Environmental Management
DOI 10.1007/s00267-014-0271-5

Managing Protected Areas Under Climate Change: Challenges and Priorities

Sven Rannow · Nicholas A. Macgregor · Juliane Albrecht · Humphrey Q. P. Crick · Michael Förster · Stefan Heiland · Georg Janauer · Mike D. Morecroft · Marco Neubert · Anca Sarbu · Jadwiga Sienkiewicz

Received: 29 April 2013 / Accepted: 24 March 2014

Abstract The implementation of adaptation actions in local conservation management is a new and complex task with multiple facets, influenced by factors differing from site to site. A transdisciplinary perspective is therefore required to identify and implement effective solutions. To address this, the International Conference on Managing Protected Areas under Climate Change brought together international scientists, conservation managers, and decision-makers to discuss current experiences with local adaptation of conservation management. This paper summarizes the main issues for implementing adaptation that emerged from the conference. These include a series of conclusions and recommendations on monitoring, sensitivity assessment, current and future management practices, and legal and policy aspects. A range of spatial and temporal scales must be considered in the implementation of climate-adapted management. The adaptation process must be area-specific and consider the ecosystem and the social and economic conditions within and beyond protected area boundaries. However, a strategic overview is also needed: management at each site should be informed by conservation priorities and likely impacts of climate change at regional or even wider scales. Acting across these levels will be a long and continuous process, requiring coordination with actors outside the "traditional" conservation sector. To achieve this, a range of research, communication, and policy/legal actions is required. We identify a series of important actions that need to be taken at different scales to enable managers of protected sites to adapt successfully to a changing climate.

Keywords Conservation management · Climate adaptation · Monitoring · Assessing sensitivity · Management practices · Legal and policy advice

S. Rannow (✉)
Biosphere Reserve River Landscape Elbe-Brandenburg, Neuhausstraße 9, Rühstädt 19322, Germany
e-mail: sven.rannow@gmx.de

N. A. Macgregor
Natural England, Nobel House, 17 Smith Square, London SW1P 3JR, UK

J. Albrecht · M. Neubert
Leibniz Institute of Ecological Urban and Regional Development, Weberplatz 1, 01217 Dresden, Germany

H. Q. P. Crick
Natural England, Eastbrook, Shaftesbury Road, Cambridge CB2 8DR, UK

M. Förster
Geoinformation in Environmental Planning Lab, Technische Universität Berlin, Sekr. EB 5, Str. d. 17. Juni 145, 10623 Berlin, Germany

S. Heiland
Department of Landscape Planning and Development, Technische Universität Berlin, Sekr. EB 5, Str. d. 17. Juni 145, 10623 Berlin, Germany

G. Janauer
Department of Limnology, University of Vienna, Althanstraße 14, 1091 Vienna, Austria

M. D. Morecroft
Natural England, Block B, Whittington Road, Worcester WR5 2LQ, UK

A. Sarbu
Department of Botany-Microbiology, University of Bucharest, Aleea Portocalelor 1-3, 060101 Bucharest, Romania

J. Sienkiewicz
Environmental Protection Institute, Krucza 5/11, 00-548 Warsaw, Poland

Introduction

Protected areas are a cornerstone of our current conservation efforts, and will continue to play an important role under climate change (Hopkins et al. 2007; Thomas et al. 2012). Putting in place appropriate climate-adapted management in these areas is therefore a high priority. But the adaptation of conservation management to a changing climate is a site-specific and potentially complex task. For adaptation to be successful, multiple issues such as conservation objectives, potential climate impacts, institutional settings, the policy and legal context, and social issues must be considered. This makes adaptation, at the local level, an inherently "transdisciplinary" activity bringing together different scientific disciplines and practical implementation (Rannow and Neubert 2014). A range of general principles and recommendations has been published, particularly over the last decade (e.g., Glick et al. 2011; Hansen and Hoffmann 2011; Heller and Zavaleta 2009; Mawdsley et al. 2009). However, most contributions are focused on problems of conservation management in general (e.g., Araújo et al. 2011; Game et al. 2011; Groves et al. 2012; Hannah 2003; Lovejoy and Hanna 2005). Relatively, few authors have focused on the specific challenges for protected areas (e.g., Baron et al. 2009; Cross et al. 2012; Lawler 2009; Welch 2005), and implementation of adaptation action on the ground is still in its infancy. Given the long time scales over which many ecological processes operate, local conservation management must begin to adapt, or at least prepare to adapt, despite considerable and unavoidable uncertainty about future changes (Conroy et al. 2011; Hagerman et al. 2010; Hunter et al. 2010).

In September 2012, an International Conference on Managing Protected Areas under Climate Change (IMPACT) was held to meet the growing need for sharing knowledge and experiences of translating local adaptation strategies for conservation management into action. Taking a transdisciplinary perspective, the conference brought together more than 120 international researchers, conservation managers, and decision-makers in the field of nature conservation. Thirty-four oral and twelve poster contributions presented methodical approaches, current experience, and good-practice examples from fifteen countries on five continents.

The conference was organized in six thematic sessions that focused on:

- Monitoring of climate-induced impacts,
- Modeling of climate-induced impacts,
- Climate change impacts on species and invasive species,
- Assessing sensitivity to climate change,
- Current and future management practices for adaptation,
- Legal aspects of and policy recommendations for climate-adapted management.

This paper summarizes the main themes, issues, and conclusions that emerged from the conference. The information presented and discussed at the conference supported the argument that more often than not, sufficient knowledge and tools exist to begin to address the effects of climate change in the management of protected areas (Driscoll et al. 2012; Hansen and Hoffmann 2011; Lawler 2009). However, this information has not been widely translated into practical advice to support action on the ground. The conference also highlighted that other barriers and constraints to successful adaptation exist in some places as a result of human land use, governance and institutional arrangements, and the way that legislation is applied.

Our aim in this paper is to identify the most pressing priorities and challenges for putting in place effective adaptation in protected areas, and to highlight some of the actions required to overcome institutional, political, and information barriers and support successful implementation. The discussion concentrates on the monitoring, assessment, and management of climate effects at the site level, and on how this can be supported by research, policy, legislation, and advice. Our intention is to address issues that are important for the application of climate change adaptation in the field, but are not prominent in the current scientific literature. We therefore touch only briefly on subjects such as integrated modeling and impacts on individual species that are covered extensively elsewhere.

Throughout the paper, we illustrate some points with specific examples that were discussed during the conference. Some of these case studies are explored in more detail in other papers in this Special Feature of Environmental Management (e.g., Ausden 2013; Cliquet 2014; Ivajnsic and Kaligaric 2014).

Monitoring of Climate-Induced Impacts

Climate change is already affecting temperature, precipitation pattern, sea levels, frequency of extreme events, and phenology, but it also shows more subtle and indirect impacts like desynchronization and spatial uncoupling of ecological interactions (Bellard et al. 2012). They result in changing species distributions and abundances in individual sites. Climate change also affects availability of resources (e.g., water) and ecosystem services (e.g., crop production). Local management is also challenged by an increasing number of adaptation activities in other sectors (e.g., flood protection and water management), and above all this there is a strong interaction with changes in land use (e.g., for biomass production). Structured and standardized long-term monitoring can provide reliable evidence of these changes in ecosystems (Kuussaari et al. 2009) and help us to understand the effects of different drivers of change. Monitoring is an essential element of adaptation to climate change. Alongside the modeling of future scenarios, monitoring in its broadest sense has framed the science of climate change impacts on the natural environment at a global scale. At a site scale, it can establish a baseline against which change can be measured and it is an essential check as to whether adaptation actions are achieving their intended outcomes. Monitoring is a cornerstone of adaptive management techniques, in which the effectiveness of actions is assessed and strategies changed in the light of experience.

Two distinct types of monitoring for conservation can be distinguished (Nichols and Williams 2006): targeted monitoring and surveillance monitoring. Targeted monitoring is a series of observations in time to indicate the extent of compliance with a formulated standard or norm relative to the normal range of variation (Hellawell 1991; Greenwood et al. 1994). Surveillance monitoring involves repeated surveys using standard methods, but does not compare this information to given standards. Either or both may be appropriate in climate change adaptation; surveillance can identify unanticipated changes and targeted monitoring is appropriate to test effectiveness of management interventions or the meeting of wider conservation objectives. One of the most important aspects of monitoring is to help identify when an objective or standard can no longer be achieved and a new one needs to be adopted.

Monitoring must be relevant to the conservation objectives for a site. In many cases, the vegetation of a site is central to conservation and the mapping of plant communities is a basic starting point for monitoring. Change in the distribution of habitat types can be monitored through repeated surveys. There are standard methods available for vegetation mapping, which are regularly used (USGS 1994; Kent 2011). At larger spatial scales, field-based vegetation mapping becomes more difficult. It is however necessary to put individual sites in a wider perspective, and this becomes even more important under climate change as the distribution of species and vegetation types changes. A variety of studies have attempted to resolve this problem by developing monitoring sampling strategies as well as upscaling and extrapolating local results to provide a broader overview (Chiarucci et al. 2008). Remote sensing has opened up new opportunities for large scale vegetation mapping and can give insights into vegetation health, biomass, and species composition (Nagendra et al. 2012). However, especially for species mapping, a variety of uncertainties have to be taken into account (Rocchini et al. 2013). A problem to consider is that satellite lifetime is approximately 5–20 years, and this can lead to inconsistencies in time series. At a site scale, airborne remote sensing offers the potential for higher resolution imagery and a variety of innovative techniques, including LIDAR for the accurate measurement of topography and the height of ground features including tree canopies (Zellweger et al. 2014).

Maintaining suitable vegetation cover is an essential component of maintaining habitats to support animal species, especially birds and mammals (Campbell 2009; Arthur et al. 2012). In response to climate change however, it is also important to be able to detect changes in animal populations themselves. Mapping of animal populations is much less standardized than vegetation mapping and tends to be biased toward those groups that are easiest to record, such as birds and butterflies. It is also the case that national monitoring schemes are designed to detect national or regional trends and may not meet the needs of site level adaptation planning.

Monitoring of the physical environment can be as important as ecological monitoring. In some cases, a relatively simple parameter such as the water level in a wetland may be the single most important determinant of the suitability of a site for many of its distinctive species. In this case, site hydrology may change as a consequence of climate change but adaptation through catchment management may be possible: monitoring water depth, with either a data logging system or a simple manual gage, will be necessary to guide this.

Monitoring the physical environment is also valuable for understanding the causes of change. Distinguishing the effects of climate change from those of other environmental changes is not straightforward. In the case of climate itself, it may be possible to rely on a nearby weather station or national data, but in other cases, for example in mountainous regions where there may be large spatial variations in climate, on-site meteorological records may be valuable. Similarly, there is added value from measurements of air pollution, soil properties, hydrology, and a range of other variables. Sites monitored for a wide range of physical variables alongside biological ones are rare at present, but examples are the UK Environmental Change Network (Morecroft et al. 2009) or the Long Term Ecological Research Network (lternet). This sort of approach is expensive and cannot be introduced at all sites. However, there are some relatively cheap, simple techniques, such as measurements of water depth, photographic records, and records of site management activities, which can be widely introduced.

While there are good examples of effective monitoring schemes, there are also significant obstacles to overcome.

Schemes can range from those with a global perspective (Walther et al. 2005) to those with a more local focus (Bock et al. 2005; Förster et al. 2008). The ideal monitoring technique is one that produces information that is locally applicable but collected following an established method and using standardized indicators, so it is compatible with data obtained from other monitoring programs. Unfortunately such methods are rare. There are also relatively few biodiversity time-series available that span decades (Magurran et al. 2010), and this is essential to track changes with climate change. Developing a common understanding or framework as well as standardized methods and indicators is an ongoing challenge but would bring many benefits and efficiencies. Newson et al. (2009) outlines the issues involved in developing a suite of climate change indicators that would also help to show progress with adaptation actions. It also has to be recognized that monitoring alone will not always be able to separate the effects of different pressures on the environment. Therefore, it is important to integrate monitoring information with the results of experimental, modeling, and process studies.

Assessing Sensitivity

The flora, fauna, and ecosystems in protected areas are expected to experience significant impacts from climate change during this century (Araújo et al. 2011; Fischlin et al. 2007; Normand et al. 2007). But impacts will differ among different species and ecosystems, and from place to place. With limited conservation resources available, understanding the relative vulnerability of species, ecosystems, and sites can help to set priorities (Summers et al. 2012). At a conceptual level, vulnerability to climate change is often presented as having three components—exposure ("the character, magnitude and rate of change the species or system is likely to experience"), sensitivity ("innate characteristics of a species or system and [their] tolerance to changes"), and adaptive capacity ("the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption") (definitions from Glick et al. 2011; see also Williams et al. 2008). When applied to complex natural systems, it can be useful to consider a more detailed set of factors within this broad conceptual framework.

Intrinsic ecological features of species, including physiological tolerances (Normand et al. 2007), the ecological envelope of habitats (Borhidi 1995; Ellenberg 1992), the magnitude of the exposure to different climate changes at different spatial scales, and factors specific to the particular site or species population are all important aspects to consider. A number of approaches for the assessment of vulnerability and sensitivity of natural systems (or individual components) to climate change has been developed and applied (Williams et al. 2008; Glick et al. 2011).

Assessments of sensitivity and vulnerability can be used to summarize structure and document existing knowledge about the potential and observed effects of climate change. The results help to identify which species and ecosystems may be most vulnerable, the factors driving that vulnerability, and where the climate change-related risks are greatest (e.g., U.S. Environmental Protection Agency 2009; Gitay et al. 2011; Harley et al. 2010). This helps researchers identify appropriate adaptation actions and focus on the most important things and in the most important areas (which could be the areas of highest vulnerability, but could also be less vulnerable areas that might function as refugia and support core populations).

A vulnerability assessment for more than 1,000 protected areas in Wales, UK, presented at the IMPACT showed the potential for a strategic approach to conservation planning in the context of climate change. It was based on the independent assessment of the vulnerability of each protected area and a more general Climatic Vulnerability Index (Wilson et al. 2013). However, more specific vulnerability and sensitivity indicators are also needed in some circumstances. A specific example presented at the conference illustrated this for alpine species with high conservation value found in the Bucegi Mountain Range in Romania. The vast majority of the taxa evaluated in this area is considered to be highly sensitive to the projected increase in temperature and/or reduction of humidity, and over 50 % of them are considered to be sensitive to the cumulative effects of these climatic factors. This example highlighted the importance of considering multiple aspects of sensitivity and cumulative effects, as this could greatly influence the relative vulnerability of different species in different places.

The concept of adaptive capacity can encompass both the environment and human management to cope with change. A case study from a protected area in Brandenburg (Germany) showed the importance of institutional aspects of vulnerability. The results highlighted that assessments can be limited not only by a lack of existing up-to-date data and knowledge, but also by organizational barriers such as inadequate exchange of information between protected areas management and responsible public government, or the lack of integrating competencies in public administration. Institutions play a significant role in the implementation of adaptation action (Berman et al. 2012). Hence, the institutional adaptive capacity of conservation agencies might need more attention in future research (Lemieux et al. 2013).

The values and services protected areas provided to people are dependent on the integrity and quality of the natural environment, and so might also be vulnerable to climate change. One particular aspect likely to be affected is outdoor recreation, which could be affected not just by changes to the natural environment but by changes in human behavior and tourism patterns as a result of climate change (Lupp et al. 2012, 2013).

To conclude, not only the assessment of vulnerability, but also of its components sensitivity and adaptive capacity, are an important step in the development of adaptation planning for protected areas (Wagner-Lücker et al. 2014). Detailed assessment methodologies and tools are being developed and tested, but these are at a relatively early stage. There are still areas of uncertainty in the application and use of such assessments. For example, there are limits to climate models (the principal source of information about exposure), particularly in the projection of changes in the frequency of extreme events (which could have a much greater impact than gradual change). Assessment methods for vulnerability have to take this into account. There are also gaps in our knowledge about the sensitivity and intrinsic adaptive capacity of many species and ecosystems. This makes it difficult to identify when major ecological changes or tipping points might occur. In addition, we lack information about how the interactions between and within different trophic levels of an ecosystem may be affected by climate change.

Nevertheless, even with all these handicaps, there is still great value in assessing vulnerability and its components as a starting point for adaptation planning. The necessary basic tools and guidelines exist. These should be incorporated into management plans for all protected areas, to consider climate threats and opportunities alongside other environmental pressures and changes. Trials of approaches with different level of detail in terms of scale (e.g., from regional level to individual biotopes) and problems addressed (e.g., from general water shortage to habitat restoration) are beginning in various countries in Europe. It will be important to share information and results so that a body of best practices can be built up.

Current and Future Management Practices

Which strategies and management instruments already exist to deal with climate change in protected areas? Are they applied in practice and, if so, in what ways and with what results? Can conclusions for other areas be drawn from these experiences? These were the guiding questions for the conference session on current and future management practices.

Examples of protected area management from across the world, from the UK and Romania to Australia and Jamaica, showed that some valuable lessons are emerging, particularly for water-based ecosystems such as coral reefs, other coastal zones, wetlands, bogs, and river habitats. The climate impacts of greatest concern in these ecosystems include drought (too little water) and flooding and heavy rainfall (too much water), as well as the modification of physical and chemical features such as temperature, salinity, share of nutrients, or the resulting shift of species.

All examples showed a range of common or similar issues experienced. The following general conclusions could be drawn:

- The concept of vulnerability is broadly accepted as a framework to assess possible effects and impacts of climate change, and to structure and guide adaptation activities.
- It is necessary to involve stakeholders and raise public awareness of climate change, its impacts on biodiversity and the resulting consequences for societies and human beings.
- Anthropogenic drivers or pressures (e.g., land use changes in agriculture and urban development) can exert a strong influence and so it is important to reduce those stress factors in order to improve the resilience of habitats. This frequently requires a greater consideration of influences from outside the protected area of interest. In some cases, external pressures such as water abstraction by other sectors constrain adaptation action by protected area managers.
- It is important to consider the complex dynamics of natural and societal processes triggered by climate change, and there is an urgent need to develop adequate management practices that are able to cope with the resulting uncertainty. Flexible management approaches, set within long-term conservation goals, are needed. Their implementation should embrace experimentation and include monitoring of outcomes in order to adapt to new knowledge or developments. The concept of adaptive management provides a sound framework for this, but there are still very few practical examples of its application in conservation.
- There is no easy single "recipe" for strategies to cope with climate change which is applicable everywhere. Instead effective and efficient strategies have to be developed according to the respective climatic changes, sensitivities, problems, and options for action in every single case. This can lead to very different solutions being appropriate in different places. Even within individual sites, decisions need to be made among different options and strategies. For example, a case study from the Adriatic Coast illustrated how sea level rise, changes in flood regime, and infrastructure development form a dangerous mix for intertidal wetlands. Site managers will need to choose an appropriate

strategy, or mix of strategies; options include improving sea-walls, creating buffer zones, and the accommodation of change through relocation and recreation of habitats (Ivajnsic and Kaligaric 2014).

A series of major questions emerged:

- Under which circumstances is it more appropriate and feasible to choose a "hands-off"-management approach that accepts change or a "hands-on" approach that attempts to resist change and/or guide the changes that take place, potentially including major interventions such as "ecosystem engineering" and translocation of species? When and where should strategies focus to resist climate impacts? Which impacts do we have to accept and which changes should we embrace or support? Closely linked to this question are considerations about the kind of nature and ecosystems humankind wants or needs to have (Hobbs et al. 2010) and what the (unforeseen) negative side-effects of both approaches could be.
- Following on from the questions above, how can managers of protected areas identify and choose appropriate "pathways" for adaptation for their sites? Assuming that in the short term reducing existing vulnerability and trying to manage for resilience is the appropriate strategy in most places, how can managers decide at what point they might need to change their strategy to one of "accommodation" or even "transformation" (Morecroft et al. 2012)? How can different future scenarios and potential ecological tipping points and decision points in the adaptation process be identified and prepared for? At what temporal and spatial scales do such decisions need to be made? What criteria should be used to inform decisions in individual sites?

In summary, there appears to be a widely shared understanding of the importance of climate change for protected area management. It seems clear that conservation management in the future will be about managing change. However, the timing and magnitude of changes, and the appropriate responses, are likely to vary considerably from place to place. Planning and management of protected areas are likely to become more complex because of the range of new factors to be considered, and because planning will need to consider multiple scales in time and space. This might force management of protected areas to reconsider guiding principles and conservation objectives (Hagerman et al. 2010; Hobbs et al. 2010).

There is also general agreement on the usefulness of some general adaptation principles. However, these principles and associated terms such as vulnerability, flexibility, and adaptive management can be defined and applied in different ways in different places. To promote the interdisciplinary and/or transdisciplinary cooperation that is needed, a greater level of agreement on the meaning of core terms and strategies would be helpful. Even more importantly, as noted above, more needs to be done to help site managers identify the adaptation options available to them and choose appropriately.

To strengthen climate adaptation in conservation management, user-friendly tools which can easily be understood and applied by the respective authorities must be developed (e.g., Cross et al. 2012).

Another issue is to combine methods of adaptive management with existing methods of risk reduction or risk management. Risk assessment can provide useful and easy applicable tools to handle and incorporate uncertainty in decision-making on adaptation pathways (Dessai and Wilby 2011; Lawler 2009). Risk management, on the other hand, can provide a suitable framework for the classification of response options (United Nations, UN 2009). Their combination will help to identify all potential actions, their priorities, and adequate timing (Rannow 2013). The available methods can include quantitative and qualitative information from different sources, join non-climatic driving forces and climate related changes, highlight useful intervention points, and develop robust adaptation action on the site level.

Further research (in collaboration with conservation practitioners) is needed in order to determine the effectiveness of different specific management options and overall strategic approaches (e.g., "hands-on" vs. "hands-off" management) in different cases. There is a paucity of good case studies in the scientific literature on any aspect of adaptation in practice, and more needs to be done to bridge the gap between research findings, general principles, and disparate examples of practical action. Two papers in this issue of *Environmental Management* help to address this gap with reference to the UK. Ausden (2013) provides a detailed summary of the approach being taken by a major conservation organization to integrate adaptation into the management plans of its nature reserves. A study by Macgregor and van Dijk (2014) presents the findings of a survey of 35 sites in one region of England and uses specific examples of practical action being taken to distill some of the major themes and lessons for adaptation.

Legal Aspects and Policy Recommendations

In both international and European policy, increasing attention is being given to the link between biodiversity and climate change (European Commission 2009, 2011; European Union 2013; UNESCO 2011). Several decisions have been taken by the Conferences of the Parties to include climate change in the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity 2009). In addition, the Bern Convention (Council of Europe 1979) provides an important multinational framework for the adaptation of conservation. Even stronger legal obligations can be found within EU legislation. However, the question remains whether these and other regulations are sufficiently flexible to face the challenges of climate change. Therefore, the existing political and legal frameworks for management of protected areas under climate change were the key aspects in this session of the conference. Most presentations came from European countries. Hence, this summary mainly concentrates on European regulations or national law. However, several aspects are also relevant at the international level and to non-European countries.

The formulation of policies and legal provisions to adapt biodiversity conservation to climate change needs to be found on: (a) exploring the possibilities to review and improve the existing policies and (b) developing recommendations for measures to mitigate climate change-induced biodiversity loss and guidelines for adaptive management of protected sites to ensure that management plans for protected areas are more climate-proof and flexible without watering down conservation requirements. Climate-proof in this context means that planning decisions are adjusted to face environmental changes due to climate change. Building resilience into existing species populations and ecosystems by removing current land use pressures and by bringing sites into a favorable condition is a vital first step to make protected areas climate-proof (Dodd et al. 2010). Further requirements may be changes in site objectives, climate change adapted management measures, and the enlargement of protected areas to buffer sites from external pressures.

Some authors provide evidence that European states have already been empowered with tools to adapt nature conservation to upcoming climatic changes (Dodd et al. 2010; Naumann et al. 2011; Trouwborst 2011). Under the Bern Convention (Council of Europe 1979) as well as under the EU Birds Directive (European Parliament and Council 2009) and Habitats Directive (European Council 1992), the EU Member States are subject to legal obligations to take the measures needed to achieve favorable conservation status on protected sites and thus, to adapt biodiversity conservation in Europe to climate change. For example, the management obligation (Art. 6 para. 1 Habitats Directive), the deterioration prohibition (Art. 6 para. 2 Habitats Directive), and the duty to assess conflicting plans or projects (Art. 6 para. 3, 4 Habitats Directive) can be regarded as suitable instruments to ensure a flexible response to the ecological demands imposed by climate change (Dodd et al. 2010). Ensuring adequate connectivity between core protected areas is not strictly regulated in Art. 10 Habitats Directive, but it is mandatory under the Bern Convention (Trouwborst 2011). Thus, efforts should be mainly directed to further clarify current duties for climate change adaptation of the Bern Convention parties and EU Member States, and much depends on the guidance of the European Commission and the jurisprudence of the European Court of Justice. However, although climate adaptation is already possible and also—at least to some extent indirectly—required under the existing law, there is still room for improvement of the legal framework to make climate adaptation more obligatory (Cliquet 2014). In this respect, more far-reaching opinions are voiced by other authors who point to the need for refining European nature conservation policies at various levels to empower conservation planners and managers with tools to facilitate climate change adaptation (Cliquet et al. 2009; Schumacher et al. 2013; Verschuuren 2010). Verschuuren (2010) goes further in concluding that the legal provisions of the current Natura 2000 network do not match the requirements that should be met in order to help biodiversity to adapt to climate change.

So far, the implementation of the European Birds and Habitats Directive has been aimed mainly at conserving the status quo of habitats and species within the network of designated sites, the "Natura 2000" network. In the light of the changing climate, this network of sites has to be understood as a dynamic system, which needs to be supplemented with other areas to improve its coherence (Cliquet et al. 2009; Möckel and Köck 2009). The existing collection of individual protected areas must be developed into a functional network. However, adaptation to climate change effects will require flexibility in regard to the conservation objectives of the existing core areas. Increasing flexibility must not come at the price of weakening the existing legal obligations, and it will be necessary to reconcile this tension. Therefore, more emphasis should be put on those measures in nature conservation that reduce potential risks of climate change, while maintaining measures to protect against other pressures that are not related to climate change (some of which might be more urgent in the short term).

The way nature conservation law is implemented is as important as the law itself. Examples presented in the session showed considerable inconsistencies between the legal system in the European Member States and its enforcement in practice. In particular, the interaction with other fields of law, such as water law and planning law, needs further attention.

In summary, the European Habitats and Birds Directives still leave much room for interpretation when considering climate change adaptation of biodiversity conservation.

Examples of insufficient regulation include monitoring and planning obligations for protected areas. To strengthen the provisions for climate change adaptation in nature protection legislation, some regulations should also be amended to clarify the need for adaptation. Another possibility for improvement of the European legal framework, without changing the Directives as such, is to supplement the Directives with policy guidelines developed at the European level, for example to strengthen the connectivity of the Natura 2000 network and monitor climate changes in habitats as well as species populations. However, the most important challenge to address in the European context is not the lack of regulations, but the incoherency of policies such as, for example, agricultural (in terms of the Common Agricultural Policy) or water (in terms of the Water Framework Directive) and nature conservation instruments, as well as the overwhelming lack of practical implementation of the binding provisions (Möckel and Köck 2009). This is probably the biggest barrier to successful adaptation from a legal and regulatory perspective and, therefore, the most urgent priority is to improve the enforcement of existing regulations.

Supporting Adaptation to Climate Change in Protected Areas

The talks and discussions during the conference, as summarized above, reinforce the conclusion that adaptation is not a single problem and has no single solution. Rather, it is an issue with multiple facets (conservation objectives, impacts of concern, organizations involved, policy and legal ramifications, social considerations), is influenced by factors that differ from place to place, and must be considered at a range of spatial and temporal scales. Thus, it is difficult to suggest that one priority outweighs all others. However, what does emerge is that adaptation in any given protected area needs to be considered at three different levels (at least).

First, it is important that adaptation is *tailored to the specific protected area and local conditions*. It needs to take into consideration the ecosystems and species present, the conservation goals of the people who manage and use the area, the potential changes likely, and the management options that appear feasible.

Second, climate change also increases the need for management in protected areas to *take a wider perspective and consider land use beyond the protected area boundaries*. Climate change increases the need to deal with pressures from outside the site (e.g., water pollution) and in some cases might increase these pressures. It is also likely to make environmental conditions more dynamic and variable, increasing the need to consider environmental flows across the site borders (e.g., hydrology, metapopulation dynamics involving species populations outside the site). Some sites might need to expand (either formally, or through buffer zones of more sympathetic land use). Thus, there is an increased need for managers of protected areas to consider wider land use beyond their borders, making links to local communities and other sectors. This might work both ways and not only benefit conservation of the protected area but also enable the protected area to provide services (such as water storage) to benefit local communities.

Third, *protected areas cannot be managed in isolation from each other*. When making (sometimes difficult) decisions about adaptation in a particular protected area, conservation managers will need to take into consideration what is happening, or likely to happen, at other sites. Sites will need to be managed increasingly as part of an overall protected area strategy over large areas and consider likely species changes and movements within and across whole bioregions. For example, protected sites have been found to be preferentially colonized by species moving northwards in response to climate change (Thomas et al. 2012), so while some sites may lose features of conservation interest, they may gain others that are of relevance for the overall network. Climate change will bring changes to species, ecological communities, and ecosystems, and an important decision at each site will be how much effort to put into resisting change. Knowledge of wider conservation considerations (for example whether a species threatened by climate change on a particular reserve is also threatened elsewhere) will enhance decisions about whether to focus on trying to retain existing species, for example, or whether to accept changes. In some cases, coordinated action across networks of protected areas will be needed to ensure the effectiveness of adaptation at the local level. When planning new protected areas, potential shifts in species' ranges, as well as current distributions, should be taken into account (Hannah et al. 2007).

These three levels provide a framework from which we can identify a series of important research, policy/legal, and communication actions that should be taken to inform and support appropriate decision-making at site level (Fig. 1).

Importantly, action across these levels will be a long and continuous process, and will require coordination with actors outside the "traditional" conservation sector. In Europe, measures to adapt the Natura 2000 network to climate change will require not only the involvement of organizations that directly own and manage conservation sites, but also of other organizations and sectors including, for example, agriculture, fisheries, commercial forestry, as well as a wide spectrum of large and small-scale private landowners, and wider society.

Existing conservation and management strategies to maintain and restore habitats and species of the Natura

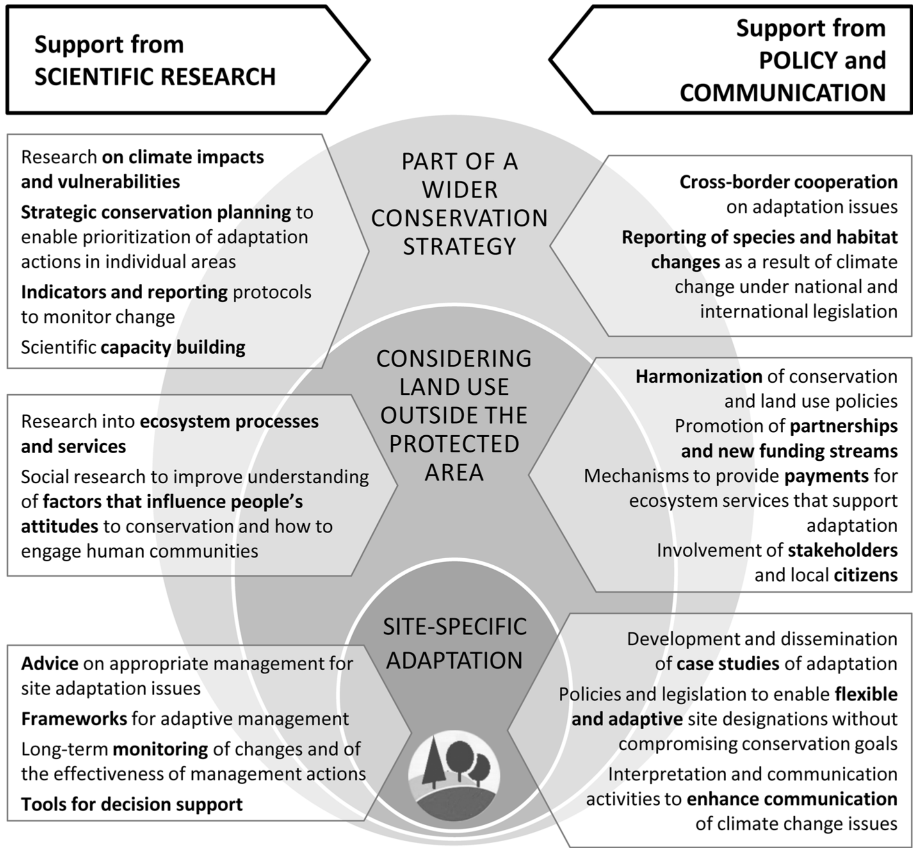

Fig. 1 The three levels at which research, policy, legal, and communication actions need to be considered to support adaptation in protected areas, and a summary of some of the most important individual actions identified at the IMPACT conference

2000 network can be expected to reduce some of the negative impacts of climate change; however, there are rates and magnitudes of climate change for which natural adaptation will become increasingly difficult in the longer term. An approach that considers the resilience of different components of the system, and acknowledges that it might be necessary to accept, or even facilitate, change of some elements (e.g., species within a community, or individual sites within a network) in order to maintain the resilience of the system overall (Morecroft et al. 2012) will help to manage this. It will also be beneficial to take an adaptive management approach that embraces uncertainty and uses rigorous monitoring, documenting of management, and experimentation to "learn by doing" (Walters and Holling 1990).

Climate change and the development of robust adaptation strategies are key challenges in conservation management of the future. Protected areas will be an essential component of successful conservation in a changing climate. They should be active partners within networks and alliances and should promote local climate adaptation. Cooperation among conservation practitioners and local land users, residents, and other stakeholders is of high importance. Inter- and transdisciplinary research on cross-cutting themes is needed to provide mutual learning between all actors and the development of effective strategies. One of the most important goals for the near future is a much greater level of harmonization between the scientific approach and practical advice and management. To facilitate this, the available scientific results must be accessible to a system of conservation management that has the capacity to incorporate and use this information. Cooperative science–management partnerships could be one way to provide the necessary scientific information to management, build local capacity to apply them and generate site-specific recommendations. The feedback and evaluation of this step in implementation is essential to improve existing theoretical concepts, but it will also help to identify user needs and align research efforts accordingly. Structured documentation of action in the field will help managers to share good-practice examples and innovative solutions derived from scientific research.

IMPACT sought to improve the integration of research outputs into conservation projects, as well as to detect unsolved problems and further research needs, and to identify actions that need to be taken to help conservation managers today make decisions about climate impacts of the future. We hope that this paper and the others in this issue contribute to that goal.

Acknowledgments IMPACT was organized as part of the project HABIT-CHANGE—Adaptive Management of Climate-induced Changes of Habitat Diversity in Protected Areas (www.habit-change.eu). This project was implemented within the INTERREG IV B CENTRAL EUROPE Program (reference number 2CE168P3) co-financed by the European Regional Development Fund (ERDF). Additional funding was provided by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) under the Grant number NE 1843/1-1. Our sincerest thanks go to everyone who made IMPACT such a successful event: the conference presenters who generously shared their time and expertise, the session chairs who managed their part of the event, and all the participants who contributed to lively and productive discussions. Last but by no means least, we thank all the partners of HABIT-CHANGE who cannot be named individually, as the project brought together more than 50 people from 17 institutions in eight countries across central Europe.

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