The cascade of uncertainty in modeling forest ecosystem responses to environmental change and the challenge of sustainable resource management

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Abstract

Increasing human activities have triggered environmental changes. These threaten the life-supporting systems that thus far have enabled continuous improvement of humanity's living conditions. Projecting the effects of environmental change on social-ecological systems is a crucial component of sustainability science and a cornerstone for the sustainable management of natural resources. Such projections rely on models and modeling chains. In climate change impact assessments, such a modeling chain reaches from socioeconomic scenario modeling through General Circulation Models to impact and management/policy models in specific sectors. At each modeling step, model-specific uncertainties about parameter values, input data or structure accumulate and lead to a cascade of uncertainty. In past impact assessments such as those presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, these uncertainties have only been partly considered. This has cast doubt on the robustness of scientific findings. Therefore, it is crucial that current uncertainties about management-relevant scientific findings are appropriately assessed since decision-makers need to base their decisions on the best-available knowledge.

The aim of this thesis is to explore the cascade of uncertainties in responses to environmental change in a structured way at the example of forest ecosystem modeling. This leads to two overarching research questions:

1. How do different types of uncertainties affect projections of the effects of environmental change on forest ecosystems?
2. What is the general framework of sustainable natural resource management in coupled social-ecological systems in which uncertainties need to be integrated?

I addressed these questions by combining quantitative and qualitative research. Firstly, I applied the process-based forest growth model 4C to forest stands across Europe (chapters 3-5). Secondly, I synthesized a large body of scientific literature to develop novel frameworks for characterizing specific types of uncertainties (chapters 2 and 6) and for describing the wider framework in which uncertainties have to be included to enhance the sustainable management of natural resources (chapter 7).

This thesis shows that forest productivity under climate change may increase in cool and wet regions and decrease in already warm and dry regions. These findings are robust despite large differences in model structure (chapter 2), climate change scenarios (chapter 3) and model parameters (chapter 4) that induce considerable uncertainty into future projections. It also stresses that there are methods available to assess uncertainties (chapter 5) but also that many climate change impact studies in forests have focused on testing the response of plants to changes in mean climate rather than climatic extremes (chapter 6). The latter may however ultimately shape the responses to climate change in reality. Finally, this thesis shows that adaptive, cross-sectoral natural resource management strategies exist that accommodate uncertain impacts of environmental and societal change and foster sustainable regional development (chapter 7).

I conclude that the cascade of uncertainty challenges sustainable natural resource management and that a more systematic treatment of uncertainties is strongly needed to generate robust projections of the impacts of environmental change on natural resources. The findings of this thesis provide a general framework in which both modelers and decision-makers can integrate model results and assess their robustness. This work ultimately contributes to science-based adaptive management and learning that are an integral part of the transformation toward resilient and sustainable social-ecological systems.

Keywords: Adaptation, Climate change, Environmental change, Forest ecosystems, Impact studies, Global Change, Models, Uncertainty, Sustainable resource management, Vulnerability