Expert Assessments of the Likely Impacts of Climate Change on Forests and Forestry in Europe

Seppo Kellomäki, Timo Karjalainen, Frits Mohren and Tuija Lapveteläinen (eds.)

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University of Wageningen, The Netherlands

JOENSUUN YLIOPISTO

University of Joensuu, Finland

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Editorial Office: European Forest Institute
Torikatu 34
FIN-80100 Joensuu, Finland
Phone: +358 13 252 020
Fax. +358 13 124 393
Email: publications@efi.fi
WWW: http://www.efi.fi/

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H. Spiecker[1], M. Lindber[2] and H.-P. Kahle[1]

[1]University of Freiburg, Institute for Forest Growth, Freiburg. Germany
[2]Potsdam Institute for Climate Impact Research, Potsdam, Germany

Current key sensitivities to weather and the mechanisms limiting forest regeneration and growth

Forest growth conditions in Germany are quite heterogeneous. Climate strongly differs from the lowlands in the North to the mountainous terrains in the South, and there is a distinct continental gradient with decreasing precipitation from West to East. Beside these mesoscale differences climate varies considerably with geomorphological conditions. There are few climate driven zonal distribution limits of tree species in Germany. One example is the northeast continental limit of European beech (*Fagus sylvatica*) in Northeast Germany. Another one is the northern limit of *Quercus pubescens* in Southwest Germany. The altitudinal vegetation zones includes zones from the altitudinal treeline in the Alps to thermophile deciduous forests in the river valleys. The natural forest composition has changed on a large scale because of intensive human activities over several centuries. Today, most of the forests are intensively managed.

In their natural environments trees have always been subject to shifting multiple stresses during their lifetime as well as during their annual growth cycle. The main physical climatic factors limiting forest growth in Germany are (in order of importance): (1) storm (branch, crown and stem breakage, windthrow, transpiration stress, needle/leaf loss), (2) snow (branch, crown and stem breakage), (3) (late-) frost (damage to buds, to leaves/needles, to roots, to stem/cambium), (4) water shortage/drought (transpiration stress, desiccation, damage to leaves/needles, abscission, damage to roots, xylem embolism), (5) hail (damage to leaves/needles and buds).

The following physical climatic factors are the key factors limiting forest regeneration in Germany: (1) light availability (shading mainly due to stand canopy closure), (2) frost, (3) water shortage/drought, (4) nutrient availability.

Management of forests (regeneration methods, tending, thinning and regeneration cuttings) has a decisive impact on forest regeneration. Moreover, interactions between physical climatic factors and other abiotic and biotic environmental factors have to be considered, e.g. processes in the soil and humus layer affecting water and nutrient availability, population dynamics of herbivores and pathogens, rates of and exposure to atmospheric pollutants.

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Due to the diversity of forests in Germany, the order of importance of the key sensitivities of growth and regeneration to weather and climate largely varies according to tree species, the developmental stage, site conditions, stand conditions, intensity and duration as well as temporal and spatial variation of climatic stresses, preconditioning (e.g. flowering, seed production), and predisposing factors (multiple/chronic stresses) like atmospheric deposition, and air chemistry.

Key impacting aspects of climate change in the future

A quantitative assessment of the likely climate change impacts at the national scale is difficult for several reasons. The impacts of climate change on forest ecosystems strongly depend on:

- *the rate of change in the climate:* If climate changes at a rapid rate relative to the speed at which forest species grow, reproduce and adapt and at which forest stands re-establish, the impact will be much more severe.
- *the magnitude of change in climate means and climate extremes:* There is high uncertainty in the prediction of the frequency and magnitude of climate extremes. Today, climate extremes are the key impacting factors on forests in Germany.
- *the regional characteristics of the future climate:* The regional resolution of climate projections is very coarse. There is still considerable uncertainty associated with the future precipitation regime. Regional impacts of climate change may point in different directions (e.g. positive in high elevations and negative in water limited ecosystems).
- *the stability, vulnerability and adaptive potential of the particular forest ecosystems:* In Germany some species, e.g. Norway spruce (*Picea abies*), have been planted on large areas and sites outside their natural range. These forests will be particularly susceptible to climate warming, because they often are growing at their tolerance limits with respect to water availability and thus have a low adaptive potential to climate change.
- *the combined effects of multiple climate change factors on forest growth:* Different global change factors may cause contrasting growth responses. For example, the effect of increasing CO_2 concentration is likely to stimulate growth, but the impact of changing temperature and precipitation may be either positive or negative. Different climate change factors may interact/counteract growth, e.g. increased transpiration demand under climate warming could partly be offset by increased water-use efficiency associated with CO_2 fertilization.

Nevertheless, it is possible to identify some general trends at the regional scale:

- The projected increase in temperature may threaten drought sensitive forest ecosystems in Germany, especially spruce dominated stands outside their natural range. It is rather unlikely that the change in precipitation and the increased water-use efficiency associated with CO_2 fertilization will fully compensate for the increasing atmospheric transpirative demand, because the observed increase of annual precipitation in the 20th century was associated with a seasonal shift of precipitation to the winter months.
- In higher elevations the projected climate change will likely have mainly positive effects on growth except on wind exposed mountain ridges where desiccation may occur. Climate change will lift the cold distribution limit of tree species further up to higher elevations. However, natural succession will probably require numerous tree generations to shift the climax species composition in high altitude forest ecosystems. Since there is nowhere to migrate, remaining natural forest ecosystems at the top of the mountain ranges will be endangered.

From past observations we know that on many central European sites growth responses of major forest tree species towards the inter-annual variability in water availability are similar, and more or less independent of the mean climatic conditions at the particular sites. This indicates that tree populations have adapted to local site conditions. Therefore, changes in climatic growth factors could have a widespread impact on forest growth.

Most vulnerable regions

The most vulnerable regions in Germany are those where in the summer months moisture availability for forest stands is already limited under present site conditions. From a geographical point of view these are especially the warm and dry lowlands in Northeast and Southwest Germany. Topographically sensitive sites are those where exposure to insolation and wind enhances evaporative atmospheric demand. From the pedologic point of view shallow soils on mountain ridges and steep slopes as well as sandy soils in plateau regions are most sensitive to increased drought stress on forest stands.

Pine plantations in dry regions have an especially high risk of forest fires and insect infestations. Spruce plantations outside their natural range may also be considered to be vulnerable to insect attacks in dry years.

Impacts of climate change on management

Climate change will have profound impacts on forest management in Germany. Since growth development of forests under changed climate conditions may differ from past observations higher uncertainty and additional risks will be involved in forest management.

Regeneration: The cultivation suitability and thus the choice of species and provenances will be affected at least in those regions where drought stress increases. Regeneration and growth of young stands will be adversely affected by increased weed competition under increased temperatures and increased site fertility.

Thinning treatments: In order to account for increasing growth rates, the cutting rates need to be increased. The timing of thinnings needs to be adjusted to altered growth dynamics. This will have special importance in mixed stands where climate change may change the growth relations between species.

Harvesting: Rotation length and harvesting strategies may need to be handled in a flexible and adaptive way in order to respond to, e.g., possible insect attacks or dieback after drought. However, due to accelerated growth the rotation lengths can be shortened while producing similar dimensions. The introduction of new tree species can also require the modification of harvesting regimes.

Timber supply: The effects on the dimension and quality of timber very much depends on thinning intensity and rotation length. The increasing forest site productivity observed during the last decades allows for higher cutting rates and leads to increased timber supply. The transformation of non-suitable mono species forest stands, into site adapted mixed forests will lead to a transitory increase in the harvesting quantities of these species.

Main adaptive options available

The main management options available to mitigate effects of climate change on forest growth and forestry in Germany are: (1) selection of site adapted species and provenances,

(2) change in species composition towards an increase in the percentage of mixed forests, (3) intensified tending and thinning, (4) adaptive thinning and harvesting strategies, (5) managing the regeneration phase in respect to weed control and species composition, (6) shortening of rotation length.

The current trend towards mixed forests with more natural species composition is an adaptive measure to climate change, because the mixture of species reduces the risk of dieback at the stand level. Furthermore, modern silvicultural strategies, which aim at increasing structural diversity in the forest stands, improve the adaptation potential of the stands and increase the choice of management options. Increasing diversity at different hierarchical levels from the forest stand to the forestry district is another adaptation option for reducing risks of large-scale forest dieback.

Main implications for other sectors and other trends

Increased forest site productivity allows for higher cutting rates and leads to higher wood supply. The expected increase in the percentage of sanitary cuts may change markets in an unpredictable way. In general, the implications for other sectors will not be very large within the next 30–50 years. Altered management strategies will influence the amenity values of forests and biodiversity in forest ecosystems. The implications for ground water resources will probably be dominated by the direct impacts of the changing climate. Ground water replenishment could be reduced because of increasing evapotranspiration in the vegetation period. On the other hand, an increasing share of deciduous species may slightly increase ground water recharge.

Main uncertainties and unknowns

The main uncertainties are caused by limited climate prediction capabilities (e.g. frequency and intensity of extreme events, regional climate change scenarios). Only limited knowledge is available about the adaptability of existing forests to climate change. Research is needed to assess the adaptation potential of different species and provenances, of stands of different species compositions at different ages and with different competition/growth histories under site conditions differing in soil moisture storage and nutrient capacity. In addition, research is needed in forest management to develop response strategies, which incorporate risk assessments and uncertainties.

Main policy implications

The main climate change implications for forest policy are characterized by management under risk and uncertainty. Flexible management strategies, adaptive to the local situation and to changes in time are needed and have to be introduced as a continuous process into management activities.

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