517444/ETU/B1], Final report. http://ec.europa.eu/environment/soil/pdf/biodiversity_report.pdf

EUROPEAN COMMISSION (2012) *A blueprint to safeguard Europe's water resources*. European Commission. http://ec.europa.eu/environment/water/blueprint/

FABRY, V.J., SEIBEL, B.A., FEELY, R.A. & ORR, J.C. (2008) Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science: Journal du Conseil,* 65, 414-432.

FAHRIG, L. (2001) How much habitat is enough? *Biological Conservation,* 100, 65-74.

FAHRIG, L. (2003) Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics,* 34, 487-515.

FAZEY, I. & FISCHER, J. (2009) Assisted colonization is a techno-fix. *Trends in Ecology and Evolution,* 24, 475.

FIORETTI, R., PALLA, A., LANZA, L.G. & PRINCIPI, P. (2010) Green roof energy and water related performance in the Mediterranean climate. *Building and Environment,* 45, 1890-1904.

FISCHER, J. & LINDENMAYER, D.B. (2000) An assessment of the published results of animal relocations. *Biological Conservation,* 96, 1-11.

FOPPENI, R., BRAAK, C.J.P.T.E.R., VERBOOMI, J. & REIJNENI, R. (1999) Dutsch sedge warbler *Acrocephalus schoenobaenus* and West-African rainfall: Empirical data and simulation modelling show low population resilience in fragmented marshlands. *Ardea,* 87, 113-127.

FORESTRY COMMISSION (2011) *Forests and Climate Change. UK Forestry Standard Guidelines*. Forestry Commission, Edinburgh. http://www.forestry.gov.uk/pdf/FCGL002.pdf/$FILE/FCGL002.pdf

FORMAN, R.T.T. & ALEXANDER, L.E. (1998) Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics,* 29, 207-C202.

FRANCO, A.M.A., HILL, J.K., KITSCHKE, C., COLLINGHAM, Y.C., ROY, D.B., FOX, R., HUNTLEY, B. & THOMAS, C.D. (2006) Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology,* 12, 1545-1553.

FRANKLIN, J.F. (1993) Preserving Biodiversity: Species, Ecosystems, or Landscapes? *Ecological Applications,* 3, 202-205.

FRANKS, J.R. & EMERY, S.B. (2013) Incentivising collaborative conservation: Lessons from existing environmental Stewardship Scheme options. *Land Use Policy,* 30, 847-862.

FREDERIKSEN, M., EDWARDS, M., MAVOR, R. & WANLESS, S. (2007) Regional and annual variation in black-legged kittiwake breeding productivity is related to sea surface temperature. *Marine Ecology Progress Series,* 350, 137-143.

FRÖLICH, K., THIEDE, S., KOZIKOWSKI, T. & JAKOB, W. (2002) A Review of Mutual Transmission of Important Infectious Diseases between Livestock and Wildlife in Europe. *Annals of the New York Academy of Sciences,* 969, 4-13.

GASTON, K.J. & BLACKBURN, T.M. (2002) Large-scale dynamics in colonization and extinction for breeding birds in Britain. *Journal of Animal Ecology,* 71, 390-399.

GASTON, K.J., CHARMAN, K., JACKSON, S.F., ARMSWORTH, P.R., BONN, A., BRIERS, R.A., CALLAGHAN, C.S.Q., CATCHPOLE, R., HOPKINS, J., KUNIN, W.E., LATHAM, J., OPDAM, P., STONEMAN, R., STROUD, D.A. & TRATT, R. (2006) The ecological effectiveness of protected areas: The United Kingdom. *Biological Conservation,* 132, 76-87.

GEHRIG-FASEL, J., GUISAN, A. & ZIMMERMANN, N.E. (2007) Tree line shifts in the Swiss Alps: Climate change or land abandonment? *Journal of Vegetation Science,* 18, 571-582.

GHERARDI, F. (2006) Crayfish invading Europe: the case study of *Procambarus clarkii*. *Marine and Freshwater Behaviour and Physiology,* 39, 175-191.

GILBERT-NORTON, L., WILSON, R., STEVENS, J.R. & BEARD, K.H. (2010) A meta-analytic review of corridor effectiveness. *Conservation Biology,* 24, 660-668.

GILBERT, L. (2010) Altitudinal patterns of tick and host abundance: a potential role for climate change in regulating tick-borne diseases? *Oecologia,* 162, 217-225.

GODDARD, M.A., DOUGILL, A.J. & BENTON, T.G. (2010) Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology & Evolution,* 25, 90-98.

GOG, J., WOODROFFE, R. & SWINTON, J. (2002) Disease in endangered metapopulations: the importance of alternative hosts. *Proceedings of the Royal Society B,* 269, 671-676.

GOSLING, L.M. & SUTHERLAND, W.J. (2000) *Behaviour and Conservation*. Cambridge University Press, Cambridge.

GÖTMARK, F., SÖDERLUNDH, H. & THORELL, M. (2000) Buffer zones for forest reserves: opinions of land owners and conservation value of their forest around nature reserves in southern Sweden. *Biological Conservation,* 9, 1377-1390.

GOUDSWAARD, K., WITTE, F. & KATUNZI, E.B. (2008) The invasion of an introduced predator, Nile perch (*Lates niloticus*, L.) in Lake Victoria (East Africa): chronology and causes. *Environmental Biology of Fishes,* 81, 127-139.

GRABHERR, G., GOTTFRIED, M. & PAULI, H. (1994) Climate effects on mountain plants. *Nature,* 369, 448.

GRANDA, E., ROSSATTO, D., CAMARERO, J.J., VOLTAS, J. & VALLADARES, F. (2014) Growth and carbon isotopes of Mediterranean trees reveal contrasting responses to increased carbon dioxide and drought. *Oecologia,* 174, 307-317.

GRIFFITH, B., SCOTT, J.M., CARPENTER, J.W. & REED, C. (1989) Translocation as a Species Conservation Tool: Status and Strategy. *Science,* 245, 477-480.

GRIMM, N.B., FAETH, S.H., GOLUBIEWSKI, N.E., REDMAN, C.L., WU, J., BAI, X. & BRIGGS, J.M. (2008) Global change and the ecology of cities. *Science,* 319, 756-760.

GROSSMANN, M. (2012) Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin. *Ecological Economics,* 83, 108-117.

GROSSMANN, M., HARTJE, V.J. & MEYERHOFF, J. (2010) *Ökonomische Bewertung naturverträglicher Hochwasservorsorge an der Elbe.* Bundesamt für Naturschutz, Bonn.

HAMBREY CONSULTING (2013) *The management of roadside verges for biodiversity.* Scottish Natural Heritage Commissioned Report.

HAMPE, A. & PETIT, R.J. (2005) Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters,* 8, 461-467.

HANNAH, L., MIDGLEY, G.F. & MILLAR, D. (2002) Climate change-integrated conservation strategies. *Global Ecology and Biogeography,* 11, 485-495.

HANSKI, I. (1998) Metapopulation dynamics. *Nature,* 396, 41-49.

HELLER, N.E. & ZAVALETA, E.S. (2009) Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation,* 142, 14-32.

HENLE, K., DAVIES, K.F., KLEYER, M., MARGULES, C. & SETTELE, J. (2004) Predictors of species sensitivity to fragmentation. *Biodiversity and Conservation,* 13, 207-251.

HEWITT, N., KLENK, N., SMITH, A.L., BAZELY, D.R., YAN, N., WOOD, S., MACLELLAN, J.I., LIPSIG-MUMME, C. & HENRIQUES, I. (2011) Taking stock of the assisted migration debate. *Biological Conservation,* 144, 2560-2572.

HICKLING, R., ROY, D.B., HILL, J.K., FOX, R. & THOMAS, C.D. (2006) The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology,* 12, 450-455.

HILEY, J.R., BRADBURY, R.B., HOLLING, M. & THOMAS, C.D. (2013) Protected areas act as establishment centres for species colonizing the UK. *Proceedings of the Royal Society B,* 280.

HOBBS, R.J. & HOPKINS, A.J.M. (1991) The role of conservation corridors in a changing climate. In: *Nature Conservation 2: The Role of Corridors* (eds D.A. Saunders & R.J. Hobbs), pp. 281–290. Surrey Beatty and Sons, Chipping Norton, Australia.

HÓDAR, J.A., CASTRO, J. & ZAMORA, R. (2003) Pine processionary caterpillar *Thaumetopoea pityocampa* as a new threat for relict Mediterranean Scots pine forests under climatic warming. *Biological Conservation,* 110, 123-129.

HODGSON, J., THOMAS, C., WINTLE, B., A & MOILANEN, A. (2009) Climate change, connectivity and conservation decision making: back to basics. *Journal of Applied Ecology,* 46, 964-969.

HOEGH-GULDBERG, O., HUGHES, L., MCINTYRE, S., LINDENMAYER, D.B., PARMESAN, C., POSSINGHAM, H.P. & THOMAS, C.D. (2008) Assisted Colonization and Rapid Climate Change. *Science,* 321.

HÖFLE, U., VICENTE, J., NAGORE, D., HURTADO, A., PEÑA, A., FUENTE, J.D.L. & GORTAZAR, C. (2004) The risks of translocating wildlife: Pathogenic infection with Theileria sp. and Elaeophora elaphi in an imported red deer. *Veterinary Parasitology,* 126, 387-395.

HONNAY, O. & JACQUEMYN, H. (2007) Susceptibility of common and rare plant species to the genetic consequences of habitat fragmentation. *Conservation Biology,* 21, 823-831.

HOPKINS, J.J., ALLISON, H.M., WALMSLEY, C.A., GAYWOOD, M. & THURGATE, G. (2007) *Conserving biodiversity in a changing climate: guidance on building capacity to adapt.* Defra, London.

HOPWOOD, J.L. (2008) The contribution of roadside grassland restorations to native bee conservation. *Biological Conservation,* 141, 2632-2640.

HOTTOLA, J., OVASKAINEN, O. & HANSKI, I. (2009) A unified measure of the number, volume and diversity of dead trees and the response of fungal communities. *Journal of Ecology,* 97, 1320-1328.

HUDGENS, B. & HADDAD, N.M. (2003) Predicting which species will benefit from corridors in fragmented landscapes from population growth models. *The American Naturalist,* 161, 808-820.

HUGHES, R.G. (2004) Climate change and loss of saltmarshes: consequences for birds. *Ibis,* 146, 21-28.

HULME, P.E. (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology,* 42, 784-794.

INOUYE, D.W. (2008) Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology,* 89, 353-362.

IPCC (2013) *Climate change 2013: the physical science basis*. Working Group I Contribution to the IPCC Fifth Assessment Report. https://www.ipcc.ch/report/ar5/wg1/

IPCC (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summary for Policymakers*. http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf

IUCN/SCC (2013) *Guidelines for reintroductions and other conservation translocations*. Version 1.0. IUCN Species Survival Commission, Gland, Switzerland. www.iucnsscrsg.org

JAMES, P., TZOULAS, K., ADAMS, M., BARBER, A., BOX, J., BREUSTE, J., ELMQVIST, T., FRITH, M., GORDON, C. & GREENING, K. (2009) Towards an integrated understanding of green space in the European built environment. *Urban Forestry & Urban Greening,* 8, 65-75.

JENTSCH, A., KREYLING, J., BOETTCHER-TRESCHKOW, J. & BEIERKUHNLEIN, C. (2009) Beyond gradual warming: extreme weather events alter flower phenology of European grassland and heath species. *Global Change Biology,* 15, 837-849.

JOHNSON, B.L. & HADDAD, N.M. (2011) Edge effects, not connectivity, determine the incidence and development of a foliar fungal plant disease. *Ecology,* 92, 1551-1558.

JONES, D., BAIN, S., DAWSON, T. & WATT, T. (2009) *Assessing the vulnerability of marine habitats in Wales to the impacts of climate change.* HR Wallingford for Countryside Council for Wales, Bangor, UK.

JONES, H.P., TERSHY, B.R., ZAVALETA, E.S., CROLL, D.A., KEITT, B.S., FINKELSTEIN, M.E. & HOWALD, G.R. (2008) Severity of the Effects of Invasive Rats on Seabirds: A Global Review. *Conservation Biology,* 22, 16-26.

JONGMAN, R.H.G., BOUWMA, I.M., GRIFFIOEN, A., JONES-WALTERS, L. & DOORN, A.M. (2011) The Pan European Ecological Network: PEEN. *Landscape Ecology,* 26, 311-326.

JONGMAN, R.H.G. & PUNGETTI, G.P. (2004) *Ecological networks and greenways, concept, design and implementation.* Cambridge University Press, Cambridge.

JOOSTEN, H., TAPIO-BISTRÖM, M.-L. & TOL, S. (2012) *Peatlands – guidance for climate change mitigation by conservation, rehabilitation and sustainable use,* Mitigation of climate change in agriculture series, No 5. Food and Agriculture Organization of the United Nations (FAO), Rome.

JULLIARD, R., JIGUET, F. & COUVET, D. (2003) Common birds facing global changes: what makes a species at risk? *Global Change Biology,* 10, 148-154.

JUMP, A.S. & PENUELAS, J. (2005) Running to stand still: adaptation and the response of plants to rapid climate change. *Ecology Letters,* 8, 1010-1020.

KERNAN, M.R., BATTARBEE, R.W. & MOSS, B. (2010) *Climate change impacts on freshwater ecosystems*. Wiley Online Library.

KETTUNEN, M., TERRY, A., TUCKER, G. & A., J. (2007) *Guidance on the maintenance of landscape features of major importance for wild flora and fauna - Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC).* Institute for European Environmental Policy (IEEP), Brussels.

KLAUS, M., HOLSTEN, A., HOSTERT, P. & KROPP, J.P. (2011) Integrated methodology to assess windthrow impacts on forest stands under climate change. *Forest Ecology and Management,* 261, 1799-1810.

KORN, H., KRAUS, K. & STADLER, J. (2012) *Proceedings of the European conference on Biodiversity and Climate Change - Science, Practice and Policy.* BfN-Skripten, 310. Bundesamt für Naturschutz, Bonn.

KORN, H., STADLER, J., BONN, A., MACGREGOR, N.A. & BOCKMÜHL, K. (2014) *Proceedings of the European conference on Climate Change and Nature Conservation in Europe – an ecological, policy and economic perspective*. BfN-Skripten, 367. Bundesamt für Naturschutz, Bonn.

KOWARIK, I. (2011) Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution,* 159, 1974-1983.

KRAUSS, J., BOMMARCO, R., GUARDIOLA, M., HEIKKINEN, R.K., HELM, A., KUUSSAARI, M., LINDBORG, R., ÖCKINGER, E., PÄRTEL, M., PINO, J., PÖYRY, J., RAATIKAINEN, K.M., SANG, A., STEFANESCU, C., TEDER, T., ZOBEL, M. & STEFFAN-DEWENTER, I. (2010) Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. *Ecology Letters,* 13, 597-605.

KROSBY, M., TEWKSBURY, J., HADDAD, N.M. & HOEKSTRA, J. (2010) Ecological connectivity for a changing climate. *Conservation Biology,* 24, 1686-1689.

KRUESS, A. & TSCHARNTKE, T. (2000) Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on Vicia sepium. *Oecologia,* 122, 129-137.

KUHN, I., BRANDL, R. & KLOTZ, S. (2004) The flora of German cities is naturally species rich. *Evolutionary ecology research,* 6, 749-764.

LADEAU, S.L., KILPATRICK, A.M. & MARRA, P.P. (2007) West Nile virus emergence and large-scale declines of North American bird populations. *Nature,* 447, 710-713.

LANE, S.N., TAYEFI, V., REID, S.C., YU, D. & HARDY, R.J. (2007) Interactions between sediment delivery, channel change, climate change and flood risk in a temperate upland environment. *Earth Surface Processes and Landforms,* 32, 429-446.

LAWRENCE, B. & KAYE, T.N. (2011) Reintroduction of Castilleja levisecta: Effects of Ecological Similarity, Source Population Genetics, and Habitat Quality. *Restoration Ecology,* 19, 166-176.

LAWSON, C.R., BENNIE, J.J., THOMAS, C.D., HODGSON, J.A. & WILSON, R.J. (2013) Active management of protected areas enhances metapopulation expansion under climate change. *Conservation Letters*, DOI: 10.1111/conl.12036.

LAWTON, J., BROTHERTON, P.N.M., BROWN, V.K., ELPHICK, C., FITTER, A.H., FORSHAW, J., HADDOW, R.W., HILBORNE, S., LEAFE, R.N., MACE, G.M., SOUTHGATE, M.P., SUTHERLAND, W.J., TEW, T.E., VARLEY, J. & WYNNE, G.R. (2010) *Making Space for Nature: A review of England's Wildlife Sites and Ecological Network*. Report to Defra.

LE VIOL, I., JULLIARD, R., KERBIRIOU, C., DE REDON, L., CARNINO, N., MACHON, N. & PORCHER, E. (2008) Plant and spider communities benefit differently from the presence of planted hedgerows in highway verges. *Biological Conservation,* 141, 1581-1590.

LENOIR, J., GÉGOUT, J.C., MARQUET, P.A., DE RUFFRAY, P. & BRISSE, H. (2008) A Significant Upward Shift in Plant Species Optimum Elevation During the 20th Century. *Science,* 320, 1768-1771.

LETTY, J., AUBINEAU, J., MARCHANDEAU, S. & CLOBERT, J. (2003) Effect of translocation on survival of wild rabbit (*Oryctolagus cuniculus*). *Mammalian Biology,* 68, 250-255.

LETTY, J., MARCHANDEAU, S. & AUBINEAU, J. (2007) Problems encountered by individuals in animal translocations: Lessons from field studies. *Ecoscience,* 14, 420-431.

LEXER, M., HÖNNINGER, K., SCHEIFINGER, H., MATULLA, C., GROLL, N., KROMP-KOLB, H., SCHADAUER, K., STARLINGER, F. & ENGLISCH, M. (2002) The sensitivity of Austrian forests to scenarios of climatic change: a large-scale risk assessment based on a modified gap model and forest inventory data. *Forest Ecology and Management,* 162, 53-72.

LINDENMAYER, D., HOBBS, R.J., MONTAGUE-DRAKE, R., ALEXANDRA, J., BENNETT, A., BURGMAN, M., CALE, P., CALHOUN, A., CRAMER, V., CULLEN, P., DRISCOLL, D., FAHRIG, L., FISCHER, J., FRANKLIN, J., HAILA, Y., HUNTER, M., GIBBONS, P., LAKE, S., LUCK, G., MACGREGOR, C., MCINTYRE, S., NALLY, R.M., MANNING, A., MILLER, J., MOONEY, H., NOSS, R., POSSINGHAM, H., SAUNDERS, D., SCHMIEGELOW, F., SCOTT, M., SIMBERLOFF, D., SISK, T., TABOR, G., WALKER, B., WIENS, J., WOINARSKI, J. & ZAVALETA, E. (2008) A checklist for ecological management of landscapes for conservation. *Ecology Letters,* 11, 78-91.

LINDENMAYER, D.B. & FISCHER, J. (2007) Tackling the habitat fragmentation panchreston. *Trends in Ecology & Evolution,* 22, 127-132.

LIVINGSTONE, D.M. (2003) Impact of Secular Climate Change on the Thermal Structure of a Large Temperate Central European Lake. *Climatic Change,* 57, 205-225.

LONG, J.L. (2003) *Introduced Mammals of the World: Their History, Distribution and Influence.* CSIRO Publishing, Collingwood, Australia.

LUQUE, S., SAURA, S. & FORTIN, M.-J. (2012) Landscape connectivity analysis for conservation: insights from combining new methods with ecological and genetic data. *Landscape Ecology,* 27, 153-157.

LYYTIMÄKI, J. & SIPILÄ, M. (2009) Hopping on one leg – The challenge of ecosystem disservices for urban green management. *Urban Forestry & Urban Greening,* 8, 309-315.

MACE, G.M., NORRIS, K. & FITTER, A.H. (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution,* 27, 24-31.

MACGREGOR, N. & VAN DIJK, N. (2014) Adaptation in Practice: How Managers of Nature Conservation Areas in Eastern England are Responding to Climate Change. *Environmental management*, DOI 10.1007/s00267-014-0254-6.

MALEVSKY-MALEVICH, S.P., MOLKENTIN, E.K., NADYOZHINA, E.D. & SHKLYAREVICH, O.B. (2008) An assessment of potential change in wildfire activity in the Russian boreal forest zone induced by climate warming during the twenty-first century. *Climatic Change,* 86, 463-474.

MARAN, T. & HENTTONEN, H. (1995) Why is the European mink (*Mustela lutreola*) disappearing? - A review of the process and hypotheses. *Annales Zoologici Fennici,* 32, 47-54.

MARTIN, E., GIRAUD, G., LEJEUNE, Y. & BOUDART, G. (2001) Impact of a climate change on avalanche hazard. *Annals of Glaciology,* 32, 163-167.

MATHEY, J., RÖßLER, S., LEHMANN, I., BRÄUER, A., GOLDBERG, V., KURBJUHN, C. & WESTBELD, A. (2011) *Noch wärmer, noch trockener? Stadtnatur und Freiraumstrukturen im Klimawandel.,* Naturschutz und biologische Vielfalt. Landwirtschaftsverlag, Münster.

MATSON, T.K., GOLDIZEN, A.W. & JARMAN, P.J. (2004) Factors affecting the success of translocations of the black-faced impala in Namibia. *Biological Conservation,* 116, 359-365.

MAWDSLEY, J.R., O'MALLEY, R. & OJIMA, D.S. (2009) A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology,* 23, 1080-1089.

MBORA, D.N.M. & MCPEEK, M.A. (2009) Host density and human activities mediate increased parasite prevalence and richness in primates threatened by habitat loss and fragmentation. *Journal of Animal Ecology,* 78, 210-218.

MCCALLUM, H. (2012) Disease and the dynamics of extinction. *Philosophical Transactions of the Royal Society B,* 367, 2828-2839.

MCCALLUM, H. & DOBSON, A. (2002) Disease, habitat fragmentation and conservation. *Proceedings of the Royal Society B,* 269, 2041-2049.

MCLACHLAN, J.S., HELLMANN, J.J. & SCHWARTZ, M.W. (2007) A framework for debate of assisted migration in an era of climate change. *Conservation Biology,* 21, 297-302.

MENÉNDEZ, R., MEGÍAS, A.G., HILL, J.K., BRASCHLER, B., WILLIS, S.G., COLLINGHAM, Y., FOX, R., ROY, D.B. & THOMAS, C.D. (2006) Species richness changes lag behind climate change. *Proceedings of the Royal Society B,* 273, 1465-1470.

MILAD, M., SCHAICH, H., BURGI, M. & KONOLD, W. (2011) Climate change and nature conservation in Central European forests: A review of consequences, concepts and challenges. *Forest Ecology and Management,* 261, 829-843.

MILLAR, C.I., STEPHENSON, N.L. & STEPHENS, S.L. (2007) Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications,* 17, 2145-2151.

MITCHELL, C.E. & POWER, A.G. (2003) Release of invasive plants from fungal and viral pathogens. *Nature,* 421, 625-627.

MOILANEN, A. & NIEMINEN, M. (2002) Simple connectivity measures in spatial ecology. *Ecology,* 83, 1131-1145.

MOSBRUGGER, V., BRASSEUR, G., SCHALLER, M. & STRIBNY, B. (2012) *Klimawandel und Biodiversität. Folgen für Deutschland*. Wissenschaftliche Buchgesellschaft, Darmstadt.

MUELLER, J.M. & HELLMANN, J.J. (2008) An assessment of invasion risk from assisted migration. *Conservation Biology,* 22, 562-567.

MUÑOZ-FUENTES, V., VILÀ, C., GREEN, A.J., NEGRO, J.J. & SORENSON, M.D. (2007) Hybridization between white-headed ducks and introduced ruddy ducks in Spain. *Molecular ecology,* 16, 629-638.

NADEN, P.S. & WATTS, C.D. (2001) Estimating climate-induced change in soil moisture at the landscape scale: an application to five areas of ecological interest in the U.K. *Climatic Change,* 49, 411-440.

NAUMANN, S., ANZALDUA, G., BERRY, P., BURCH, S., DAVIS, M., FRELIH-LARSEN, A., GERDES, H. & SANDERS, M. (2011) *Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe*. Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment.

NAUMANN, S., KAPHENGST, T., GRADMANN, A., DAVIS, M. & MERBOLD, I. (in press) *Ökosystembasierte Ansätze zur Klimaanpassung und zum Klimaschutz im deutschsprachigen Raum: Erfolgsfaktoren und Hindernisse konkreter Umsetzungsprojekte*. BfN Skripten, Bundesamt für Naturschutz, Bonn.

NICHOLLS, R.J. & DE LA VEGA-LEINERT, A.C. (2008) Implications of Sea-Level Rise for Europe's Coasts: An Introduction. *Journal of Coastal Research*, 24, 285-287.

NIEMELÄ, J. (2014) Ecology of urban green spaces: The way forward in answering major research questions. *Landscape and Urban Planning*, 125, 298–303.

NOORDIJK, J., SCHAFFERS, A.P., HEIJERMAN, T. & SÝKORA, K.V. (2011) Using movement and habitat corridors to improve the connectivity for heathland carabid beetles. *Journal for Nature Conservation,* 19, 276-284.

NORTH, A., PENNANEN, J., OVASKAINEN, O. & LAINE, A.-L. (2011) Local adaptation in a changing world: the roles of gene-flow, mutation, and sexual reproduction. *Evolution,* 65, 79-89.

NOSS, R.F. (2007) Focal species for determining connectivity requirements in conservation planning. In: *Managing and designing landscapes for conservation: Moving from perspectives to principles* (eds D.B. Lindenmayer & R.J. Hobbs), pp. 263-279. Cambridge University Press.

NOWAK, D.J. (2010) Urban biodiversity and climate change. In: *Urban biodiversity and design* (eds N. Müller, P. Werner & J. Kelcey), pp. 101-107. Wiley & Blackwell Publishing, Oxford.

NOWAK, D.J., GREENFIELD, E.J., HOEHN, R.E. & LAPOINT, E. (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution,* 178, 229-236.

NUÑEZ, T., LAWLER, J.J., MCRAE, B.H., PIERCE, D.J., KROSBY, M.B., KAVANAGH, D.M., SINGLETON, P.H. & TEWKSBURY, J.J. (2013) Connectivity Planning to Address Climate Change. *Conservation Biology,* 27, 407-416.

OHLEMÜLLER, R., ANDERSON, B.J., ARAÚJO, M.B., BUTCHART, S.H.M., KUDRNA, O., RIDGELY, R.S. & THOMAS, C.D. (2008) The coincidence of climatic and species rarity: high risk to small-range species from climate change. *Biology Letters,* 4, 568-572.

OLIVER, T.H., GILLINGS, S., GIRARDELLO, M., RAPACCIUOLO, G., BRERETON, T.M., SIRIWARDENA, G.M., ROY, D.B., PYWELL, R. & FULLER, R.J. (2012) Population density but not stability can be predicted from species distribution models. *Journal of Applied Ecology,* 49, 581-590.

OPDAM, P. & WASCHER, D. (2004) Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation,* 117, 285-297.

OSTERBURG, B., RÜTER, S., FREIBAUER, A., WITTE, T.D., ELSASSER, P., KÄTSCH, S., LEISCHNER, B., PAULSEN, H., ROCK, J., RÖDER, N., SANDERS, J., SCHWEINLE, J., STEUK, J., STICHNOTHE, H., STÜMER, W., WELLING, J. & WOLFF, A. (2013) *Handlungsoptionen für den Klimaschutz in der deutschen Agrar- und Forstwirtschaft.,* Thünen Report 11. Johann Heinrich von Thünen-Institut, Braunschweig.

OVASKAINEN, O. (2012) Strategies for Improving Biodiversity Conservation in the Netherlands: Enlarging Conservation Areas vs. Constructing Ecological Corridors. Report to the Dutch Council for the Environment and Infrastructure, Helsinki.

OVASKAINEN, O. & HANSKI, I. (2004) From individual behavior to metapopulation dynamics: Unifying the patchy population and classic metapopulation models. *The American Naturalist,* 164, 364-377.

OVASKAINEN, O., LUOTO, M., IKONEN, I., REKOLA, H., MEYKE, E. & KUUSSAARI, M. (2008) An empirical test of a diffusion model: Predicting clouded apollo movements in a novel environment. *American Naturalist,* 171, 610-619.

OVASKAINEN, O., SATO, K., BASCOMPTE, J. & HANSKI, I. (2002) Metapopulation Models for Extinction Threshold in Spatially Correlated Landscapes. *Journal of Theoretical Biology,* 215, 95-108.

PARK, A.W. (2012) Infectious disease in animal metapopulations: the importance of environmental transmission. *Ecology and Evolution,* 2, 1398-1407.

PARMESAN, C. (2006) Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of ecology, Evolution and Systematics,* 37, 637-669.

PARMESAN, C. & YOHE, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature,* 421, 37-42.

PEARCE-HIGGINS, J.W. (2011) How ecological science can help manage the effects of climate change: A case study of upland birds. In: *The Changing Nature of Scotland* (eds S.J. Marrs, S. Foster, C. Hendrie, E.C. Mackey & D.B.A. Thompson), pp. 397-414. TSO Scotland, Edinburgh.

PEARCE-HIGGINS, J.W., BRADBURY, R.B., CHAMBERLAIN, D.E., DREWITT, A., LANGSTON, R.H.W. & WILLIS, S.G. (2011) Targeting research to underpin climate change adaptation for birds. *Ibis,* 153, 207-211.

PERINI, K., OTTELÉ, M., FRAAIJ, A.L.A., HAAS, E.M. & RAITERI, R. (2011) Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment,* 46, 2287-2294.

PETIT, R.J., AGUINAGALDE, I., DE BEAULIEU, J.-L., BITTKAU, C., BREWER, S., CHEDDADI, R., ENNOS, R., FINESCHI, S., GRIVET, D., LASCOUX, M., MOHANTY, A., MÜLLER-STARCK, G., DEMESURE-MUSCH, B., PALMÉ, A., MARTÍN, J.P., RENDELL, S. & VENDRAMIN, G.G. (2003) Glacial refugia: hotspots but not melting pots of genetic diversity. *Science,* 300, 1563-1565.

PIRNAT, J. (2000) Conservation and management of forest patches and corridors in suburban landscapes. *Landscape and Urban Planning,* 52, 135-143.

POSSLEY, J., MASCHINSKI, J., RODRIGUEZ, C. & DOZIER, J.G. (2009) Alternatives for Reintroducing a Rare Ecotone Species: Manually Thinned Forest Edge versus Restored Habitat Remnant. *Restoration Ecology,* 17, 668-677.

POST, E., FORCHHAMMER, M.C., BRET-HARTE, M.S., CALLAGHAN, T.V., CHRISTENSEN, T.R., ELBERLING, B., FOX, A.D., GILG, O., HIK, D.S., HØYE, T.T., IMS, R.A., JEPPESEN, E., KLEIN, D.R., MADSEN, J., MCGUIRE, A.D., RYSGAARD, S., SCHINDLER, D.E., STIRLING, I., TAMSTORF, M.P., TYLER, N.J.C., VAN DER WAL, R., WELKER, J., WOOKEY, P.A., SCHMIDT, N.M. & AASTRUP, P. (2009) Ecological Dynamics Across the Arctic Associated with Recent Climate Change. *Science,* 325, 1355-1358.

PREISS, J., PITAH, U., SCHARF, B., ENZI, V., OBERARZBACHER, S., HANCVENCL, G., WENK, D., STEINBAUER, G., OBERBICHLER, C., LICHTBLAU, A., ERKER, G., FRICKE, J. & HAAS, S. (2013) *Leitfaden Fassadenbegrünung.* Report von 'ÖkoKauf Wien', Arbeitsgruppe 25 Grün- und Freiräume. Wien.

PROCHES, S., WILSON, J.R.U., VELDTMAN, R., KALWIJ, J.M., RICHARDSON, D.M. & CHOWN, S.L. (2005) Landscape Corridors: Possible Dangers? *Science,* 310, 781-782.

PÜTTKER, T., MEYER-LUCHT, Y. & SOMMER, S. (2007) Effects of fragmentation on parasite burden (nematodes) of generalist and specialist small mammal species in secondary forest fragments of the coastal Atlantic Forest, Brazil. *Ecological Research,* 23, 207-215.

RAHEL, F.J. & OLDEN, J.D. (2008) Assessing the Effects of Climate Change on Aquatic Invasive Species. *Conservation Biology,* 22, 521-533.

RANDIN, C.F., ENGLER, R., NORMAND, S., ZAPPA, M., ZIMMERMANN, N.E., PEARMAN, P.B., VITTOZ, P., THUILLER, W. & GUISAN, A. (2009) Climate change and plant distribution: local models predict high-elevation persistence. *Global Change Biology,* 15, 1557-1569.

RANDOLPH, S.E. (2004) Evidence that climate change has caused 'emergence' of tick-borne diseases in Europe? *International Journal of Medical Microbiology Supplements,* 293, Supplement 37, 5-15.

RANDOLPH, S.E. (2010) To what extent has climate change contributed to the recent epidemiology of tick-borne diseases? *Veterinary Parasitology,* 167, 92-94.

REED, D.H. & FRANKHAM, R. (2003) Correlation between Fitness and Genetic Diversity. *Conservation Biology,* 17, 230-237.

RICCIARDI, A. & SIMBERLOFF, D. (2009a) Assisted colonization is not a viable conservation strategy. *Trends in Ecology & Evolution,* 24, 248-253.

RICCIARDI, A. & SIMBERLOFF, D. (2009b) Assisted colonization: good intentions and dubious risk assessment. *Trends in Ecology & Evolution,* 24, 476-477.

ROUGET, M., COWLING, R.M., PRESSEY, R.L. & RICHARDSON, D.M. (2003) Identifying spatial components of ecological and evolutionary processes for regional conservation planning in the Cape Floristic Region, South Africa. *Diversity and Distributions,* 9, 191-210.

ROWLEY, A.F., CROSS, M.E., CULLOTY, S.C., LYNCH, S.A., MACKENZIE, C.L., MORGAN, E., O'RIORDAN, R.M., ROBINS, P.E., SMITH, A.L., THRUPP, T.J., VOGAN, C.L., WOOTTON, E.C. & MALHAM, S.K. (2014) The potential impact of climate change on the infectious diseases of commercially important shellfish populations in the Irish Sea—a review. *ICES Journal of Marine Science: Journal du Conseil*. DOI10.1093/icesjms/fst234.

RUDD, H., VALA, J. & SCHAEFER, V. (2002) Importance of Backyard Habitat in a Comprehensive Biodiversity Conservation Strategy: A Connectivity Analysis of Urban Green Spaces. *Restoration Ecology,* 10, 368-375.

RUETER, S., ROCK, J., KÖTHKE, M. & DIETER, M. (2011) Wieviel Holznutzung ist gut fürs Klima? *AFZ - Der Wald,* 15, 19-21.

SANDVIK, H., COULSON, T.I.M. & SÆTHER, B.-E. (2008) A latitudinal gradient in climate effects on seabird demography: results from interspecific analyses. *Global Change Biology,* 14, 703-713.

SAUNDERS, A. & NORTON, D. (2001) Ecological restoration at Mainland Islands in New Zealand. *Biological Conservation,* 99, 109-119.

SCHAICH, H. & MILAD, M. (2013) Forest biodiversity in a changing climate: which logic for conservation strategies? *Biodiversity and Conservation,* 22, 1107-1114.

SCHEFFER, M., CARPENTER, S.R., LENTON, T.M., BASCOMPTE, J., BROCK, W., DAKOS, V., VAN DE KOPPEL, J., VAN DE LEEMPUT, I.A., LEVIN, S.A., VAN NES, E.H., PASCUAL, M. & VANDERMEER, J. (2012) Anticipating Critical Transitions. *Science,* 338, 344-348.

SCHERRER, D. & KÖRNER, C. (2011) Topographically controlled thermal-habitat differentiation buffers alpine plant diversity against climate warming. *Journal of Biogeography,* 38, 406-416.

SCHLAEPFER, M.A., HELENBROOK, W.D., SEARING, K.B. & SHOEMAKER, K.T. (2009) Assisted colonization: evaluating contrasting management actions (and values) in the face of uncertainty. *Trends in Ecology & Evolution,* 24, 471-472.

SCHMIDT, K.A. & OSTFELD, R.S. (2001) Biodiversity and the dilution effect in disease ecology. *Ecology,* 82, 609-619.

SCHMIEGELOW, F. (2007) Corridors, connectivity, and biological conservation. In: *Managing and designing landscapes for conservation: Moving from perspectives to principles* (eds D.B. Lindenmayer & R.J. Hobbs), pp. 251-262. Blackwell Publishing, Oxford.

SCHWARTZ, M.W. & MARTIN, T.G. (2013) Translocation of imperiled species under changing climates. *Annals of the New York Academy of Sciences*, 1286, 15–28.

SCHWEIGER, O., BIESMEIJER, J.C., BOMMARCO, R., HICKLER, T., HULME, P.E., KLOTZ, S., KÜHN, I., MOORA, M., NIELSEN, A., OHLEMÜLLER, R., PETANIDOU, T., POTTS, S.G., PYŠEK, P., STOUT, J.C., SYKES, M.T., TSCHEULIN, T., VILA, M., WALTHER, G.R., WESTPHAL, C., WINTER, M., ZOBEL, M. & SETTELE, J. (2010) Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biological Reviews,* 85, 777-795.

SCHWEIGER, O., HEIKKINEN, R.K., HARPKE, A., HICKLER, T., KLOTZ, S., KUDRNA, O., KÜHN, I., PÖYRY, J. & SETTELE, J. (2012) Increasing range mismatching of interacting species under global change is related to their ecological characteristics. *Global Ecology and Biogeography,* 21, 88-99.

SCHWEIGER, O., SETTELE, J., KUDRNA, O., KLOTZ, S. & KÜHN, I. (2008) Climate change can cause spatial mismatch of trophically interacting species. *Ecology,* 89, 3472–3479.

SCOTT, D., MALCOLM, J.R. & LEMIEUX, C. (2002) Climate change and modelled biome representation in Canada's national park system: implications for system planning and park mandates. *Global Ecology and Biogeography,* 11, 475-484.

SEBAIO, F., BRAGA, É.M., BRANQUINHO, F., MANICA, L.T. & MARINI, M.Â. (2010) Blood parasites in Brazilian Atlantic Forest birds: effects of fragment size and habitat dependency. *Bird Conservation International,* 20, 432-439.

SEDDON, P.J. (2010) From reintroduction to assisted colonization: Moving along the conservation translocation spectrum. *Restoration Ecology,* 18, 796-802.

SEDDON, P.J. & LEECH, T. (2008) Conservation short cut, or long and winding road? A critique of umbrella species criteria. *Oryx,* 42, 240-245.

SEDDON, P.J., SOORAE, P.S. & LAUNAY, F. (2005) Taxonomic bias in reintroduction projects. *Animal Conservation,* 8, 51-58.

SEIDL, R., RAMMER, W., JÄGER, D. & LEXER, M.J. (2008) Impact of bark beetle (*Ips typographus* L.) disturbance on timber production and carbon sequestration in different management strategies under climate change. *Forest Ecology and Management,* 256, 209-220.

SEKERCIOGLU, C.H., SCHNEIDER, S.H., FAY, J.P. & LOARIE, S.R. (2008) Climate Change, Elevational Range Shifts, and Bird Extinctions. *Conservation Biology,* 22, 140-150.

SEMLITSCH, R.D. & BODIE, J.R. (2003) Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology,* 17, 1219-1228.

SHAFER, C.L. (1999) National park and reserve planning to protect biological diversity: some basic elements. *Landscape and Urban Planning,* 44, 123-153.

SHULTZ, S., B. BRADBURY, R., L. EVANS, K., D. GREGORY, R. & M. BLACKBURN, T. (2005) Brain size and resource specialization predict long-term population trends in British birds. *Proceedings of the Royal Society B,* 272, 2305-2311.

SIMBERLOFF, D. (1988) The Contribution of Population and Community Biology to Conservation Science. *Annual Review of Ecology and Systematics,* 19, 473-511.

SIMBERLOFF, D. (2010) Invasive species. In: *Conservation biology for all* (eds N.S. Sodhi & P.R. Ehrlich), pp. 131-152. University Oxford Press, Oxford, UK.

SIMBERLOFF, D., MARTIN, J.-L., GENOVESI, P., MARIS, V., WARDLE, D.A., ARONSON, J., COURCHAMP, F., GALIL, B., GARCÍA-BERTHOU, E., PASCAL, M., PYŠEK, P., SOUSA, R., TABACCHI, E. & VILÀ, M. (2013) Impacts of biological invasions: what's what and the way forward. *Trends in Ecology & Evolution,* 28, 58-66.

SINGER, F.J., PAPOUCHIS, C.M. & SYMONDS, K.K. (2000) Translocations as a Tool for Restoring Populations of Bighorn Sheep. *Restoration Ecology,* 8, 6-13.

SMALLSHIRE, D., ROBERTSON, P. & THOMPSON, P. (2004) Policy into practice: the development and delivery of agri-environment schemes and supporting advice in England. *Ibis,* 146, 250-258.

SMITHERS, R.J., COWAN, C., HARLEY, M., HOPKINS, J., PONTIER, H. & WATTS, O. (2008) *England Biodiversity Strategy Climate Change Adaptation Principles. Conserving biodiversity in a changing climate*. Department for Environment, Food and Rural Affairs, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69270/pb13168-ebs-ccap-081203.pdf

SOORAE, P.S. (2010) Global Re-introduction perspectives: Additional case-studies from around the globe. IUCN/SSC Re-introduction Specialist Group, Abu Dhabi, UAE.

SOULÉ, M.E. & GILPIN, M.E. (1991) The theory of wildlife corridor capability. In: *Nature Conservation 2: The Role of Corridors* (eds D.A. Saunders & R.J. Hobbs), pp. 3-8. Surrey Beatty and Sons, Chipping Norton, Australia.

SOUSSANA, J.-F. & DURU, M. (2007) Grassland science in Europe facing new challenges: biodiversity and global environmental change. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources,* 272, 1-11.

SOUSSANA, J.-F. & LÜSCHER, A. (2007) Temperate grasslands and global atmospheric change: a review. *Grass and Forage Science,* 62, 127-134.

ST-LAURENT, M.-H., DUSSAULT, C., FERRON, J. & GAGNON, R. (2009) Dissecting habitat loss and fragmentation effects following logging in boreal forest: Conservation perspectives from landscape simulations. *Biological Conservation,* 142, 2240-2249.

SUKKOP, H. & WURZEL, A. (2003) The Effects of Climate Change on the Vegetation of Central European Cities. *Urban Habitats,* 1, 66-86.

SUNDBERG, S. (2013) Spore rain in relation to regional sources and beyond. *Ecography,* 36, 364-373.

SWART, R., BIESBROEK, R., BINNERUP, S., CARTER, T.R., COWAN, C., HENRICHS, T., LOQUEN, S., MELA, H., MORECROFT, M., REESE, M. & REY, D. (2009) *Europe adapts to climate change: Comparing national adaptation strategies.* PEER Report No 1. Helsinki: Partnership for European Environmental Research. http://www.peer.eu/fileadmin/user_upload/publications/PEER_Report1.pdf.

TAYLOR, B.D. & GOLDINGAY, R.L. (2010) Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. *Wildlife Research,* 37, 320-331.

TEEB (2010) *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*. http://www.teebweb.org

TEIXEIRA, C., DEAZEVEDO, C., MENDL, M., CIPRESTE, C. & YOUNG, R. (2007) Revisiting translocation and reintroduction programmes: the importance of considering stress. *Animal Behaviour,* 73, 1-13.

THACKERAY, S.J., JONES, I.D. & MABERLY, S.C. (2008) Long-term change in the phenology of spring phytoplankton: species-specific responses to nutrient enrichment and climatic change. *Journal of Ecology,* 96, 523-535.

THACKERAY, S.J., SPARKS, T.H., FREDERIKSEN, M., BURTHE, S., BACON, P.J., BELL, J.R., BOTHAM, M.S., BRERETON, T.M., BRIGHT, P.W., CARVALHO, L., CLUTTON-BROCK, T., DAWSON, A., EDWARDS, M., ELLIOTT, J.M., HARRINGTON, R., JOHNS, D., JONES, I.D., JONES, J.T., LEECH, D.I., ROY, D.B., SCOTT, W.A., SMITH, M., SMITHERS, R.J., WINFIELD, I.J. & WANLESS, S. (2010) Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Global Change Biology,* 16, 3304-3313.

THOMAS, C.D. (2011) Translocation of species, climate change, and the end of trying to recreate past ecological communities. *Trends in Ecology & Evolution,* 26, 216-221.

THOMAS, C.D., CAMERON, A., GREEN, R.E., BAKKENES, M., BEAUMONT, L.J., COLLINGHAM, Y.C., ERASMUS, B.F.N., DE SIQUEIRA, M.F., GRAINGER, A., HANNAH, L., HUGHES, L., HUNTLEY, B., VAN JAARSVELD, A.S., MIDGLEY, G.F., MILES, L., ORTEGA-HUERTA, M.A., PETERSON, A.T., PHILLIPS, O.L. & WILLIAMS, S.E. (2004) Extinction risk from climate change. *Nature,* 427, 145-148.

THOMAS, C.D., FRANCO, A.M.A. & HILL, J.K. (2006) Range retractions and extinction in the face of climate warming. *Trends in Ecology & Evolution,* 21, 415-416.

THOMAS, C.D., GILLINGHAM, P.K., BRADBURY, R.B., ROY, D.B., ANDERSON, B.J., BAXTER, J.M., BOURN, N.A.D., CRICK, H.Q.P., FINDON, R.A., FOX, R., HODGSON, J.A., HOLT, A.R., MORECROFT, M.D., O'HANLON, N.J., OLIVER, T.H., PEARCE-HIGGINS, J.W., PROCTER, D.A., THOMAS, J.A., WALKER, K.J., WALMSLEY, C.A., WILSON, R.J. & HILL, J.K. (2012) Protected areas facilitate species' range expansions. *PNAS,* 109, 14063-14068.

THOMPSON, J.D. (1991) The biology of an invasive plant: What makes Spartina anglica so successful? *Bioscience,* 41, 393–401.

THORELL, M. & GOTMARK, F. (2005) Reinforcement capacity of potential buffer zones: Forest structure and conservation values around forest reserves in southern Sweden. *Forest Ecology and Management,* 212, 333-345.

TISCHENDORF, L. & FAHRIG, L. (2000a) How should we measure landscape connectivity? *Landscape Ecology,* 15, 633-641.

TISCHENDORF, L. & FAHRIG, L. (2000b) On the usage and measurement of landscape connectivity. *Oikos,* 1, 7-19.

TOMPKINS, D.M., SAINSBURY, A.W., NETTLETON, P., BUXTON, D. & GURNELL, J. (2002) Parapoxvirus causes a deleterious disease in red squirrels associated with UK population declines. *Proceedings of the Royal Society B,* 269, 529-533.

TORCHIN, M.E., LAFFERTY, K.D., DOBSON, A.P., MCKENZIE, V.J. & KURIS, A.M. (2003) Introduced species and their missing parasites. *Nature,* 421.

TORCHIN, M.E. & MITCHELL, C.E. (2004) Parasites, pathogens, and invasions by plants and animals. *Frontiers in Ecology and the Environment,* 2, 183-190.

TRAVESET, A. & RICHARDSON, D.M. (2006) Biological invasions as disruptors of plant reproductive mutualisms. *Trends in Ecology & Evolution,* 21, 208-216.

TRAVIS, J.M.J. & DYTHAM, C. (1999) Habitat persistence, habitat availability and the evolution of dispersal. *Proceedings of the Royal Society B,* 266, 723-728.

TRENHAM, P.C., SHAFFER, H.B., KOENIG, W.D., STROMBERG, M.R., COPEIA, S., MAY, N. & BRADLEY, H. (2000) Life History and Demographic Variation in the California Tiger Salamander (*Ambystoma californiense*). *Copeia,* 2000, 365-377.

TYRVÄINEN, L., MÄNTYMAA, E. & OVASKAINEN, V. (2013) Demand for enhanced forest amenities in private lands: The case of the Ruka-Kuusamo tourism area, Finland. *Forest Policy and Economics*, DOI: 10.1016/j.forpol.2013.1005.1007

ULRICH, R.S., SIMONS, R.F., LOSITO, B.D., FIORITO, E., MILES, M.A. & ZELSON, M. (1991) Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology,* 11, 201-230.

VAN IERLAND, E., DE GROOT, R., KUIKMAN, P., MARTENS, P., AMELUNG, B., DAAN, N., HUYNEN, M., KRAMER, K., SZONYI, J., VERAART, J., VERHAGEN, A., VAN VLIET, A., VANWALSUM, P. & WESTEIN, E. (2001) *Integrated assessment of vulnerability to climate change and adaptation options in the Netherlands*. Alterra, RIVM Report 410200088, Wageningen. http://hdl.handle.net/10029/258679

VICKERY, J.A., BRADBURY, R.B., HENDERSON, I.G., EATON, M.A. & GRICE, P.V. (2004) The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. *Biological Conservation,* 119, 19-39.

VIGNOLA, R., LOCATELLI, B., MARTINEZ, C. & IMBACH, P. (2009) Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? *Mitigation and Adaptation Strategies for Global Change,* 14, 691-696.

VILÀ, M. & HULME, P.E. (2011) Jurassic Park? No thanks. *Trends in Ecology & Evolution,* 26, 496-497.

VÖGELI, M., LEMUS, J.A., SERRANO, D., BLANCO, G. & TELLA, J.L. (2011) An island paradigm on the mainland: host population fragmentation impairs the community of avian pathogens. *Proceedings of the Royal Society B,* 278, 2668-2676.

VÖGELI, M., SERRANO, D., PACIOS, F. & TELLA, J.L. (2010) The relative importance of patch habitat quality and landscape attributes on a declining steppe-bird metapopulation. *Biological Conservation,* 143, 1057-1067.

VON DER LIPPE, M. & KOWARIK, I. (2008) Do cities export biodiversity? Traffic as dispersal vector across urban–rural gradients. *Diversity and Distributions,* 14, 18-25.

VON HAAREN, C. & REICH, M. (2006) The German way to greenways and habitat networks. *Landscape and Urban Planning,* 76, 7-22.

VOS, C.C., BERRY, P., OPDAM, P., BAVECO, H., NIJHOF, B., HANLEY, J.O., BELL, C. & KUIPERS, H. (2008) Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. *Journal of Applied Ecology,* 45, 1722-1731.

VUILLEUMIER, S., WILCOX, C., CAIRNS, B.J. & POSSINGHAM, H.P. (2007) How patch configuration affects the impact of disturbances on metapopulation persistence. *Theoretical population biology,* 72, 77-85.

WALTHER, G.-R. (2010) Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society B,* 365, 2019-2024.

WALTHER, G.-R., BEIßNER, S. & BURGA, C.A. (2005) Trends in the upward shift of alpine plants. *Journal of Vegetation Science,* 16, 541-548.

WALTHER, G.-R., ROQUES, A., HULME, P.E., SYKES, M.T., PYŠEK, P., KÜHN, I., ZOBEL, M., BACHER, S., BOTTA-DUKÁT, Z., BUGMANN, H., CZÚCZ, B., DAUBER, J., HICKLER, T., JAROŠÍK, V., KENIS, M., KLOTZ, S., MINCHIN, D., MOORA, M., NENTWIG, W., OTT, J., PANOV, V.E., REINEKING, B., ROBINET, C., SEMENCHENKO, V., SOLARZ, W., THUILLER, W., VILÀ, M., VOHLAND, K. & SETTELE, J. (2009) Alien species in a warmer world: risks and opportunities. *Trends in Ecology & Evolution,* 24, 686-693.

WARREN, M.S., HILL, J.K., THOMAS, J.A., ASHER, J., FOX, R., HUNTLEY, B., ROY, D.B., TELFER, M.G., JEFFCOATE, S., HARDING, P., JEFFCOATE, G., WILLIS, S.G. & GREATOREX-DAVIES, J.N. (2001) Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature,* 414, 65-69.

WAUTERS, L.A. & GURNELL, J. (1999) The mechanism of replacement of red squirrels by grey squirrels: A test of the interference competition hypothesis. *Ethology,* 105, 1053-1071.

WEBBER, B.L., SCOTT, J.K. & DIDHAM, R.K. (2011) Translocation or bust! A new acclimatization agenda for the 21st century? *Trends in Ecology & Evolution,* 26, 495-496; author reply 497-498.

WHITFORD, V., ENNOS, A.R. & HANDLEY, J.F. (2001) "City form and natural process"—indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning,* 57, 91-103.

WICHTMANN, W. & WICHMANN, S. (2011) Environmental, Social and Economic Aspects of a Sustainable Biomass Production. *Journal of Sustainable Energy an Environment,* Special Issue, 77-81.

WILBY, R.L. & PERRY, G.L.W. (2006) Climate change, biodiversity and the urban environment: a critical review based on London, UK. *Progress in Physical Geography,* 30, 73-98.

WILLIAMS, P., HANNAH, L., ANDELMAN, S., MIDGLEY, G., ARAÚJO, M., HUGHES, G., MANNE, L., MARTINEZ-MEYER, E. & PEARSON, R. (2005) Planning for Climate Change: Identifying Minimum-Dispersal Corridors for the Cape Proteaceae. *Conservation Biology,* 19, 1063-1074.

WILLIAMSON, M., FITTER, A. & URL, S. (1996) The Varying Success of Invaders. *Ecology,* 77, 1661-1666.

WILSON, A. & MELLOR, P. (2008) Bluetongue in Europe: vectors, epidemiology and climate change. *Parasitology Research,* 103, 69-77.

WILSON, L. (2010) *Climate change vulnerability assessment of designated sites in Wales.* ADAS for Countryside Council for Wales, Bangor, UK. http://www.ccgc.gov.uk/landscape--wildlife/managing-land-and-sea/climate-change---what-we-do.aspx.

WILSON, R.J., GUTIÉRREZ, D., GUTIÉRREZ, J., MARTÍNEZ, D., AGUDO, R. & MONSERRAT, V.J. (2005) Changes to the elevational limits and extent of species ranges associated with climate change. *Ecology Letters,* 8, 1138-1146.

WINDER, M. & SCHINDLER, D.E. (2004) Climatic effects on the phenology of lake processes. *Global Change Biology,* 10, 1844-1856.

WINFIELD, I.J., HATELEY, J., FLETCHER, J.M., JAMES, J.B., BEAN, C.W. & CLABBURN, P. (2010) Population trends of Arctic charr (*Salvelinus alpinus*) in the UK: assessing the evidence for a widespread decline in response to climate change. *Hydrobiologia,* 650, 55-65.

WITH, K.A. (2004) Assessing the Risk of Invasive Spread in Fragmented Landscapes. *Risk Analysis,* 24, 803-815.

WORRALL, F., ROWSON, J.G., EVANS, M.G., PAWSON, R., DANIELS, S. & BONN, A. (2011) Carbon fluxes from eroding peatlands – the carbon benefit of revegetation following wildfire. *Earth Surface Processes and Landforms,* 36, 1487-1498.

WÜSTEMANN, H., HARTJE, V., BONN, A., HANSJÜRGENS, B., BERTRAM, C., DEHNHARDT, A., DÖRING, R., DOYLE, U., ELSASSER, P., MEHL, D., OSTERBURG, B., REHDANZ, K., RING, I., SCHOLZ, M. & VOHLAND, K. (2014) *Naturkapital und Klimapolitik – Synergien und Konflikte. Kurzbericht für Entscheidungsträger*. Naturkapital Deutschland – TEEB DE report. Technische Universität Berlin, Berlin; Helmholtz-Zentrum für Umweltforschung – UFZ, Leipzig. http://www.naturkapital-teeb.de

11 APPENDIX

11.1 2011 Conclusions and recommendations elaborated by the ENCA Climate Change Group

In April 2011, the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz), in collaboration with the ENCA Climate Change Group and the University of Greifswald, held an international conference on biodiversity and climate change. The aim of the event was to share knowledge and experiences among European scientists, conservation practitioners and policymakers, to improve both the integration of research outputs into practical conservation projects and the identification of further research needs. The event brought together over 200 participants from 22 European and four non-European countries.

Talks and posters at the conference covered a wide range of topics, including impacts research, vulnerability assessment, adaptation strategies, ecological networks and ecosystem services; across a wide range of biogeographic regions and ecosystems in Europe. The conference also covered some aspects of climate change mitigation and international topics.

Based on information presented in talks and posters during the conference and in the final panel discussion, the ENCA Climate Change Group has agreed the following conclusions and recommendations. These cover three broad topics: communication and sharing information; implementing adaptation; and further research priorities (Korn, Kraus & Stadler 2012).

The 2013 conclusions, presented in this report, build on these 2011 conclusions.

Improving the exchange of information between and among scientists and policy makers

Although the science-policy interface has been improved in recent years, there are still deficits which should be overcome by taking into account the following points:

a) Scientists working at the interface of biodiversity and climate change need to be aware of the political dimension of their findings. In order to provide adequate input for informed policy decisions the interdisciplinary exchange between natural scientists and scholars working in the humanities and social sciences needs to be improved.

b) Scientists should try to improve the communication to decision makers of issues such as:

- Possible synergies as well as possible trade-offs between different ecosystem services
- Possible tipping points and thresholds of ecosystems and the related implications for on the benefits they provide
- How to interpret uncertainty in research results
- The valuation of ecosystem services, particularly cultural services and non-use values of biodiversity

c) The way of communicating scientific findings to decision makers could be enhanced through:

- Communicating scientific findings in a concise but precise way that focuses on key conclusions without compromising on the correctness of the information.
- Good practice examples of good conservation, to demonstrate what adaptation for the natural environment means in practice.
- Improved outreach and communication of the findings as an integral part of all research projects

- More conferences and other events that bring together scientists from across the range of relevant disciplines and policy makers, with a focus on communicating information in a non-technical way

d) Communication is a two-way process. Vice versa, decision makers should be more receptive to new scientific findings and help identify further research needs.

e) At an international level, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), as a newly established body to support the science-policy interface in the field of biodiversity, can learn from the experiences of the Intergovernmental Panel on Climate Change (IPCC). IPBES should deal with the topic of biodiversity and climate change in an integrated manner.

f) In order to improve the scientific basis in the field of biodiversity and climate change the storage, sharing of and multiple use of existing data through established platforms etc. (e.g. the Global Biodiversity Information Facility) should be enhanced.

Implementing research findings and developing adaptation strategies

a) Implementation could be improved by:

- Making conservation research more interdisciplinary and having better links between natural and social scientists
- Better involvement of civil society and local communities from the outset
- Identification and communication of case studies to provide good examples of adaptation in action. Adaptation principles and concepts such as resilience and adaptive management are now reasonably well established; good examples of these concepts being applied in a rigorous way on the ground are still quite rare.

b) There is an increasing need to consider larger scale approaches, for example:

- Conservation of whole landscapes/catchments
- Consideration of large scale processes such as hydrology
- Better understanding of the relative importance of protected areas versus sustainable use of the intervening matrix
- Best practice examples and guidelines on the design and management of ecological networks, sharing ideas across the many countries that are now considering or establishing them
- Green infrastructure, as a concept comprising a variety of well established conservation measures, as well as general land-use issues in the wider landscape have to be seen in an integrated, transboundary context
- An increased need for cross-border cooperation

c) It appears likely that some conservation objectives might need to be reappraised, for example:

- the need to consider when and how to accept change (but the likely continuing importance of current important areas even if ecosystems change)
- accepting species not previously present in an area and possibly changing management to accommodate them
- assessing conservation value of an area if current high priority species move
- considering whether to accept translocation of species from countries where they can no longer survive

d) There is a need to consider economic aspects and to integrate conservation with other sectors and with other land uses such as agriculture

e) Limited conservation resources and increased pressures are likely to require careful prioritisation of objectives and where effort is focused

Some research priorities

a) Better understanding is needed of the variety of factors that influence individual species responses and ability to adjust to climate change, including physiological thresholds, the effects of predator, competitor and prey species, the role of different habitat features in facilitating or hampering adaptation, and the role of genetic diversity and potential for in situ adaptation in the evolutionary sense

b) Long term monitoring of changes needs to be continued and expanded. There is growing evidence that without it changes will not be detected or interpreted appropriately

c) The role of different habitat features in ecological networks – the relative importance of connectivity vs. habitat quality for different species; the balance of protected vs. areas in which conservation is integrated into other land uses

d) The need to try out some different management approaches (such as altering level of habitat heterogeneity and establishing a wider range of microhabitat) and monitor the effects so we’re better prepared if the time comes when new approaches are needed

e) Better understanding and mapping of ecosystem services to inform better spatial planning and location of green infrastructure

f) Improved understanding of the synergies between biodiversity conservation and adaptation and mitigation benefits for people

11.2 Case studies presented at the 2011 ENCA workshop in Edinburgh

This sections lists the case studies, that have not been included in the main text of this report.

- **Elaborating a scientific basis for ex-situ conservation and recolonisation of threatened plants in Switzerland**
  Gian-Reto Walther (Swiss Federal Office for the Environment)
- **Climate change adaptation on RSPB reserves – putting theory into practice**
  Malcolm Ausden (RSPB)
- **Catchment scale restoration of freshwater pearl mussel populations: their resilience to climate change**
  Iain Sime (Scottish Natural Heritage)
- **Adaptation options for Scotland's cold-temperate rainforest epiphytes**
  Chris Ellis (Royal Botanic Garden Edinburgh)
- **Using agri-environment schemes to promote adaptation in England**
  Mike Morecroft (Natural England)
- **Adaptive management of climate-induced changes of habitat diversity in protected areas**
  Marco Neubert, Lars Stratmann, Sven Rannow (Leibniz Institute of Ecological and Regional Development)
- **Managing wetlands to be resilient to climate change**
  Andrew McBride (Scottish Natural Heritage)
- **Assessing the opportunity for enhancing biodiversity resilience to climate change in the Cambrian Mountains**
  Rob McCall (Countryside Council for Wales)
- **CoastAdapt: the sea as our neighbour. People and habitats on a low lying coast with rising sea levels**
  Stewart Angus (Scottish Natural Heritage)
- **Scottish saline lagoons: an unknown quantity ... and quality ... and future?**
  Stewart Angus (Scottish Natural Heritage)

11.3 Questionnaire for 2013 Survey on Climate Adaptation in Nature Conservation in Europe

Start Page (English Version)

European Network of Heads of Nature Conservation Agencies (ENCA) / German Federal Agency for Nature Conservation (BfN)

Questionnaire - Input for report to European Conference Please FEEL FREE TO CIRCULATE to colleagues
Climate Change and Nature Conservation in Europe - an ecological, policy and economic perspective, 25 - 27 June 2013, Bonn, Germany
www.eclareon.eu/en/ccnce

Please return this questionnaire by 8 May 2013 to aletta.bonn@fu-berlin.de

This questionnaire is divided into five short sections:
Part 1. Background information about your nature reserve or conservation project
Part 2. Impacts of climate change
Part 3. Integrating adaptation into conservation goals
Part 4. Management actions and monitoring
Part 5. Information used, and barriers to action

There are 29 questions in total. Please answer all questions that appear relevant. Most questions can be answered by selecting answers from drop-down menus or writing a brief written answer. Space is provided for longer answers, and we would be very grateful for any more detailed information you can provide.

Please fill in a separate questionnaire form for each different conservation sites/projects/reserves. However, if you have:
- a number of sites that are close to each other and managed in a coordinated way;
- or a number of separate sites that comprise similar ecosystems managed in similar ways and with similar climate issues and adaptation actions being taken on all sites...
... you might want to consider them as a single 'conservation site' for the purposes of this survey.
If you have many sites, please start by completing the questionnaire for those conservation sites in which adaptation has been considered in more detail, before completing additional questionnaire forms for other areas if time permits.

Thank you very much in advance for your time and expertise!
Aletta Bonn, Nick Macgregor, Horst Korn & Jutta Stadler (ENCA, BfN, Free University of Berlin)

Please go to sheet 2 to fill in the questionnaire

Questions Page (English Version)

Questionnaire 'Adaptation in conservation sites in Europe' on behalf of ENCA and BfN

Part 1. Background information

Q1 Which country is the site in?

Please select from drop-down menu (list of countries)

Q2 Name of nature reserve/site/conservation project (if multiple named sites or reserves are included within this conservation area, please list them all)
(Below, the term 'site' is used to describe the overall conservation area being considered in the questionnaire)
Comment Box
Geographic coordinates (if known)
Website address (if available)
Your organisation type (use dropdown list)
- NGO –Foundation
- Local Authority
- Regional Authority
- National Authority
- Park-Reserve Authority
- Business
- Research Institute
- other

Q3 Please describe your general role in the site (e.g. reserve manager, regional conservation officer, researcher etc.) and your type of organisation

Comment Box

Q4 Which of the following habitat types occur in the site?

Please select any that account for a significant part of the site and its conservation interest (Natura 2000 categories)

Please select Yes or No from the drop-down menu / Comment Box.

- Marine areas, Sea inlets
- Tidal rivers, Estuaries, Mud flats, Sand flats, Lagoons (including saltwork basins)
- Salt marshes, Salt pastures, Salt steppes
- Coastal sand dunes, Sand beaches, Machair
- Shingle, Sea cliffs, Islets
- Standing open water (inland)
- Rivers and Streams
- Bogs
- Fens, Marshes, Water fringed vegetation
- Heath, Scrub, Maquis and Garrigue, Phrygana
- Dry grassland, Steppes
- Humid grassland, Mesophile grassland
- Alpine and sub-Alpine grassland
- Extensive cereal cultures (including Rotation cultures with regular fallowing)
- Ricefields
- Improved grassland
- Other arable land
- Broad-leaved and mixed woodland
- Coniferous woodland
- Artificial forest monoculture (e.g. Plantations of poplar or Exotic trees)
- Non-forest areas cultivated with woody plants (incl. Orchards groves, Vineyards,Dehesas)
- Inland rocks, Screes, Sands, Permanent Snow and Ice
- Other

Q5 Approximate size of the site in ha

Size of the site under conservation management (ha)

Size of the wider relevant network area / larger conservation area of which the site is part of (ha) (please list only if applicable)

Comment Boxes

Q6 Which of the following statements best describe the land ownership and management arrangements on the site?

Please select more than one if the site contains more than one type

- The land is owned and managed by your conservation organisation
- The land is owned by a different government or non-government organisation but directly managed by your organisation
- The land is privately owned (e.g. owned by one or more farmers, or a water company) but directly managed by your organisation (alone or with other conservation bodies)

- The land is privately owned and managed for conservation through an agreement under which management is shared between your organisation and the landowner
- The land is privately owned and managed for conservation primarily through providing advice, equipment, funding or other resources to the land owners (i.e. the land owners do the direct management)
- other (please give details)

Q7 What are the primary conservation goals of the site?

Please select all that apply. Please select Yes or No from the drop-down menu / Comment Box.

- Maintaining/conserving one or more particular species
- Maintaining/conserving one or more particular communities/habitats/vegetation types
- Restoring degraded ecosystems/habitat creation
- Providing regulating ecosystem services (e.g. water quality, carbon storage, managing flood risk, please specify)
- Providing cultural ecosystem services (e.g. historic/cultural landscapes, please specify)
- Sustainable farming
- Recreation
- Public engagement, education
- Other

Part 2. Impacts of climate change

Q8 Has an assessment been made of how the natural environment in your site might be vulnerable?

Please use the drop-down menu to select one of the following:

- No, vulnerability has not been assessed in any detail
- Yes, a simple vulnerability assessment has been done, based on general ecological knowledge and general published information and/or using results of studies in other areas
- Yes, a detailed vulnerability assessment has been done for this specific site

Q9 If a vulnerability assessment has been undertaken, was it done in collaboration with other conservation sites in the area?

Please use the drop-down menu to select one of the following: yes / no / don't know

Q10 What possible consequences of climate change do you think are likely to have the greatest impact on the species and ecosystems on the site?

Please select as many of the issues below as apply. To make the survey simpler to complete, we have tried to condense the list as far as possible, but this has led to some over-simplification of what is a potentially long and complex list.

Please select Yes or No from the drop-down menu / Comment Box.

- Changing species distributions as a result of changing temperature and rainfall patterns (e.g. valued species no longer being able to survive in their current ranges; new species becoming established; changing ecological communities)
- Changing seasonal events and growing/mating seasons (e.g. changing plant growth)
- Changes in food web/ trophic level disruptions (e.g. phenological mismatch)

- Effects of increased pests and invasives
- Habitat loss / extent of habitat decrease
- Fragmentation
- Effects of drought + high temperatures (incl water availability)
- Effects of increased fire regime
- Effects of increased sea temperature
- Effects of river flooding
- Effects of sea level rise and coastal flooding
- Effects of extreme precipitation and storm events
- Effects of changes to human behaviour as a result of climate change (e.g. changed farming practices, water use, recreation)
- Effects of changes to human responses to climate change such as mitigation policies or engineered adaptation responses
- Effects on water quality of changing rainfall patterns and rising temperatures
- Effects on aquatic ecosystems of changes in stream flow
- Other impacts (please give details)

Q11 At what point in time do you think the impacts you noted above will become a serious issue for the achievement of your conservation goals and how the site should be managed?

Please go to the 'timing' column in Q8 above (column J) and, for each impact you have ticked, use the drop down menu to choose one of the following:

- Now/in the next few years
- Within ten years
- Within 20 years
- Within 50 years
- Longer than 50 years
- Unlikely ever to be a serious issue compared with other pressures

Part 3. Integrating adaptation into conservation goals

Q12 To what extent is adaptation to climate change currently a factor in the design, planning and management of the site? (Regardless of whether it has led to changes in previous management.)

Please select one answer only. Please select Yes or No from the drop-down menu / Comment Box.

- Not at all (please go to part 5)
- Adaptation is a minor factor in management plans/actions
- Adaptation is a major consideration in management plans/actions
- The whole conservation site was established with adaptation as a central objective

Q13 For how long has adaptation explicitly been part of the planning and management of the site?

Please use the drop-down menu to select one of the following:

- less than one year
- one to two years

- three to five years
- six to ten years
- more than ten years

Q14 In broad terms, which of the statements below best describe your main goals in relation to adaptation?

Please select all that apply yes/no / Comment Box

- Maintaining existing populations of particular species or groups of species in spite of climate pressures
- Increasing ecological connectivity to enable species to move within/ through/ in and out of the area
- Enabling new species to become established in the conservation area
- Maintaining the overall ecosystem in its current structure/state
- Letting the ecosystem change, or actively helping it to do so (e.g. letting a freshwater wetland change to brackish/saline)
- Other goal (please give details)

Q15 Have you set specific qualitative or quantitative targets to measure progress towards these goals?

Please select Yes or No from the drop-down menu / Comment Box

Q16 Is the adaptation work being done on your site intended to make a specific contribution to enhancing ecological networks and connectivity (e.g. as part of wider work your organisation is doing)?

(Yes/No; If you answer no to this question, please go to part 4 of the questionnaire (Q21)

Q17 If you answered yes to Q16, over what spatial scales are the ecological networks to which your site contribute considered/developed?

Please select all that apply. Please select Yes or No from the drop-down menu / Comment Box

- Increasing connectivity within the site itself
- Management of the site is being planned as part of a wider regional-scale ecological network
- Management of the site is being planned with reference to large-scale species movements across your country, or across Europe (e.g. as a site to accommodate new species arriving from southern countries)

Q18 Are the ecological networks mentioned above being designed with the movement of a particular species or group of species in mind?

Please select Yes, No or Don't know from the drop-down menu / Comment Box

Q19 Have any particular tools or methods been used to determine the physical structure of these networks? (E.g. size and shape of core habitat areas, length and type of corridors, distance between patches)

Please select Yes, No or Don't know from the drop-down menu / Comment Box

Q20 Does your planning of ecological networks involve cooperation with other conservation sites in the area? (e.g. to consider species movement between sites, or consider how one site might provide habitat to replace habitat lost in another site)

Please select Yes or No from the drop-down menu / Comment Box

Part 4. Management actions and monitoring

Q21 On the basis of the projected climate impacts and adaptation goals above, have your management actions changed?

Please select one

- Previous management (i.e. what was done before climate change became a consideration) is adequate for adaptation, without changes.
- Previous management is appropriate with some small changes (e.g. in timing/extent of actions).
- Management actions have been significantly changed to address adaptation, and/or new management actions introduced.
- Management has addressed climate adaptation from the outset and has not changed

Q22 What do you consider to be the most important specific actions that you are taking on your site to help the natural environment adapt?

Please select as many of the following categories as apply. This can include actions that would be done even in the absence of climate change, as long as they are also being done with adaptation in mind. Please indicate if new or specific for climate adaptation.

Please select yes or no from the drop-down menu / Comment Box

- Species-level management (supplementary feeding; re-introduction)
- Species-level management (e.g. controlling invasive species)
- Enlarging, buffering and linking habitat patches or creating new patches (including compensatory habitat to replace other areas)
- Maintaining or altering the structure of vegetation (e.g. increasing heterogeneity of vegetation; changing vegetation height; planting trees for shade)
- Managing water levels/water supply
- Measures to protect against or safely accommodate flooding
- Actions to reduce non-climate pressures on the environment (e.g. water pollution)
- Directly intervening to fight fires
- Directly intervening in response to flooding after it occurs (e.g. pumping out floodwater)
- Directly intervening in response to drought after it occurs (e.g. pumping water into the site)
- Other actions not covered above

Q22b Are any of these management actions intended as climate adaptation benefits for people?

Please select yes or no from the drop-down menu / Comment Box

Q22c What are the approximate costs of these climate adaptation management actions for the site/per year

Please select from the drop-down menu

<5,000 Euro
5,000 - 10,000 Euro
10,000 - 50,000 Euro
50,000 - 100,000 Euro
100,000 - 500,000 Euro

500,000 - 1 Mio Euro
>1 Mio Euro
not estimated
Comment Box

Q23 Are any of these management actions coordinated with other nature reserves or sites?

Please select yes or no from the drop-down menu / Comment Box

Q24 Do you monitor changes in any of the following on your site?

Please select yes from the drop-down menu or leave blank/ Comment Box

- Species (flora)
- Species (fauna)
- Habitats/vegetation types
- Physical processes (erosion, greenhouse gas emissions, water table/flow etc)
- Water quality
- Recreational use
Other

Q25 Are any of your management actions being undertaken in an explicitly experimental way, with the results recorded, analysed and used to modify future management? (For example, are you testing and comparing different management approaches to determine which works best to achieve a particular goal?)

Please select yes or no from the drop-down menu / Comment Box

Part 5. Sources of information used; barriers to action

Q26 To what extent would you say your approach to managing the site to cope with future environmental change is based on your experience of past changes in the area, such as past extreme weather events?

Please use the drop down menu to select one of:

- not at all
- a bit
- a lot
- almost entirely
Comment Box

Q27 What other sources of information have been most useful/important in helping you to understand possible climate impacts, incorporate adaptation into your conservation goals, and identify the necessary management actions?

Please select as many as apply, using the drop down menu (choose either 'important' or 'very important', leave blank if not used/not found useful) / Comment Box

- Expert knowledge
- Personal ecological knowledge and experience of site staff
- Scientists in your own organisation
- Other colleagues in your own organisation
- External scientific researchers
- Other conservation site managers in the region
- Other experts

- Published information
- Climate projections (IPCC etc) and/or modelled outputs of impacts (e.g. flow rate, water quality)
- Reports published by government or non-government organisations (e.g. biodiversity adaptation principles)
- Articles in scientific journals
- Other journals or magazines (e.g. British Wildlife, Ecos, New Scientist)
- Information from the internet
- Books
- Newspaper/radio/TV
- Other published information

Q28 Which of the following, if any, do you feel are currently the greatest barriers to taking action to adapt to climate change on your conservation site?

Please select as many as apply and rank them (1 - 9) / Comment Box

- Uncertainty about climate impacts and how they will affect complex ecosystem processes and species interactions
- Lack of knowledge about appropriate actions to take in response
- Lack of resources (e.g. limited availability to land)
- Lack of resources (e.g. money/staff)
- Current conservation practices and strategies (e.g. designations)
- Government policies
- Public opinion /perception
- Difficulty influencing other sectors / taking necessary action outside the site
- Other

Q29 Do you think climate change creates any opportunities for conservation on this site?

Please select yes or no from the drop-down menu / Comment Box

Please use this box for any other comments you would like to make that weren't covered by the questions above

Comment Box

Responses to this survey will be treated in confidence and only summary results (i.e. not individual responses) will be made available to others. However, we would be grateful if you could provide your contact details so we can contact you in case of questions. If you are happy to be contacted, please fill in the details below.

Name:

Organisation:

Phone:

Email:

11.4 List of conservation projects included in ENCA/BfN survey

ID	Country	Nature reserve/ site/ conservation project (multiple sites within conservation area)	Conservation designation/ Project type	Website address
AU16	Austria	Nationalpark Donau-Auen	National Park	www.donauauen.at
AU45	Austria	Untere Lavant/ Life Lavant	LIFE project	www.life-lavant.at
BE24	Belgium	LIFE Elia, Creating 160km of green corridors under overhead lines	LIFE project	www.life-elia.eu
BU30	Bulgaria	Atanasovsko Lake reserve, Ramsar site, Natura zone, project LIFE Nature 'Salt of Life' project (LIFE11 NAT/BG/000362)	LIFE project / Ramsar site	http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4322
BU49	Bulgaria	Life for the Burgas Lakes (LIFE08/NAT/BG/000277), with 3 target SPAs - Atanasovsko ezero, Burgasko ezero, Mandra-Poda	LIFE project	www.burgaslakes.org
CH68	Switzerland	Riserva naturale Bolle di Magadino	Ramsar site	www.bolledimagadino.com
CY15	Cyprus	LIFE+ 08 NAT/CY/000453	LIFE project	www.plantnet.org.cy
CZ56	Czech Republic	LIFE09 NAT/CZ/000364 "Integrated Protection of Rare Butterfly Species of Non-forest Habitats in the Czech Republic and Slovakia", Landscape protected area Bílé Karpaty; Sites: SCI Bílé Karpaty, Čertoryje, Hodoňovská dolina, Hrušová dolina + stepping stones	LIFE project	www.ochranaprirody.cz/life
CZ57	Czech Republic	LIFE09 NAT/CZ/000363 "Active protection of the Sites of Community Importance with thermophilous habitat types and species in Lounské středohoří hills", Landscape protected area České středohoří; Sites: SCI Křížové vršky, SCI Raná-Hrádek, SCI Oblík-Srdov-Brník, SCI Hořenec-Číčov, SCI Všechlapy-Kamýk, SCI Sinutec-Dlouhý Kopec, SCI Milá, SCI Třtěnské stráně + stepping stones.	LIFE project	www.ochranaprirody.cz/life
DE06	Germany	Müritz-Nationalpark	National Park	www.mueritz-nationalpark.de
DE08	Germany	Biosphärenreservat Bliesgau	Biosphere reserve	www.biosphaere-bliesgau.eu

DE18	Germany	Naturnahe Gewässer- und Auenentwicklung der Ems bei Einen- Eigendynamik und Habitatvielfalt LIFE08 NAT/D/000008	LIFE project	www.ems-life-nrw.de
DE20	Germany	LIFE rund ums Heckengäu	LIFE project	www.life-heckengaeu.de
DE22	Germany	Luchwiesen, Merstallwiesen (Storkow) / LIFE Binnensalzstellen	LIFE project	www.mugv.brandenburg.de/info/salzstellen
DE23	Germany	Rietzer See / LIFE Binnensalzstellen	LIFE project	www.mugv.brandenburg.de/info/salzstellen
DE26	Germany	Nationalpark Niedersächsisches Wattenmeer	National Park	https://www.nationalpark-wattenmeer.de/niedersaechsisches-wattenmeer
DE27	Germany	Nationalpark Hamburgisches Wattenmeer	National Park	www.nationalpark-wattenmeer.de/hh
DE29	Germany	Biosphärenreservat Rhön, Hessischer Teil	Biosphere reserve	http://biosphaerenreservat-rhoen.de/de/
DE31	Germany	SPA Gebiete im Biosphärenreservat Schorfheide-Chorin	Biosphere reserve	www.schorfheide-chorin.de
DE38	Germany	Spreewald Biosphere Reserve	Biosphere reserve	www.br-sw.brandenburg.de
DE42	Germany	Nationalpark Unteres Odertal	National Park	www.nationalpark-unteres-odertal.eu
DE43	Germany	Polder Kieve	no conservation designation	www.moorfutures.de/polder-kieve-mecklenburg-vorpommern
DE46	Germany	Nationalpark Berchtesgaden	National Park	www.nationalpark-berchtesgaden.de
DE47	Germany	UNESCO-Biosphärenreservat Schaalsee	Biosphere reserve	www.schaalsee.de
DE51	Germany	Biosphärenreservat Flusslandschaft Elbe-Brandenburg	Biosphere reserve	www.nationale-naturlandschaften.de/nnl/biospharenreservat-flusslandschaft-elbe-brandenburg
DE58	Germany	Bollwinsee und Großer Gollinsee/ LIFE Kalkmoore Brandenburg	LIFE project	www.kalkmoore.de
DE59	Germany	Gramzowseen / LIFE Kalkmoore Brandenburg11	LIFE project	www.kalkmoore.de
DE60	Germany	Töpchiner See / LIFE Kalkmoore Brandenburg	LIFE project	www.kalkmoore.de
DE61	Germany	Pohnsdorfer Stauung bei Preetz	Natura 2000	www.schrobach-stiftung.de/pohnsdorf.htm
DE63	Germany	LIFE Vielfalt auf Kalk	LIFE project	www.kreis-hoexter.de/de/tourismus-kultur/life

DE64	Germany	Maxsee / LIFE Kalkmoore Brandenburg	LIFE project	www.kalkmoore.de
DE71	Germany	Rheinauen Rastatt / FFH-Gebiet 7015-341	LIFE project / Natura 2000	www.rheinauen-rastatt.de
DE72	Germany	Nationalpark Kellerwald-Edersee	National Park	www.nationalpark-kellerwald-edersee.de
FI03	Finland	Project sites are dispersed througout the country in the rural areas outside of state land and conservations areas. List of sites can be found at the finnish webpage. Project Life+ Return of Rural Wetlands	LIFE project	www.kosteikko.fi; www.kosteikko.fi/en
FI09	Finland	Boreal Peatland LIFE (LIFE08NAT/FIN00596), 54 Natura 2000 sites	LIFE project / 54 Natura 2000 sites	www.metsa.fi/sivustot/metsa/en/Projects/LifeNatureProjects/BorealPeatlandLife/Sivut/BorealPeatlandLife.aspx
FI28	Finland	Oulanka National Park	National Park	www.outdoors.fi
GR52	Greece	LIFE11 NAT/GR/001014 Ethnikos Drymos Oitis GR2440007 and GR2440004 Oros Kallidromo GR2440006	LIFE project / National Park	http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4304&docType=pdf
IR07	Ireland	Blackwater SAC	Special Area of Conservation (SAC)	www.duhallowlife.com
IT14	Italy	project LIFE+11ENV/IT/00168 "Making public goods provision the core business of Natura 2000"	LIFE project	www.lifemgn-serviziecosistemici.eu
IT41	Italy	Sentina Nature Regional Reserve (LIFE RE.S.C.WE.)	LIFE project	www.life-rescwe.it
LA66	Latvia	LIFE11 NAT/LV/000371 - NAT-PROGRAMME /National Conservation and Management Programme for Natura 2000 sites in Latvia	LIFE Project / all Natura 2000 sites in Lativa	www.daba.gov.lv
PO48	Poland	Biebrza National Park	National Park	www.biebrza.org.pl
RO05	Romania	Danube Delta Biosphere Reserve	Biosphere reserve	www.ddbra.ro
RO37	Romania	ROSCI0227 Sighişoara - Târnava Mare		www.fundatia-adept.org
UK01	United Kingdom (England)	Mottey Meadows National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006106.aspx
UK02	United Kingdom (England)	The Stiperstones National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006135.aspx

UK04	United Kingdom (England)	Aqualate Mere National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006003.aspx
UK10	United Kingdom (Scotland)	Caerlaverock National Nature Reserve	National Nature Reserve	www.nnr-scotland.org.uk/caerlaverock
UK11	United Kingdom (England)	Castle Hill, Mount Caburn,Lullington Heath National Nature Reserves	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006030.aspx
UK12	United Kingdom (Wales)	Corsydd Eifionydd SAC	Special Area of Conservation (SAC)	http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0030121
UK13	United Kingdom (Scotland)	Creag Meagaidh National Nature Reserve	National Nature Reserve	www.nnr-scotland.org.ukj/creag-meagaidh
UK19	United Kingdom (Wales)	Gower Ash Woods	Special Area of Conservation (SAC)	http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUcode=UK0030157
UK21	United Kingdom (England)	Humberhead Peatlands National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006766.aspx
UK32	United Kingdom (Wales)	Bae cemlyn / Cemlyn Bay	Special Area of Conservation (SAC)	http://jncc.defra.gov.uk/ProtectedSites/SACselection/sac.asp?EUCode=UK0030114 http://jncc.defra.gov.uk/pdf/SPA/UK9013061.pdf http://angleseynature.co.uk/webmaps/cemlynbay.html www.northwaleswildlifetrust.org.uk/cemlynwebpages/cemlynindex.html
UK33	United Kingdom (Wales)	Abermenai to Aberffraw Dunes	Special Area of Conservation (SAC)	www.ccgc.gov.uk/landscape--wildlife/protecting-our-landscape/special-sites-project/wye-to-yerbeston-sac-list/y-twyni-o-abermennai-i-aberffr.aspx
UK35	United Kingdom (Wales)	Mwyngloddiau Fforest Gwydir/Gwydyr Forest Mines SAC	Special Area of Conservation (SAC)	http://jncc.defra.gov.uk/protectedsites/SACselection/SAC.asp?EUCode=UK0030161 www.ccgc.gov.uk/landscape--wildlife/protecting-our-landscape/special-sites-project/halkyn-to-mynydd-sac-list/mwyngloddiau-fforest-gwydir-sa.aspx
UK36	United Kingdom (Wales)	Llyn Dinam	Special Area of Conservation (SAC)	www.ccgc.gov.uk/landscape--wildlife/protecting-our-landscape/special-sites-project/halkyn-to-mynydd-sac-list/llyn-dinam-sac.aspx?lang=en http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0030186 http://angleseynature.co.uk/webmaps/llynnauyfali.html

UK39	United Kingdom (England)	Teesmouth National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006937.aspx
UK40	United Kingdom (Scotland)	Tentsmuir National Nature Reserve, North east Fife, Scotland. (Tentsmuir Point & Abertay Sands, Tayport Heath and Morton Lochs.)	National Nature Reserve	www.tentsmuir.org
UK44	United Kingdom (England)	Thursley National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006148.aspx
UK50	United Kingdom (England)	Castle Eden Dene NNR, Thrislington Plantation NNR, Cassop Vale NNR	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006029.aspx
UK53	United Kingdom (England)	Exmoor Mires Project, Exmoor National Park, England	National Park	www.exmoormires.org
UK54	United Kingdom (England)	Fenn's, Whixall & Bettisfield Mosses National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006173.aspx
UK55	United Kingdom (Scotland)	Flanders Moss National Nature Reserve	National Nature Reserve	www.nnr-scotland.org.uk/flanders-moss
UK65	United Kingdom (England)	Shapwick Heath National Nature Reserve	National Nature Reserve	www.naturalengland.org.uk/ourwork/conservation/designations/nnr/1006131.aspx
UK67	United Kingdom (Scotland)	Moine Mhor National Nature Reserve	National Nature Reserve	www.nnr-scotland.org.uk
UK70	United Kingdom (Wales)	Menai Strait & Conwy Bay marine SAC	Special Area of Conservation (SAC)	http://jncc.defra.gov.uk/protectedsites/sacselection/n2kforms/UK0030202.pdf www.ccgc.gov.uk/landscape--wildlife/protecting-our-landscape/special-sites-project/regulation-35-advice.aspx