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Review

Climate change and European forests: What do we know, what are the uncertainties, and what are the implications for forest management?

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ABSTRACT

The knowledge about potential climate change impacts on forests is continuously expanding and some changes in growth, drought induced mortality and species distribution have been observed. However despite a significant body of research, a knowledge and communication gap exists between scientists and non-scientists as to how climate change impact scenarios can be interpreted and what they imply for European forests. It is still challenging to advise forest decision makers on how best to plan for climate change as many uncertainties and unknowns remain and it is difficult to communicate these to practitioners and other decision makers while retaining emphasis on the importance of planning for adaptation.

In this paper, recent developments in climate change observations and projections, observed and projected impacts on European forests and the associated uncertainties are reviewed and synthesised with a view to understanding the implications for forest management. Current impact assessments with simulation models contain several simplifications, which explain the discrepancy between results of many simulation studies and the rapidly increasing body of evidence about already observed changes in forest productivity and species distribution. In simulation models uncertainties tend to cascade onto one another; from estimating what future societies will be like and general circulation models (GCMs) at the global level, down to forest models and forest management at the local level.

Individual climate change impact studies should not be uncritically used for decision-making without reflection on possible shortcomings in system understanding, model accuracy and other assumptions made. It is important for decision makers in forest management to realise that they have to take long-lasting management decisions while uncertainty about climate change impacts are still large. We discuss how to communicate about uncertainty – which is imperative for decision making – without diluting the overall message. Considering the range of possible trends and uncertainties in adaptive forest management requires expert knowledge and enhanced efforts for providing science-based decision support.

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1. Introduction

More than twenty years of climate change impact research have improved our understanding of the climate system (Krupa and Kickert, 1989; Solomon et al., 2007; Rummukainen, 2012) and its impact on ecosystems. While a new set of climate change projections have been made available for the Fifth IPCC Assessment Report (van Vuuren et al., 2011), most impact assessments are still based on the previous generation of climate change projections of the Fourth IPCC Assessment Report (Christensen et al., 2007). These scenarios have now been around for several years, however a knowledge and communication gap still remains as to how these climate change scenarios can be interpreted and what they imply for European forestry.

The knowledge about potential climate change impacts on European forests is continuously expanding (Lindner et al., 2010; Campioli et al., 2012; Hlásny et al., 2012; Spathelf et al., 2014) and some changes in growth (Piao et al., 2011; Sánchez-Salguero et al., 2012), drought-induced mortality (Allen et al., 2010), and species distribution (Delzon et al., 2013) have already been observed. However, it is still challenging to advise forest decision makers on planning for climate change impacts (Ogden and Innes, 2009; Peterson et al., 2011). Many uncertainties and unknowns remain (Millar et al., 2007; Yousefpour et al., 2012) and it is difficult to communicate these to practitioners and other decision makers while retaining emphasis on the importance of planning for adaptation (Spittlehouse and Stewart, 2003).

Because of resource and time limitations, many climate change impact studies focus only on a small selection of climate change scenarios instead of providing a full suite of possible futures, and the chosen scenarios often vary between alternative impact assessments. Practitioners and other decision makers often lack the expertise to understand why different studies yield differing and sometimes conflicting results. Observations of adverse climate change impacts have been increasingly reported over recent years (e.g. Sánchez-Salguero et al., 2012; Rigling et al., 2013; Ruffault et al., 2013). In contrast, the majority of published model simulations of climate change impacts indicate increasing productivity and larger carbon stocks compared to the baseline climate (Reyer, 2013). There could be several explanations for such deviations between observations and simulations. For example, the environmental conditions at the sites with adverse observed climate change impacts could differ from those where the models have been applied. Another possible explanation could be that the critical factors leading to the observed impacts, especially when extreme events are involved, are not well represented by the simulation models. Identifying the reasons for the deviations between model results and observed growth responses to climate change is crucial, as we often rely on model projections to explore future climate change impacts. Communicating the uncertainty around climate change impacts without diluting the message is a difficult task. There are many sources of uncertainty including those originating from future climate, from the sensitivity and response of forests, from simulation models, and from non-climate factors such as invasive exotic species or pests influencing climate change impacts (Reyer, 2013; Fischer et al., 2013).

The objective of this paper is to analyze and synthesize scientific knowledge as a basis of offering decision support to practitioners and decision makers in forest management. Regional climate projections for Europe are discussed and recently observed changes in mean climate variables as well as in climate extremes are described. Observed and projected climate change impacts on European forests are summarized and a description of the inherent uncertainty in climate change impact modelling is presented. The interpretation and communication of state of the art knowledge to non-scientific audiences is also discussed. This work should assist decision makers and practitioners in interpreting and responding to observed and projected climate change, its impacts on forestry and its implicit uncertainties.

2. Regional climate change projections – mean trends and extremes

Several limitations apply when using climate models to understand the likely effects on forest ecosystems. First, general circulation models (GCMs) project future climate for very large pixels, which are far too big to make a meaningful statement about the local climate relevant to single forest stands or local management decisions (Flint and Flint, 2012). Downscaling is necessary, but adds inherent uncertainty to the values obtained from such scaling exercises (Fowler et al., 2007). Second, forests do not respond linearly to changes in climate parameters such as annual temperature and precipitation (Stephenson, 1990), which are often used when communicating climate scenario results to decision makers. Third, climate model results vary much more at regional compared to the continental and global level. Average ensemble climate data should not be interpreted as the most likely scenario at the regional level because in reality, climate change will not happen uniformly across the continent. Depending on the (unpredictable) future location of atmospheric circulation patterns there will be regions with lower and higher temperature and precipitation changes. Therefore, using mean trends in these two variables from many models, before translating them into meaningful predictors, does not allow one to fully understand the range of likely impacts. Ensemble mean climate data always extenuate the possible regional climate change. Rather, one has to downscale all models individually, for all climate variables, generate physiologically meaningful variables thereof for each model output, and only summarize in the form of ensembles the forest response to climate change. This is a very time consuming task, yet necessary to see the full picture of likely responses. Fourth, forests only partly respond to changes in climate means. Many responses are to extremes rather than to means (Reyer et al., 2013b), and therefore, larger uncertainties in the projections of climate extremes cause considerable uncertainties when assessing the likely response of forest ecosystems towards the end of the current century. Finally, every species, and every life stage of each species responds differently to changing climate variability. While all will respond to some extent to a general increase in temperature and a regional increase or decrease in precipitation, the climate seasonality with its seasonal shifts in extremes will very differently affect the

Table 1
Mean climate trends for the period 2051–2080 for European regions from six RCMs compared to the period 1951–2000 (see Supplementary material, Table S.1).

	Northern Europe	Central Europe	Southern Europe
Summer temperatures	+1.5–2.6 °C higher in NE	+1.3–2.7 °C higher towards S and E	+2.6–4.1 °C higher away from coasts
Winter temperatures	+2.5–4.2 °C higher in NE	+1.5–3.5 °C higher in E and mountains	+2.0–2.8 °C consistently all over
Summer precipitation	+0-25% increase higher in NE	−0–25% reduction higher in W and S	−25–50% reduction higher in S
Winter precipitation	+5–40% higher in N and mountains	−10–+15% reduction in W and S	−35–+15% reduction in S and W