Chapter 5
Climate Change Impact Modelling Cascade – Benefits and Limitations for Conservation Management

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5.1 Introduction

Even if all political targets are met, climate change is expected to increase temperatures within the next decades globally and to change climate regimes locally, resulting in shifting water regimes and extreme weather events. In Central Europe temperatures are expected to increase and the climatic water balance, especially in summer, to decrease (see Sect. 3.3.1). Consequently, adaptation to climate change will become a necessity. Thus, it is crucial to overcome the notion that accepting the need for adaptation implies admitting the failure of climate policy. In fact, there are some instruments which provide high synergies between adaptation and mitigation, for example, in the area of forest conservation or ecosystem based adaptation as defined by the Convention on Biological Diversity (CBD). In short, adaptation to climate change is becoming increasingly important for nature conservation management. But adaptation to which specific climate change impacts?

One answer is expected to come from the area of modelling. Modelling is increasingly important for understanding and projecting climate change impacts. Hence, model results can serve as a basis for adaptation. However, there is a gap

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between the kind of information models can provide and what managers of natural areas need. The perception of models differs between disciplines and between science and practice. Models range from semantic descriptions of assumed interrelations to computer based mathematical models; the term ‘model’ is often used for computer based models only.

During recent decades, model-based prediction of biological responses to climate change has become a very active field of research. In the field of climate change modelling, models primarily enable understanding of global climate cycles. The development of models could demonstrate the impact of human activities on the earth climate system. Models serve to structure knowledge, to formulate hypotheses and to illustrate future developments. In the field of nature conservation management, the development of alternative scenarios is of special interest. Different management options may lead to different futures. Ex-ante assessment of the outcome of specific management measures in conjunction with different climate change impact scenarios may support management – but may also lead to deep frustration because of the high degree of uncertainty about future developments. Especially the necessary combination of different model types, such as climate models, vegetation models, and hydrological models, including all their underlying assumptions and uncertainties, renders it difficult for managers to identify useful options for decision making.

Even though there have been extensive studies to model the impacts of climate change on biodiversity, the results are still sobering. In 2002 the IPCC found that “most models of ecosystem changes are not well suited to projecting changes in regional biodiversity” (IPCC 2002: 15). More and more authors have picked up this critical attitude towards the modelling of climate effects (e.g. Biesbroek et al. 2009; Opdam et al. 2009; Pyke et al. 2007). After a far-reaching survey of literature on conservation issues, Heller and Zavaleta (2009) concluded that “many articles based on concrete modeling work or empirical studies of species responses to climate change tended either to not elaborate their results to management directives, or to present recommendations in vague terms such as, ‘restoration should be considered’” (Heller and Zavaleta 2009: 17). Therefore, Heller and Zavaleta highlighted the need to pay more attention of transferring modelling results into the decision context of management issues (Heller and Zavaleta 2009). This problem is not only limited to conservation management but to adaptation to climate change in general (Millner 2012).

In this chapter we are describing concrete model approaches used to support decision-making within the HABIT-CHANGE project context. Facing climate change, climate impact models are currently seen as a big support for the development of alternative management scenarios. Handling uncertainties and understanding the ‘model cascade’ will help in judging where models will supply useful information. A short overview of model approaches and their assumptions is presented as a basis for adaptive management and their benefits as well as limitations are discussed.

5.2 The Long Model Cascade

A major problem in communicating model results is the long 'model cascade' with partly hidden assumptions about future development. Results from one model are fed into the next one, which itself relies on assumptions or hypotheses. This results in a chain or cascade of models that starts with projections of the global greenhouse gas emissions, moves on to the impact of the global climate system and on to regional or local impacts on flora and fauna (Fig. 5.1). The relevance and reliability of the final outcome might, thus, be difficult to judge with regard to modelling uncertainties. To have an impression of the usefulness of the specific contribution

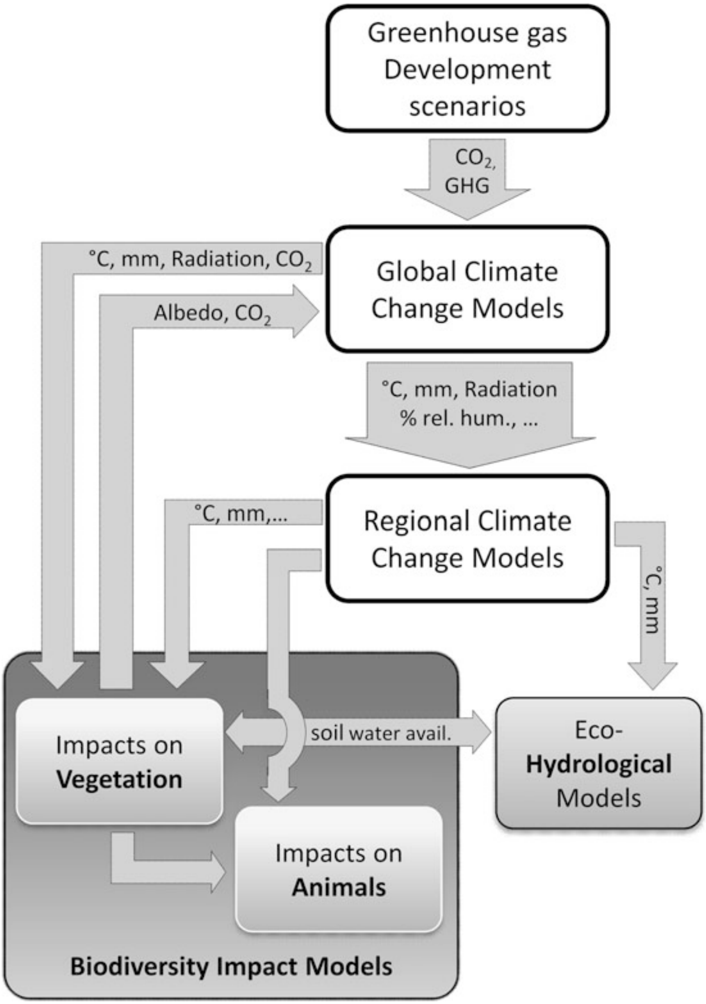

Fig. 5.1 The chain/cascade from emission scenarios to regional climate impact models

of models to adapt the management of protected areas with regard to climate change, we follow the course of this model cascade and make various underlying assumptions and models transparent.

5.2.1 Climate Models

Some prior steps are necessary for regional climate change impact projections. A big challenge for earth system analysis was to understand the interplay between human activities, greenhouse gases, and the climate system of the earth (IPCC 2007). The higher the concentration of greenhouse gases, the higher the energy of the atmosphere is. This results in higher global mean temperatures and subsequently increased global evaporation. Here, the model cascade starts (Fig. 5.1). Each model type builds at least partly on physically based assumptions, hypotheses and input data from prior cascade results (Table 5.1). In the Special Emission Scenarios (SRES; Nakićenović and Swart 2000) projections about the future development of earth's population with regard to population numbers, economic development, energy sources etc. were developed. According to these scenarios (e.g. B1, A2 etc.) concentrations of greenhouse gases are projected. This provides input for global circulation or climate models (GCMs). These global models normally work on a global grid (e.g. at the resolution of 50×50 km^2).

For a park manager, a 50×50 km^2 resolution is far from being useful for management adaptation. For example, in mountainous regions with climate variables differing at a small scale a resolution of several hundred metres is required to be helpful. Currently, there are two alternative model approaches to derive more regional and local resolutions. It is possible to downscale the results from global models dynamically to a resolution of 10×10 km (0,08°), an option chosen by the Max Planck Institute for Meteorology in Hamburg with the climate model REMO (Jacob and Podzun 1997). Alternatively, statistical regional climate models scale down trends from global climate models based on data from local weather stations and only include the global temperature trend as a parameter. This is how regional climate models such as STAR or WettReg work (Orlowsky et al. 2008). While the latter reflect the local conditions more precisely, the former has the advantage of also including new climatic conditions and long-term developments.

However, most park managers focus on living organisms, mainly plants, where temperature and precipitation alone are not sufficient parameters to identify climate change impacts. A more useful integrated indicator is the climatic water balance (CWB). The CWB expresses the difference between precipitation and potential evaporation. In the framework of the HABIT-CHANGE project, climate change projections have been provided for all the investigation areas (Stagl et al. submitted). In Fig. 5.2 the results are displayed via boxplots for two selected investigation areas for three time periods: (a) For the Natural Park Bucegi (Romania) the climate models indicate, despite the existing inter-model uncertainties, a clear trend towards a reduction of potential water availability for the

Table 5.1 Model assumptions, hypothesis and data along the model cascade

Model type/ focus	Greenhouse gas development	Global climate change	Regional climate change	Hydrological climate change impacts	Climate change impacts on vegetation	Climate change impacts on animals
Assumption/ hypothesis/ mechanism	Population growth, economic growth, use and consumption of fossil fuels, deforestation	Increasing green house gases	Regional modification of global trends by land surface	Climate, soil, and vegetation impacts the water cycle	Distribution and physiology of plants determined mainly by solar energy, temperature and moisture	Distribution of animals determined mainly by temperature and moisture
Model/tool	(Extrapolation of greenhouse gases)	Global Circulation Models (GCMs)	Regional Climate Models (RCMs)	Hydrological models	Statistical models (e.g. bioclimatic envelope modelling (BEM)), artificial neural networks (ANN); dynamic models	Statistical models (e.g. bioclimatic envelope modelling (BEM); artificial neural networks (ANN); distribution (absolute, relative) of species
Data	Greenhouse gas concentration	Global temperature, precipitation etc. mainly at 50 × 50 km grid	Regional temperature, precipitation etc. down to 1 × 1 km	Soil water, run-off, groundwater recharge at the catchment scale	Distribution (absolute, relative) of plant functional groups and/or species	Distribution, abundance
Examples	SRES-Scenarios	ECHAM, NCAR PCM, CSIRO, Hadley	REMO, STAR, WettReg	SWIM, SWAT	BIOMOD; LPJ GUESS	BIOMOD
Literature	IPCC 2000 Special Report on Emission Scenarios (SRES)	Wilby and Wigley (1997) and Gleckler et al. (2008)	Christensen and Christensen (2010)	Krysanova et al. (2000)	Kühn et al. (2009)	Lawler et al. (2009)

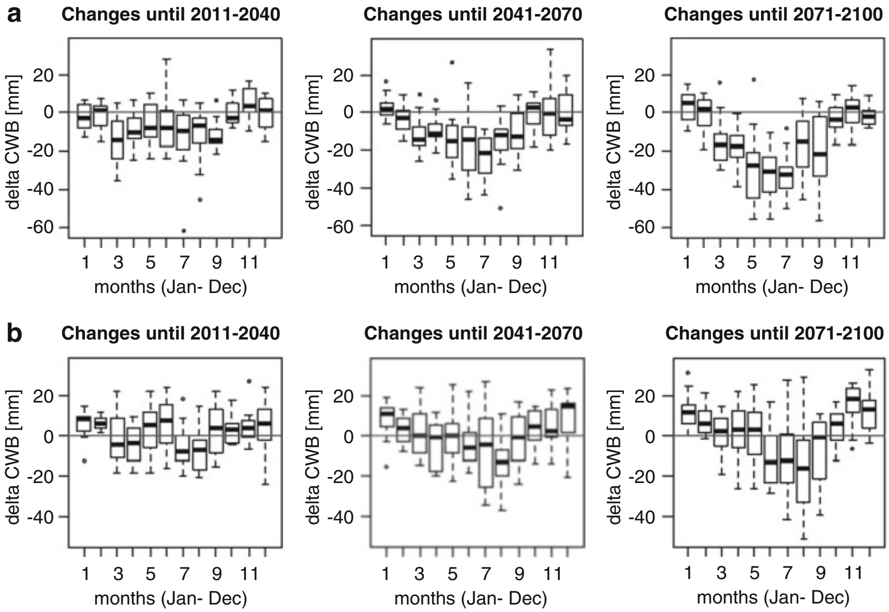

Fig. 5.2 Changes of Climatic Water Balance (*CWB*) as integrated climate change indicator for the area (**a**) Natural Park Bucegi (Romania) and (**b**) Vessertal – Thuringian Forest Biosphere Reserve (Germany). The graphs show the projected changes in the CWB as a multi-model box-whiskers plot for the years 2011–2040, 2041–2070 and 2071–2100, in each case relative to 1961–1990 (absolute differences in mm), for the A1B greenhouse gas emission scenario. The boxplots show the changes simulated from an ensemble of 14 different GCM-RCMs combinations (provided by ENSEMBLES project (van der Linden and Mitchell 2009)) and the variation between the model results. For each month the box depicts the lower and the upper quartile (25th to 75th percentile) of the spread and the *thick black line* stands for the median value. The whiskers show the maximum and minimum value of the model spread (except outliners (*black dots*)). The Climatic Water Balance is calculated by the method described in Sect. 3.3

months March to September, but particularly in summer. (b) For the area of the Vessertal – Thuringian Forest Biosphere Reserve (Germany) the model results spread is more pronounced, as indicated by longer boxes and higher variance. More than 50 % of the RCM-GCMs results indicate a trend for a CWB decrease in summer and a slight increase of the CWB in the winter months. The figures do not only show the directions of changes which should be considered but also indicate the uncertainty assigned to the choice of a model.

5.2.2 Hydrological Models

The CWB is an indicator which is directly calculated from climatic data; it does not consider local physio-geographical parameters like soil conditions or the influence of the vegetation. To consider supplementary parameters, hydrological process-based models support understanding of the behaviour of hydrologic systems as a response to climate change. Such models include evapotranspiration, surface run-off, subsurface and interflow, and river channel flow. For HABIT-CHANGE the hydro-ecological model SWIM (Krysanova et al. 2000; Hattermann et al. 2008) was applied. SWIM is a hydrological model at the scale of a catchment area (for details refer to Chap. 3). It integrates relevant hydrological processes to investigate the impacts of climate changes, such as water percolation, groundwater recharge, plant water uptake, soil evaporation, and river routing. SWIM allows the development of scenarios, for example, with a focus on the habitat type, and it provides information relevant to vegetation dynamics, i.e. the available soil water (Holsten et al. 2009). However, model results rely strongly on the quality and the resolution of the input data (like observed runoff, soil and land use data) for the specific investigation area.

5.2.3 Modelling Distribution and Occurrence of Plants and Animals

While the projection of potential impacts of climate change on water resources is very helpful and can be linked to specific management options, many protected areas aim to conserve specific plants or animals. Most modelling work to assess the potential impact of climate change on biodiversity relies on habitat modelling of plants and animals, and provides risk assessments for specific species or habitats (Normand et al. 2007; Hickler et al. 2012). Most of these approaches use statistical approaches, such as Bioclimatic Envelopes (BEM), and do not consider functional relationships, as, for example, with dynamic vegetation models (DVMs). Although DVMs are able to analyse changing patterns of competition their disadvantage is that they are resolved either at the basis of plant functional types or selected (tree) species (Kühn et al. 2009; Bellard et al. 2012). An additional uncertainty arises from other model shortcomings, e.g. the adaptive capacity of single species or species associations possibly being underestimated (Thuiller et al. 2008; Fordham et al. 2012).

When focusing on nature conservation issues the impact of climate change alone would not be so extensive if habitat destruction and fragmentation were not so widely advanced permitting species to adapt their distribution area (Opdam and Wascher 2004). The inclusion of land use parameters improves model results significantly.

So far, the major outputs of modelling the impacts on plants and animals (fungi are not yet a focus) are limited to projected changes in probabilities of occurrence. Furthermore, plants, animals, and fungi represent only a specific hierarchy or scale of biodiversity and nature conservation goals. Climate change affects biodiversity on different scales from changing mutation rates of genes and phenology to energy fluxes and ecosystem services (Vohland 2008; Bellard et al. 2012).

5.3 Reflection About the Role of Modelling in Conservation Management

Models are by definition simplified descriptions of reality. They have to neglect information and processes that are considered irrelevant for the modelling purpose. It is critical to realise "that model output is not the same as empirical data, and that modelled projections of the future contain significant uncertainties" (Hansen and Hoffmann 2011). These uncertainties derive from lacking or unsuitable data, measurement errors, or systematic mistakes in the data acquisition (Price and Neville 2003; Willis and Birks 2006). But even the simplified structure of models may result in uncertainties of results that have to be illustrated by the modellers. Modelling the complexity of biological systems and their interaction with management is a challenging task (McKenzie et al. 2004). Natural systems are characterised by system inherent variation. This makes it hard to identify signals of relevant effects from background noise of usual fluctuations (Hakonson 2003). An additional source of uncertainty derives from subjective interpretations. In an impressive selection of models developed and applied for environmental management, Pilkey and Pilkey-Jarvis (2007) prove how the selection of input data and interpretation of thresholds, system behaviour, as well as modelling results corrupts their usability in management. In this context transparency of modelling work is a prerequisite for the use of results in the decision-making context.

In consequence, modelling results can include a wide range of sources of uncertainty. This is especially true when results are built on a cascade of coupled models in a 'model chain' since all models add their own uncertainty to the overall results.

An important approach to handling uncertainty in model output is the quantification of uncertainty levels in results (see Ayala 1996; Bugmann 2003; Oreskes et al. 1994; Sarewitz and Pielke 1999). Yet, practical work with modelling results shows that quantification of uncertainty is no easy task. This is even more so as the validation of modelling results for complex systems, particularly with regard to predictions about long term future developments, involves major theoretical problems (Harris et al. 2003; Oreskes et al. 1994; Oreskes 2003; Sarewitz and Pielke 1999). Even if models have successfully simulated past or present changes this does not guarantee that they are also able to predict future changes, e.g. if the earth climate system and its biodiversity are pushed into unprecedented conditions in the context of climate change (Hansen and Hoffmann 2011).

As a first consequence, a cautious use of modelling results for decision-making is recommended (Millner 2012). Uncertainty must be considered when using modelling results for management decisions.

The gap between modelling and management issues is attributed to the different objectives of (natural) sciences and decision-oriented management. According to Opdam et al., the analytical and reductionist approach of scientific work is able to provide clues on driving forces and key elements, but lacks the ability to provide solutions and foster decisions if they are not especially tailored to do so (Koomen et al. 2012; Opdam et al. 2009). Further problems arise from the usual procedures of modelling and the integration of stakeholders and decision-makers. Relevance, legitimacy, and transparency are considered key aspects for the acceptance and implementation of scientific results (Meinke et al. 2006). Before modelling efforts are started, existing knowledge should be examined to determine whether it is sufficient to support decisions and how the existing information can be translated to the relevant decision-making context.

Modelling efforts use a lot of valuable resources for data acquisition, processing, model development, calibration, and validation. Usually these resources can be acquired in relation to research projects, but the limitation of resources must be considered if modelling approaches and procedures are transferred to a permanent task like conservation management. In the field of conservation management resources, whether manpower or budget, are chronically scarce and their use must yield the best possible output. Consequently, it is crucial to move modelling work beyond pure prediction (Dawson et al. 2011) and strengthen its integration in risk assessment, protocols of screening and monitoring, and integrated management in protected areas (Bellard et al. 2012). If modelling is to be integrated in management it must be based on an evaluation of the information need in protected areas. An assessment of its use in the management process must be done in order to guarantee maximum usability. The discussion of modelling goals and expected results will also guarantee the relevance and legitimacy of modelling endeavours. There is no doubt that modelling can provide various benefits for conservation management; however, the objectives of nature conservation need to be considered in modelling design, development, and presentation of results. Modelling for conservation management can be useful to:

- Structure the discussion about problems at hand and help develop hypotheses on consequences.
- Identify driving forces and hot spots where action is needed.
- Provide efficient and effective indicators to identify and monitor changes.
- Identify critical changes and thresholds to trigger action.
- Illustrate consequences of management options.

5.4 Developments for the Future

Understanding the interrelation between management measures and the impact of climate change is an important task for modelling in conservation management. This should allow the testing of hypotheses and the identification of alternatives in management. As a result, modelling that can be effectively used in the management of protected areas should take management options into account and provide possibility to project different future developments with regard to conservation strategies.

Model development needs to be done in cooperation with local management and stakeholders to guarantee transparency of models and their results. One possibility is a formalised co-production of knowledge. Experiences from visualisations of climate change effects have shown that stakeholder involvement should be considered at least (Pond et al. 2010):

1. when goals and objectives of modelling are discussed;
2. when alternatives are identified that need to be considered and
3. when results are assessed and discussed to derive consequences for management.

This general concept could also give guidance for the use of modelling in conservation management.

5.4.1 The Use of Models for Scenarios

Peterson et al. (2003) have suggested different methods to handle uncertainty in decision-making. To make decisions and plan for uncontrollable situations characterised by high uncertainty, the use of scenarios is often suggested (Peterson et al. 2003). Consequently, models in earth sciences are often used to simulate scenario results (e.g. GCMs). Several authors have also suggested using scenario approaches to handle uncertainty in conservation management and provide robust adaptation strategies (e.g. Julius and West 2008).

Scenarios as such are meant to project potential alternative developments. They should help managers identifying potential future situations and answer the question 'What do we do if this event, trend, or change happens?' Hence, scenarios are not meant to represent the most likely or even preferred development (Sträter 1988). They should prepare managers for a multitude of future situations. In most cases rare and unlikely extreme scenarios can help foster preparation for the unexpected better than mainstream scenarios or business-as-usual projections. In the context of scenario work models can be used to project system behaviour in response to different developments (e.g. increase or decrease of annual precipitation). Identifying relevant developments and transferring them to projections is of high importance for the process. A good scenario needs to be "carefully researched, full of relevant detail, oriented towards real-life decisions, and designed (one hopes) to bring forward surprises and unexpected leaps of understanding" (Schwartz 1992: XIIV).

Godet (2000) has suggested five criteria for a good scenario:

- It needs to be oriented to the problem at hand.
- It needs to be relevant for the questions of decision-makers.
- It needs to be coherent in itself.
- It needs to build on plausible assumptions.
- It needs to be transparent to the users.

Scenario development is regarded as supporting decision-making in situations with high uncertainty. Nevertheless, scenarios rarely provide sufficient decision support in complex situations. Decision makers are trained neither to analyse the different outcomes of climate impact modelling nor to develop management scenarios under the conditions of climate change. Hence, the adaptation of management needs to be included in a broader assessment framework to be useful in a decision-making context. This framework should comprise methods to compare scenario results as well as methods to evaluate options and prioritise actions. Risk management is suggested as one tool to provide this framework (e.g. Rannow 2011, 2013; Lorenzoni et al. 2005; Willows and Connell 2003). 'Stress tests' that help to identify critical changes and thresholds for resilience of ecosystems might be another tool (Brown and Wilby 2012).

5.5 Conclusion – How to Deal with Models?

Including the results from modelling climate change impacts can be important and provide a useful instrument to highlight possible negative impacts of climate change, especially when analysed in combination with land use change and degradation, as well as assessing the consequences of different management options. However, modelling results can only support the decision-making process in combination with other methods. Models cannot be better than their input data. If the density of climate stations and temporal resolution is very low or if the functional relationships are unknown, models might show up with numbers but they cannot be interpreted properly. At the local scale the identification of key parameters is complicated and should be done in cooperation with protected area managers as well as local experts. A special challenge in modelling is reflecting user needs and ensuring the applicability of results for decision-making and adaptation of management.

Consequently, modelling results on local to regional scales are accompanied by high uncertainties. These uncertainties must be taken into account and treated accordingly when management decisions are based on modelling results. This is best done through the joint development of management scenarios that include the whole spectrum of climate change impacts. The definition of relevant scales for decision-making and the acceptable limits of uncertainty must be considered a prerequisite for this. Uncertainty of facts should not corrupt decisions and needs to be separated from uncertainty of decisions. Models should be included in a wider framework to make them useful for the decision-making process in conservation management. Risk management, no-regret measures, and adaptive management have great potential to foster the profitable application of modelling results in conservation management. However, it should be emphasised that projections based on computer models are not the only option to prepare for climate change and support decisions for adaptation actions. Analysing and mapping sensitivity might be a useful method to identify driving factors, thresholds for resilience and management options even when results from climate models or detailed model based analysis are missing, as illustrated in Chap. 8.

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