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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Preface

This publication provides a generalised assessment of the likely impacts of climate change on forests and forestry in Europe. The analysis is based on the judgements by experts representing different parts of Europe. The expert assessments provide an outline of how the climate change may affect productivity, timber supply and management of forest resources, and the implications for environmental policies. Country-specific reports and expert judgments prepared by the contributing authors are available in Part II.

It is our pleasure to acknowledge all the contributors and to thank them for the smooth collaboration and the work that they conducted in assessing the likely impacts of climate change on European forests based on pieces of scientific knowledge still far from complete. We would also like to thank Dr Greg Watson for editing the language of these proceedings.

Joensuu and Wageningen, June 2000

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Part I: General Assessment

General Assessment

Summary

- The genetic variability of most common tree species is probably large enough to allow them to acclimatise to average changes in temperature and precipitation. However, in the Mediteranean region and continental Europe, increased droughts and forest fires may be the major risk for forests. In western Europe, drought and fire risks will also be increased. In northern Europe, increased precipitation will be large enough to compensate for increased evapotranspiration, and there seems to bee no major risk for the existence of forests.
- An increase in growth has been recorded in some coutries like Austria, Norway, and Germany. The climate change with its increased CO_2, the increased nitrogen deposition, and changes in management practices are assumed to be behind this increased growth. The tree species composition may turn into a higher dominance of deciduous tree species, even in northern Europe, where coniferous species currently dominate.
- In northern Europe, the preference for natural regeneration in management provides huge genetic potentials for forests to adapt to the climate change. In other parts of Europe, increased droughts may result in uncertainties in natural regeneration. In these conditions, the preference for a tree provenance of more southern origin and wider spacing in plantations may reduce the impacts of the climate change. Throughout Europe, regular management with shorter rotation enhances the turnover of the current tree populations with a faster introduction of more resistant tree species and provenances into forests.
- Insect and pest populations are expected to increase but the extent to which they may be controlled by natural enemies or if they require management control is not known. Currently, non-damaging organisms may reach pest level and invading species may be dangerous. Conditions favouring the spread and epidemic status of pathogens are also poorly known. Interactions with wildlife generally, and effects on biodiversity, are poorly known.

Keywords: climate change impacts, Europe, forest, forestry

1. Introduction

1.1 Forests in Europe

The forests in Europe span over three bioclimatic zones; i.e. from semiarid in the south (Mediterranean region) through temperate (western and central Europe) to cool (northern Europe) (Figure 1, Table 1). On a south-north gradient this implies decreasing temperature and increasing humidity, with a decreasing water limitation and increasing temperature limitation for forests. On a west-east gradient, the maritime climate turns to the continental one with decreasing humidity and increasing water limitations for forests. Following the current temperature and humidity gradient over Europe, the forests of Europe in this review are divided into the Boreal forests (boreal zone), the Atlantic forests (humid temperate forests), the Continental forests (dry temperate forests) and the Mediterranean forests. Note that Boreal forests in this study (Boreal) is equal to the forest in the European part of the boreal zone. Temperate forests in central Europe are divided into Atlantic and Continental forests with the emphasis in the differences being in the availability of soil water. The Mediterranean forests represent the forests in the dry temperate zone in the Mediterranean Basin.

The area of forest land in Europe is 175.7 million hectares according to recent UN-ECE/FAO report (2000), of which 58.3 million hectares are in Nordic countries, 63.6 million hectares in Central Europe, and 53.8. million ha in Southern Europe (including Turkey). Total growing stock in Europe according to the same report is 25134 million m^3, of which 5696 million m^3 are in Nordic countries, 13779 million m^3 are in Central Europe and 5659 million m^3 are in Southern Europe. European forests grow annually around 748 million m^3 (net annual increment), of which 195 million m^3 are in Nordic countries, 397 million m^3 are in Central Europe, and 156 million m^3 are in Southern Europe. Annual fellings in late 1980s and 1990s were approximately 449 million m^3/year, of which 136 million m^3 were in Nordic countries, 246 million m^3 were in Central Europe and 66 million m^3 were in Southern Europe (no data from Greece) (UN-ECE/FAO 2000).

Throughout Europe, the main part of the forests is managed except northwestern Russia, where there is a dominance of old-growth natural forests. In northern Europe, forestry is mainly based on native tree species, which invaded this region post-glacially. The role of introduced species is especially large in the Atlantic forests. The productivity of the introduced conifers substantially exceeds that of the native deciduous species making the introduced confers economically attractive. The long time-scale of forest production, with a rotation length of 40–160 years according to species and region, implies that the climate change will occur in the life span of the existing tree stands. The rate of change may substantially exceed the migration rate of most tree species (IPCC 1996). Possible changes in the tree species composition of the European forest are mainly associated with management rather than natural composition or migration.

The range of European forests is primarily limited by climate, either through moisture availability or through temperature (both being absolute amounts and seasonal distributions) (Berninger 1997). However, many forested regions of Europe have been cleared through land-use practices, particularly in western, central, and southern Europe. Only in northern Europe (Scandinavia and northwestern Russia) are forests still dominating the landscape. Consequently, the current tree species composition is mainly determined by past land use and management activities rather than by natural factors (Ellenberg 1986). In western, central and southern Europe, the introduction of new tree species has been among the main tools for increasing forest growth. Under climate change this is seen to be a potential risk for forestry.

Figure 1. Forests divided into four bioclimatic zones as used in this review.

Forest resources have been increasing in Europe during the past decades (e.g. Kuusela 1994; Kauppi et al. 1992). Growth changes have also been noticed (Spiecker et al. 1996) and possible causes have been suggested, such as increasing temperature and longer growing season, changes in precipitation patterns, nitrogen deposition, increased CO_2 concentrations, changes in land-use and management. Possible causes for accelerating growth are still uncertain and interactions between various factors are to be examined (see e.g. Karjalainen et al. 1999). Some of the ongoing research projects are expected to provide further information on this (e.g. "Long-term Regional Effects of Climate Change on European Forests: Impact Assessment and Consequences for Carbon Budget", see web-page: http://www.ibn.dlo.nl/lteef-II and "Relationships Between Recent Changes of Growth and Nutrition of Norway Spruce, Scots Pine and European Beech Forests in Europe", see web-page: http://www.efi.fi/projects/RECOGNITON.

In Boreal forests, climate change implies a large increase in temperatures and precipitation, especially in winter. Higher summer precipitation may compensate for the enhanced evapotranspiration with water availability being sufficient for forests. Longer growing seasons (number of days with a daily mean temperature $\geq$ +5 °C) reduce the duration of snow cover and soil frost. An increase in strong winds (wind velocity $\geq$15 m s^{-1}) will probably be smaller than in the Atlantic forests, where the winter precipitation may increase but summer precipitation will reduce. In the southern parts of the Atlantic forests, the reduction in the summer precipitation may increase the frequency of droughts. The Continental forests may also experience a higher frequency of droughts. In the Mediterranean forests, the seasonality of precipitation may increase with more precipitation in winter and less precipitation in summer. A drastic increase in the frequency of droughts may occur. In Continental and Mediterranean forests, the frequency of strong winds may increase but not to the same extent as in northern and western Europe. Throughout Europe, the mean increase in temperature and increase/decrease in precipitation are still less than the year-to-year variability, especially in northern Europe.

1.2 Objectives of the assessment

These proceedings aim at assessing the likely impacts of climate change on forests and forestry in Europe. The analysis is based on judgements by experts representing different parts of Europe and, thus, the bioclimatic forest regions presented in Figure 1. The expert assessments provide an information outline on how climate change may affect productivity, timber supply and management of forest resources, and the implications for environmental policies. Country-specific reports and expert judgments have been included in Part II of this publication.

2. Methods and material

The experts who provided their assessment are the contributing authors of this report. They were asked to assess how the climate change may effect productivity, timber supply and management of forest resources in the country or region, with which they are familiar. Furthermore, they were asked to assess how the impacts on forest and forestry might affect the environmental policy in the region or country, which they represented. The content of the assessment (writing tasks) was as follows, with a note that the maximum length should not exceed 5 pages + tables. The original tables, which the contributors were asked to fill in, are presented in Appendix 1.

The experts were asked to assess:

- current key sensitivities to weather and the mechanisms limiting forest regeneration and growth (like drought, low temperature, wind and snow damage, fire risk, insects and fungi);
- key impacting aspects of climate change in future;
- most vulnerable regions (like coastal areas, high elevations etc.), give a listing and why a region is vulnerable;
- impacts of climate change on management (soil management and preparation, species and provenance selection, precommercial thinnings and thinnings (timing and intensity), rotation length, harvesting methods and conditions);
- impacts on timber supply (timber assortments and amount: species and dimensions, quality);
- main adaptive options available (those already in use and what should be applied: for example, management patterns, shelterbelts etc. land-use policy);
- main implications for other sectors (how the changes in the forests and forestry e.g. will effect forest industry, agriculture, ground water resources, recreation, management of biodiversity, and other sectors);
- main implications for other trends (e.g. climate change may aggravate near-term issues such as groundwater depletion, biodiversity, soil erosion, acidification etc.);
- main uncertainties and unknowns (in biological knowledge, in socio-economic understanding, future management systems, time and scale issues etc.);

- main policy implications (adaptation and risk management: changes in management policy, changes in forests and forestry in environmental policy, possible changes in the role of forestry in economics);
- relative impact of climate change on forest growth: percentage change (at least plus or minus, but preferably an estimate of the percentage) in growth by 2020, 2040, 2060;
- other issues to be discussed.

The experts were provided with the bioclimatic forest map presented in Figure 1 in order to allow them to locate their environment in relation to the statistics on forests in Europe as presented in the introduction. Furthermore, the experts were provided with an estimate of how the climate was expected to change by 2050, as presented in Table 1. It is assumed that the atmospheric concentration of carbon dioxide will increase from the current 360 ppm (parts per million in volume) up to 530 ppm by 2050 in all regions.

The analysis and the generalisation of the assessments are based on the tabulation of the scoring in different tables provided by the experts. Furthermore, the content of the reports are contrasted against the objectives of this study in order to find a general outline of how the climate change is expected to impact upon forests and forestry in different parts of Europe.

Table 1. Assumed changes that will occur in annual mean temperature and precipitation by 2050 in different bioclimatic regions used in this report.

Region	Change in temperature, °C	Change in precipitation, %
Boreal	+2…+4	+0…+15
Atlantic	+1…+2	+0…+10
Continental	+2	+10...+20
Mediterranean	+1…+3	-15…+10

3. Results

3.1 Key sensitivities of forests to climate and weather

In the Atlantic and Mediterranean regions, abiotic factors (temperature, drought, wind, fire, and snow) have a small negative impact on *regeneration* (Figure 2). In the Boreal and Continental region, the impact on regeneration was assessed as neutral. The impacts of biotic factors (insects, fungi, animals) on regeneration was assessed to be large negative throughout Europe except in the Atlantic region, where the impact was neutral or slightly negative. *Growth* was expected to be most affected in the Continental and Mediterranean region. In this respect, the biotic factors were expected to have more impact than abiotic factors. In the Atlantic regions, abiotic and biotic factors were assessed to have equal impact on growth. In the Boreal region, biotic factors may have more impact on growth than the abiotic factors.

Temperature mostly controls regeneration and growth in northern Europe, where precipitation is large enough to suffice the evaporative demand and the risk of *drought* is small. In these conditions, high temperatures enhance both regeneration and growth and low temperatures have the opposite effect. In other forest regions, temperature, as such, may only have a small effect on regeneration or regeneration and growth are rather neutral in relation to temperature. Drought may substantially limit regeneration success and even growth, especially in southern Europe.

Snowfall may reduce the success of regeneration and growth mainly in northern Europe. *Wind* may increase regeneration success through enhanced dispersal throughout Europe. On the other hand, wind may reduce forest growth, especially in the Atlantic region, where the risk of wind damages is the highest, as was the case in the December 1999 storm. *Fire*

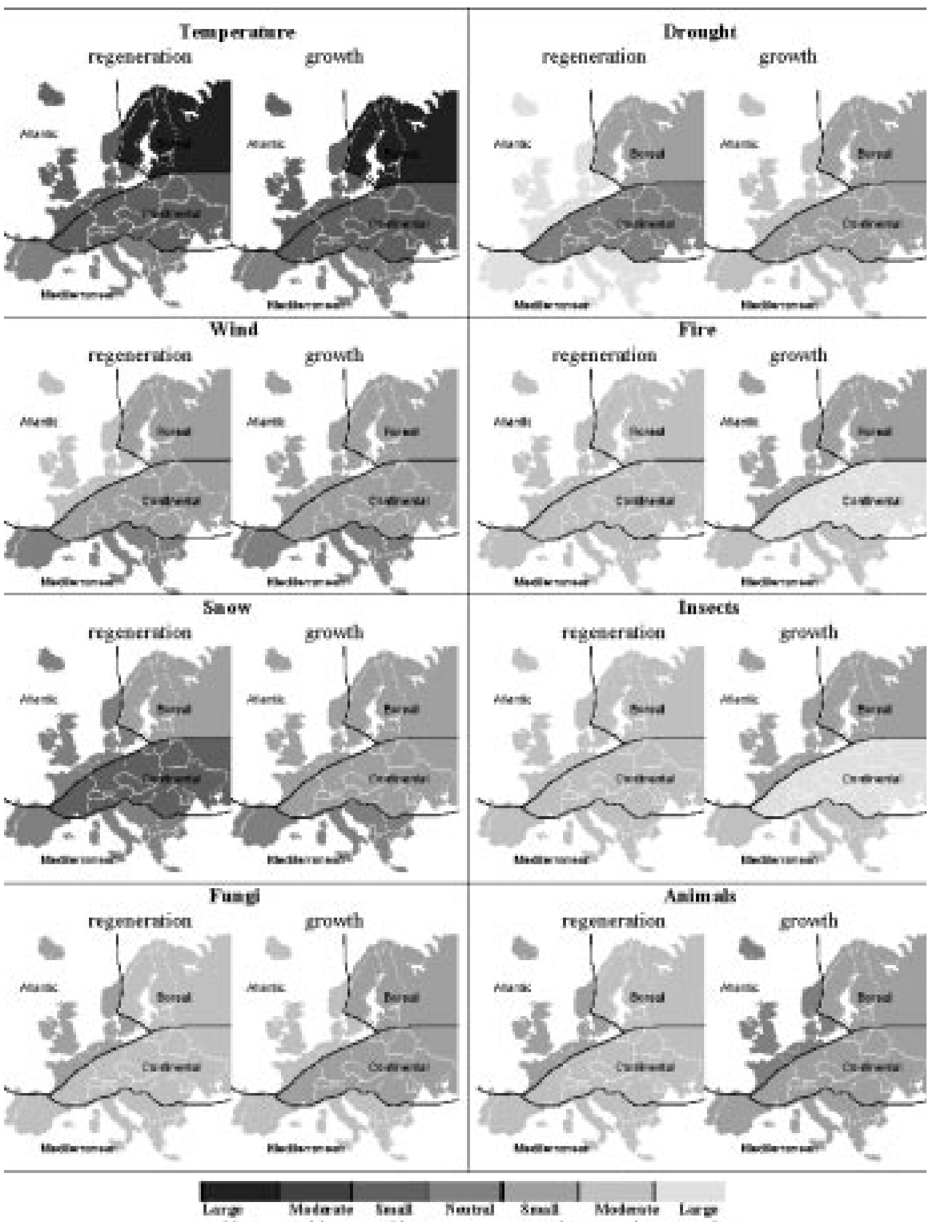

Figure 2. Impacts of single abiotic and biotic factors (occurrence or magnitude increasing) on regeneration and growth.

effects on the regeneration and growth most in the Mediterranean region, but has small effects on the rest of Europe, where the risk of fire is currently small.

Insects and *fungi* reduce the success of regeneration throughout Europe. The grazing of large herbivores, like moose and deer, further reduces regeneration success. However, grazing is no special problem for established and mature trees as it is in the case of seedling stands. Grazing reduces regeneration success throughout Europe.

3.2 Regions where impacts of the climate change are likely to be largest

In the *Boreal* region, the current forests at the polar and alpine timberline would be subjected to large changes under a changed climate (Figure 3). In these conditions, the functioning and subsequent structure and tree species composition of forests may undergo a thorough modification with a loss in their value for conservation, recreation and landscaping, and reindeer husbandry. On the other hand, the timber producing capacity of these forests may increase substantially, and thus provide more opportunities for forestry.

In the *Atlantic* region, the forests at the coastal areas on sandy soils with low water holding capacity (e.g. Jylland in Denmark) may be vulnerable due to limited water supply during summer time and the risk of wind damages. The summer drought may also threaten the existence of forest in *Continental Europe*; i.e. on lowland northeastern and southwestern Germany, Poland, Czech Republic, Slovakia and northern France. The homogenous *Picea abies* forests may suffer in particular from summer droughts, which may enhance attacks

Figure 3. Forest regions, where impacts of climate change are most likely to be largest.

from insects and fungi and increase the risk of forest fires. Topographically sensitive sites are those where exposure to insolation and wind enhances the evaporative atmospheric demand (Germany). The pollution load on these forests may interact with drought and increase the vulnerability of forest in Continental Europe.

In the *Continental forests* and in the *southern parts of the Atlantic forests*, the drought risk is also increased, but under these conditions precipitation is still supporting forest cover. In *northern Europe* and *the northern part of the Atlantic forests*, the increase in precipitation is large enough to compensate for the increased evapotranspiration, and there is no major risk for the existence of forests. The species composition of these forests may experience major modifications with increasing dominance of deciduous species and a decline in the dominance of coniferous species.

The existence of forests is most endangered in the *Mediterranean* region. This is mainly due to low summer precipitations, which will no more support the prevailing vegetation cover. In particular forests in coastal areas and high elevation zones, where vegetation is already subjected to environmental extremes, are considered vulnerable i.e. in Italy. The detrimental effect of reducing precipitation is further aggravated by an increased fire risk.

3.3 Consequences of climate change for forests and forestry and adaptation implications

In the *Boreal conditions* with increased precipitation and reduced drought risk, several existing tree species, either native or exotic will probably grow faster with a more rapid life cycle and a consequent enhancement of turnover of tree populations. This requires shorter rotation times and regular thinnings in order to avoid biotic damages associated with diminishing tree growth. The preference for natural regeneration in management provides a huge genetic potential for adapting forest to the climate change. In northern Europe, this choice may be realistic, since natural regeneration is a common practice in forestry and even in forest plantations natural seedlings substantially affect the total success of reforestation. The preference for natural regeneration may, in the long run, lead to an inevitable shift in tree species composition towards a more frequent dominance of deciduous tree species resulting in a larger supply of hardwood timber (Figure 4).

The increasing precipitation and the increasing dominance of deciduous species reduce fire risk. The preference for coniferous species may require intensification of plantation practices in terms of careful choice of tree provenance and tree species with more optimal responses to the changing climate. The tree improvement programmes may be launched in order to increase the genetic potentials of tree plantations to adapt to higher temperatures with a lower risk of being damaged by spring and autumn frosts. However, effective results and the availability of suitable material requires a minimum of about 25 years with longer periods for adequate testing (Review…1996). Natural deciduous regrowth in coniferous plantations may require more precommercial cuttings in favour of coniferous species. Later, more frequent and intensive thinnings may delay too early decline in the tree growth and reduce risks of biotic damages. Regular thinnings will also increase the mechanical strength of trees due to the enhanced growth and thus reduce the risk of abiotic damages.

In the northern parts of the *Atlantic* forests (e.g. Scotland), the adaptation may follow the same patterns as those for the boreal forests, but the risk of spring and autumn frost will not probably cause any particular concern. Shorter rotation times may also be needed in forests in the Atlantic region, with a need to revise the growth and yield tables and the harvesting schedules. In southern parts of Atlantic forests (e.g. southern UK), the reduction of precipitation may increase the drought risk, especially during the latter part of the prediction period. This tendency may reduce the success of natural regeneration of the current species. Forest plantations with more drought tolerant species, especially conifers, may reduce these problems. Furthermore, the proper selection of tree provenance representing trees of more southern origin and species to increase the capacity of forests to resist impacts of the increasing frequency of drought episodes is needed. The impacts of drought may also be reduced with wider spacing in plantations and in thinnings. The probable loss of amount and quality of timber may be reduced through the breeding programmes, which aim at combining high productivity and drought tolerance.

An overall increase in timber supply, in particular an increased amount of deciduous species, is also expected to occur in the Atlantic region (e.g. Denmark), with a reduction in the timber quality in relation to the enhanced growth rate (e.g. U.K.). In the U.K. the growth of conifer plantations in the northern part of the country is expected to increase, but the growth of high quality hardwood can be expected to decrease in the southern part of the country due to summer droughts (Figure 4). In Denmark, the expected moderate increase in temperature and precipitation is likely to promote tree growth in general. Species, which have their northern limit in southern Scandinavia, will probably benefit the most. The most common planted tree in Denmark, *Picea abies*, is expected to react adversely. In general, with the present climate change scenario wood production in Denmark will probably increase further, additionally promoted by an increase in atmospheric CO_2 concentrations.

In the *Continental region,* an increased risk of pest outbreaks is among the largest concerns, with problems in regeneration and site preparation. Furthermore, the revision of site classification systems may be needed and the impacts of fertilisation and thinning on growth should be reassessed. Shortening of rotation lengths is also expected.

The supply of deciduous timber may increase along with the reduction of coniferous timber in the region, e.g. in Austria (Figure 4.) In particular, the supply of timber of pioneer species with short life span is expected to increase with an increasing supply of small-dimensioned timber (e.g. Czech Republic). In Slovakia a slight decrease in the general timber supply is possible in the future. The commercial value of timber production is expected to decrease in the Swiss Alps. In Germany a transitory increase in the harvesting quantities of timber from mixed stands is possible due to substitution of mono species spruce stands with better-adapted mixed stands. The increased forest site productivity allows higher cutting rates and leads to increased timber supply. The effects on dimension and quality of timber depend very much on thinning intensity and rotation length. Overall disturbances in timber markets are likely to occur.

In the *Mediterranean region,* a tendency towards shorter rotation lengths is expected as well. Thinnings should be conducted to limit soil water depletion, particularly in drier sites. In relation to afforestation and reforestation, provenances with proper temperature and water stress adaption should be selected and utilized. The overall timber supply is expected to increase in the Mediterranean region e.g. in Italy (Figure 4), where *Pinus sylvestris,* in particular, is expected to benefit quite a lot from warmer conditions. However some problems may occur, since the conditions in coastal areas will probably be more adverse for timber production.

In the *Continental* and *Mediterranean regions*, the impacts of increasing drought are severe and there is a need for large-scale tree improvement programmes in order to increase the genetic potentials of tree plantations to adapt to higher temperatures, to reduce the risk of being damaged by drought. Furthermore, new drought tolerant species outside Europe may be used to replace existing ones. Soil management and planting techniques need to be developed to meet the special conditions raised by the increasing drought risk in the Mediterranean region. In particular, the strong seasonality in precipitation with high winter precipitation and severe summer drought may require that the management of forest

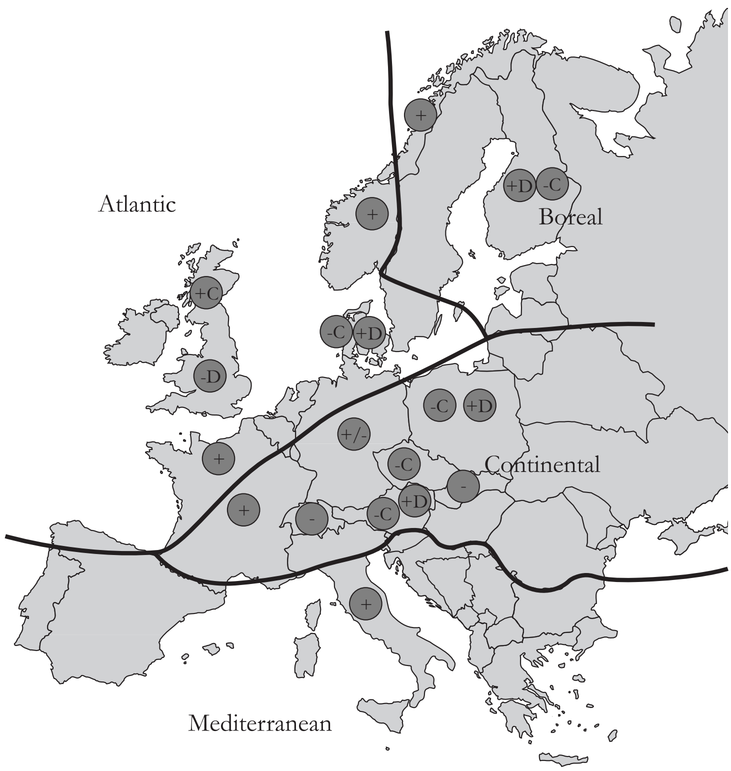

Figure 4. Climate change impacts on timber supply (+ overall positive trend, - overall negative trend, +C/-C increasing/decreasing supply of coniferous species, respectively, +D/-D increasing/decreasing supply of deciduous species, respectively).

plantations may need other techniques, which are now proper in the dry subtropics. The impacts of drought may also be reduced through wider spacing in plantations and later in thinnings. The probable loss of the amount and quality of timber may be reduced through breeding programmes, which aim at combining high productivity and drought tolerance. The fire risk will increase substantially, especially in the continental forests, and the fire fighting will need special attention and measures, also outside the Mediterranean region.

The main impacts on forests and forestry and adaptive options available are summarized in Box 1 with some representative examples selected from country specific reports.

3.4. The main uncertainties

When assessing the impacts of the climate change on forests and forestry, the main uncertainties are related to the climate scenarios, which are still applying much larger spatial resolutions than that applied in management. In particular, the drought effects are soil-specific with only a few possibilities to match the spatial variability of soil properties with the spatial variability of weather and climate.

Much is known of the short-term ecophysiological responses of many European tree species. On the other hand, the main part of the ecophysiological knowledge represents

Box 1. The main impacts of climate change on forests and forestry and adaptive options available.

The Boreal region and the northern parts of the Atlantic region

- *Future conditions:* higher temperature and precipitation, shorter duration of snow cover and soil frost, enhanced decomposition of soil organic matter.
- *Impact on forests:* enhanced growth and regeneration, increased dominance of deciduous species, reduced fire risk, increased risk for wind and snow damages.
- *Adaptive measures:* shorter rotation and regular thinnings (Finland, Estonia, Denmark), preference for natural regeneration and in plantation preference for more southern origin tree species (Finland, Denmark), preference for deciduous species (Norway, Finland, Estonia), regular tending and precommercial thinning of deciduous species in favour of conifers in coniferous stands, suppression of enhanced growth of herbs and grasses in seedling stands and regeneration areas (Finland), limited import of fresh timber from areas with pests potentially damaging forests under the climate change, use of species and provenance mixtures instead of monocultures, and overall promotion of close-to-nature management (Denmark).

The southern parts of the Atlantic region and the Continental region

- *Future conditions:* higher temperature, reduced precipitation, increased drought risk, reduced risk of spring and autumn frost, enhanced decomposition of soil organic matter, increased fire risk.
- *Impact on forests:* drought risk (southern UK, Hungary), higher risk for pest outbreaks (Slovakia, Germany, Czech Republic, Austria), reduced success of natural regeneration and growth of existing deciduous species, increasing weed competition and soil fertility (Germany).
- *Adaptive measures:* shorter rotation and regular thinnings with wider spacing (Czech Republic, France, Germany), preference for drought tolerance conifers in plantations with wider spacing (UK), tree improvement programmes to increase the drought tolerance of tree plantations, more emphasis on success of regeneration e.g. weed control (Germany), careful tree species selection (Slovakia, Germany, Czech Republic, Hungary, Northern France), limited import of fresh timber from areas with pests potentially damaging forests under the climate change, increase in the overall stability of forest ecosystems by restoring disturbed forest ecosystems towards more natural conditions (Austria, Germany, Slovakia).

The Mediterranean region

- *Future conditions:* higher temperature, strong seasonality in precipitation with high winter precipitation and extreme summer drought, severe fire risk.
- *Impacts on forests:* severe drought risk, reduced success of natural regeneration and growth of existing deciduous species, death of some tree species, increased frequency of damaging fire (Italy).
- *Adaptive measures:* shorter rotation, soil management and planting techniques need to be further developed to meet the chancing environmental conditions (drought), introduction of new tree species currently successful in dry subtropics, possible need for new techniques in management of forest plantations now proper in dry subtropics, large-scale tree improvement programmes to increase the genetic potentials of tree plantations to adapt to higher temperatures and increasing drought, wider spacing in plantations and later in thinnings, more reserves and special measures for fire fighting, limited import of fresh timber from areas with pests potentially damaging forests under climate change.

experiments and measurements of seedlings at the juvenile phase and only very little is known about how older and maturer trees are responding to the climate change. Interface between ecophysiological responses and forest management is, to a large extent, missing. There is indeed need for more information on the life cycle of the European key tree species related to their ecophysiological responses, reproductive biology, phenology and partitioning of assimilated carbon to provide the parameters for models describing species response to climate variables over decades and centuries. Models are proper tools for studying interaction between forest management and climate change.

Insect and pest populations are expected to increase, but the extent to which they may be controlled by natural enemies, or if they require management control, is not known. Currently, non-damaging organisms may reach pest level and invading species may cause damages. Conditions favouring the spread and epidemic status of pathogens are also poorly known. Interactions with wildlife generally and effects on biodiversity are, as well, poorly known.

3.5 The main implications for other sectors and other trends

A warmer climate may increase the success of main agricultural crops in the boreal areas, which may increase the competition between forestry and agriculture for land resources with limitations for the increase of forest areas otherwise occurring. The concurrent decline and mortality of some tree species, particularly in the heavily populated areas in western, central and southern Europe would have a major impact on flora, fauna and landscapes. In northern Europe, increased precipitation, cloudiness, rain days, and the reduced duration of snow cover and soil frost would adversely affect forest work and lead to a lower profitability of forest production and a decrease in recreational possibilities. On the other hand, the climate change may create new opportunities for landscaping and recreation in terms of expanding the tree species selection capable of surviving under changing climatic conditions.

Increased wind damages, especially in northern and western Europe may more frequently result in an imbalance in orderly harvesting procedures with increased costs and disturb timber markets with an imbalance between the supply and demand of timber. At the same time, the increased productivity of forests in northern and western Europe provides new opportunities for the wood-processing industry to expand it’s capacity. The reliance of the European forest industry on outside timber sources may reduce or remain at the current level even with the case of the reducing productivity of forests in central and southern Europe. The shift of the tree species composition towards a larger dominance of deciduous species requires a careful analysis of how the European timber resources and future needs of wood-based products will be matched in the future.

In Europe, the forested areas are the main source of ground water, and they absorb precipitation and reduce the risk of excess surface flow and floods and erosion. In this respect, the ground water resources in northern and western Europe are in no danger as is the case in central and southern Europe. In these conditions, the reduction of forest cover and the enhanced seasonality with the increased role of the winter precipitation may increase surface flow and floods with a consequent need to reconsider water management. In northern Europe, the increasing precipitation may also increase the risk of floods even though the forest cover buffers watersheds. On the other hand, the climate change may induce eutrofication of lakes and rivers, as in Finland, where the majority of the lakes are shallow with a slow turnover of water.

In many European countries, forests and forest reserves provides the main opportunities to maintain the biodiversity and conserve rare and endangered species. The need to expand the tree species selection to include exotic species or the preference of only a few resistant local

Box 2. The impacts of climate change on other sectors and other trends.

The Boreal region

- *Impacts on other sectors:* decrease of peatland (Norway), increase in peat production (Estonia), if wheat cultivation becomes more profitable, limited increase of forested area (Estonia), changes in agricultural cultivation with possible increased opportunities (Finland), possible changes in energy consumption and structure e.g. decreased need for heating during winter, increased possibilities to utilise water power in energy production (Finland).
- *Other trends:* Temporary decrease in overall plant species diversity in case climate change is too rapid (Estonia), possible increase in frost damages (Estonia, Finland, Norway), paludifications (Estonia, Finland), enhanced susceptibility to infestations of insects and pathogens (Norway, Finland), increased outflowing of nutrients and soil eutrophication of lakes and rivers (Finland).

The Atlantic region

- *Impacts on other sectors:* Decline of some tree species may have adverse effects on flora, fauna, landscape, and recreational values in heavily populated areas (United Kingdom). Necessary change in forest management practices may have positive side effects on recreational and biodiversity conservation values of forests.
- *Other trends:* Increased risk of insects and pathogens damages, substitution of some agricultural land with forested land and thus possible positive impacts on ground water quality (Denmark).

The Continental region

- *Impacts on other sectors*: More agricultural land for unproductive classes (Hungary), problems with nature conservation, when planting other than indigenous species (Hungary), a need for new arrangements in water management sector (southern France, Slovakia, Hungary), increase of recreational value of forests (Czech Republic, Germany).
- *Other trends:* Higher risk for storm and wind damages and avalanches (Austria), soil erosion (Austria, Switzerland, Slovakia, Czech Republic, Hungary), changes in groundwater resources and quality (Germany, Czech Republic, southern France, Slovakia, Hungary), increase in overall diversity, if species-rich communities enlarge (Switzerland), enhanced susceptibility to infestations of insects and pathogens (Hungary), changes in amenity values and biodiversity of forests (Germany), retreat of permafrost (Switzerland).

The Mediterranean region

- *Impacts on other sectors:* Decrease in recreational values of forests (possible negative impacts on tourism) (Italy).
- *Other trends:* Higher risk for drought damages, impacts on soil water level (Italy).

species in order to maintain the productivity of forests would reduce the opportunities to implement the national and pan-European conservation programmes. The greatest impacts are likely to occur at the forest margins in Boreal and Mediterranean regions. In mountainous areas, the current management of forests for reducing the risk of landslide or avalanches would have to be reconsidered due to the upward movement of the timberline and changes occurring in the tree species composition.

The main implications of climate change for other sectors and other trends are summarised in Box 2, with some representative examples selected from country specific reports.

Box 3. The main policy implications of climate change.

The Boreal region

- Importance of forestry is most likely steadily decreasing at the expense of growth of other sectors like industry and transit service, some forest land may be turned into agricultural land (Estonia), possible changes in the energy sector and energy taxation in the future, more flexible and anticipatory forest management (Finland).

The Atlantic region

- Encouragement of the diversification of forests e.g. by planting more mixed forests, usage of well adapted regeneration materials, reconsideration of soil management, and pest and disease strategies (Denmark). Further research in the general aspects of the stability of ecosystems under stress should be encouraged, including biogeochemical, gene-ecological, ecophysiological and system ecological aspects (Denmark).

Continental region

- Gradual species substitution (northern France), additional research of forest management for developing response strategies which incorporate risk assessment and uncertainties, flexible management strategies, adaptation to local situation and changes in time are needed, implementation of adaptive planning strategies as a continuous process in the management activities (Germany), public funding supports management strategies, which promote development of uneven aged mixed stands (Austria), launching of CO_2 tax (Switzerland), dissemination of information and common awareness about climate change and related risks, need for education also in the higher political level (Czech Republic), inclusion of climate change impacts to the state's forest strategy and policy (Slovakia).

The Mediterranean region

- Changes in environmental policy priorities e.g. prioritising forest fire prevention (Italy), careful selection of well-adapted species and provinances

3.6 The main policy implications

In northern areas, the possible increase in competition for the land resources between agriculture and forestry enhances the need to balance, in the agricultural and forest policies, the allocation of land resources for different purposes. On the other hand, the increase in productivity of forests in northern Europe and partly in western Europe with consequent benefits for the owner and the societies should encourage management on sustainable basis and the expansion of forest covered area. There is an obvious need to reformulate the national forest policies to utilise these opportunities. In this context, forestry may also, in the future, provide many opportunities to support socio-economic development in rural and sparsely populated areas throughout Europe.

Future forest policy and the consequent management should also balance the increasing capacity of forests to sequestrate carbon and the potentials to increase the supply of timber into the inner markets of Europe, while sustaining wood-using industries. The possible shift of tree species composition towards increasing dominance of hardwoods may affect the wood-processing techniques and this should also be considered in future investments. The changes in the area of forest cover, tree species composition and age structure are also a challenge for the conservation policy. How one can conserve rare and endangered species and implement national and pan-European conservation programs will be one of the issues in this respect.

The main policy implications according to country specific reports are listed in Box 3.

4. Discussion

In *northern Europe*, *Picea abies* and *Pinus sylvestris* are likely to invade tundra regions under warmer conditions (Sykes and Prentice 1996). These changes would be accompanied by a reduced dominance of both species in the southern parts of boreal forests with a concurrent increase of deciduous trees (Kellomäki and Kolström 1994). Climate projections suggest a displacement of climatic zones suitable for boreal forests of about 150–550 km over the next century (IPCC 1996). This shift is faster than the estimated potential of many species to migrate (20–200 km per century) (Davis 1981; Birks 1989) or the capability of many soils to develop a new structure. The uncertainties associated with the expansion of forest limit and individual tree species are also related to effects of weather and climate on the quantity and quality of seed crop, seed dispersal and establishment of seedlings, which are currently limiting the northward expansion of boreal forests (Kellomäki and Väisänen 1995; Kellomäki et al. 1997). There is some evidence, however, that the biomass of northern forests has grown during recent decades (Houghton 1996; Lakida et al. 1997; Lelyakin et al. 1997; Myneni et al. 1997).

In *western and central Europe*, the changing climate may increase the competitive capacity of deciduous trees to such an extent that natural conifers may be replaced by deciduous species in large areas. Model computations (Kräuchi 1995) indicate that *Picea abies* may be replaced by *Fagus sylvatica* and other broad-leaved species in mountainous zone in southern Germany (Lindner et al. 1997, Lasch et al. 1999). In Switzerland, the temperature increase of 3 °C would help deciduous trees invade the subalpine belt with a consequent invasion of coniferous trees to the alpine zone (Kräuchi and Kienast 1993). However, Hättenschwiler and Körner (1995) found no indication of an upward movement of *Pinus sylvestris* in the Swiss Central Alps in response to summer temperatures during the period 1982–1991, when temperatures were, on average, 0.8 °C warmer than those of the period 30 years before. They argued that the primary control of the altitudinal distribution of

Pinus sylvestris and *Pinus cembra* is more likely to be between-species competition than temperature. In the deciduous zone, colline *Carpinion* forests would expand at the expense of sub-mountain and low-mountain beech forests (Brzeziecki et al. 1995). Such results have not yet been confirmed by empirical studies.

Changes in the forests of southern Europe are most likely to be driven primarily by changes in water availability. Furthermore, changes in temperature (particularly reductions in frost occurrence) may affect the expansion of some tree species (e.g. *Quercus pyrenaica* and *Quercus rotundifolia)* whenever the water availability is sufficient. Changes in precipitation will determine the relative importance of sclerophyllous and deciduous species; water availability in the period April-June would be particularly important (Gavilán and Fernández-González 1997). In the Pyrenees, a northward and upward movement of Mediterranean ecotypes is likely to occur along with warming accompanied by drier conditions.

Until now, there is no solid evidence that the introduced species would be less adaptable to the current climate, if the tree species choice is based on extensive provenance tests to identify phenologically suitable ecotypes (Lines 1987). The within population variability is often greater than that between species, and it allows trees to adapt to quite large climatic variability. On the other hand, tree improvement programmes attempt to account for sufficient genetic variability by either assembling selected populations to cover the range of climates that exist now or by testing genotype x environment interaction across a number of sites. The genetic variability of most common tree species is probably large enough to accommodate the mean changes in temperature and precipitation. Problems may be encountered with the changes in the frequency and amplitude of extreme events such as drought, wind and spring and summer frost (Review…1996: 84–85).

Currently, there is a tendency to prefer native tree species and a more nature-oriented approach in management (Innes 1993; Lämås and Fries 1995). This may, in the long term, shift the tree species composition closer to that determined by the prevailing climatic and edaphic conditions in Europe. This is expected to increase the capacity of forests to acclimatise to changing climate, but there is no solid evidence to support this assumption (see e.g. Fries et al. 1997). Simulation studies in northeastern Germany suggest that there is a considerable potential to improve climatic adaptation of forests by means of adaptive forest management strategies (Lindner 2000). Depending on local conditions, an adaptive management is able to partly mitigate the reduction in forest productivity under the climate change (Lindner 1999). On the other hand, the European forests are also subject to a variety of other anthropogenic influences, such as nitrogen deposition, sulphur emission, ozone injury, and changes caused by unbalanced game populations (Kinney and Lindroth 1997; Posch et al. 1996; Slovik 1996), which are likely to interact with climatic change to bring about a complex series of responses that will differ from place to place (Thornley and Cannell 1996; Bugmann 1997; Young 1997). Future forest communities are likely to be composed of tree species assemblages not necessarily occurring today (Lindner et al. 1997).

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Part II: Country Reports

Austria

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The Austrian National Forest Inventory reported an unexpected high current annual volume increment for the 1980s compared to previous observation periods (Schieler and Schadauer 1993). Although parts of the reported increase are due to differences in the inventory design, there is a substantial increase in volume increment (more than 17%) compared to previous growth periods. The inventory period 1992–1996, which was based on the same methodical concept as the inventory of 1986–1990, exhibited a decrease in volume growth from 9.4 to 8.2 $m^3/ha/yr^{-1}$ (Büchsenmeister et al. 1997). It is important to note that these numbers did not explicitly remove possible effects on forest growth, due to changing stand age, reforestation of agricultural land resulting in highly productive timber stands, and treatment impacts.

Similar patterns are evident for the height increment development from long-term observation plots of the Institute of Forest Growth Research in Vienna, Austria. Figure 1 shows the difference between observed and predicted 5-year height increments of two different locations Hirschlacke (n□700) and Litschau (n□1800), beginning in 1983. The periodical height increment predictions are driven by a tree height increment model based on 9946 felled tree data from the late 1950s. This ensures that possible age trends in the observed height increment rates can be eliminated and that the differences between observed and predicted individual tree height increment rates are mainly due to changing growth conditions. The positive values indicate higher height increment rates compared to the model's predictions. Again a substantial improvement in the height increment is detectable for the late 1980s while height growth improvement decreases for the early 1990s.

Recent studies by Hasenauer et al. (1999, 2000) analyzing climate data of 1961–1995, suggest that Austrian forests have responded to the improved climatic conditions, particularly in the late 1980s mainly due to an increase in temperature and the temperature related growing season length. They analyze the climate data, net primary production and increment information (after eliminating age affected growth changes) for 1179 increment cores of Norway spruce. While precipitation has not changed, a significant increase (a=0.05) in the average annual temperature (1.13 °C), minimum temperature (1.23 °C), winter temperature (2.70 °C), and the growing season length (14 days) are evident since 1961 (Fig. 2). For the early 1990s, lower radial increment rates are detectable (Fig. 1), indicating that the Pinatubo volcanic eruption in June 1991 may have resulted in a temporary decline of forest growth (Hasenauer et al. 2000).

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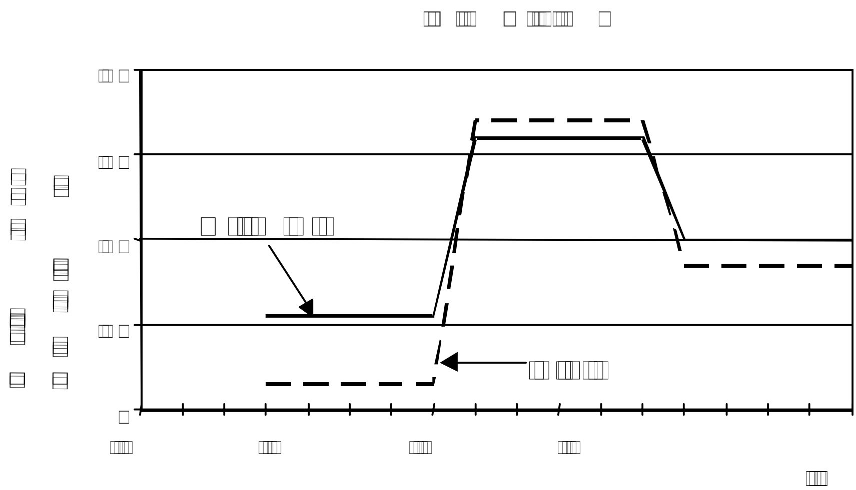

Figure 1. Observed minus predicted 5-year height increment predictions of two locations including more than 2,500 individual trees in Austria. The magnitude of the difference can be interpreted as an indication for periodical variations in height increment due to varying growing conditions.

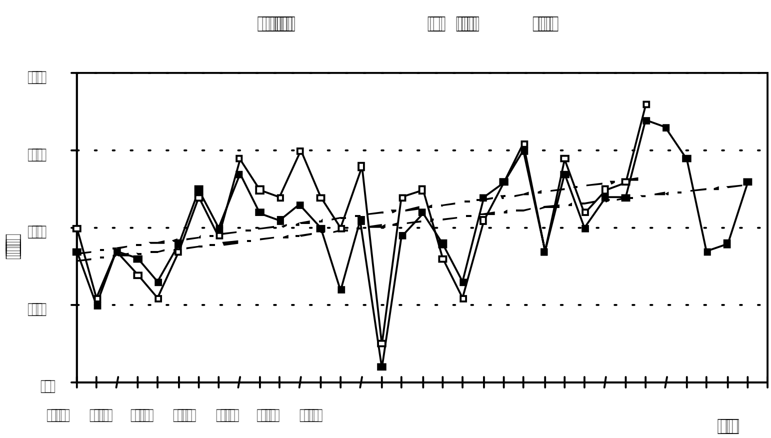

Figure 2. Average annual precipitation, temperature growing season (defined as the sum of days with daily temps > 5 °C) and increment index (after eliminating possible age trends) including the regression lines for the time span 1961 to 1995 (Hasenauer et al. 2000).

Most vulnerable regions

In Austria, maximum precipitation occurs during the summer months. In most areas, precipitation is not the limiting factor. However, at the eastern and southeastern edge of the Alps (border of the former Slovenia) the mean annual precipitation is low (about 400–500 mm), so even a small decrease in precipitation or changes in precipitation patterns may have severe impacts on the stress scenario of the remaining forests.

Another important issue concerns secondary coniferous stands in areas below 1000 m in elevation or beyond their natural range. These stands are extremely sensitive to environmental stress factors and are highly susceptible to progressive loading of air pollution and changing climate. These stands are considered to be degraded due to litter ranking, grazing, and profit oriented wood production by promoting fast growing coniferous stands. It is expected that potential climate change (temperature increase/changes in precipitation patterns) may directly effect these forest ecosystems as well as indirectly by favoring insect outbreaks and/or fungi infections.

Management impacts

It is assumed that stand management under changing climatic conditions has to be close to old growth or natural stands because it increases biodiversity, soil fertility (or at least keep it stable), improves the resilience of stands and insures that stands are less susceptible to physical and/or biotic disturbances.

Timber supply

The total volume of Austrian forest increased from 780 to 988 million m^3 between the 1960s and the 1990s, mainly because of an increase in the forest covered land area and the fact that approximately only 70% of the annual increment rates were harvested. To this point in time, growth changes due to changing climate had no impact on timber supply. For the future it is expected that the supply of coniferous trees, mainly Norway spruce (the most important commercial tree species with 61% timber growing stock) will decrease, while the supply of broadleaf timber may increase. All climate change scenarios (increasing temperature, decreasing precipitation, etc. can also been seen in Table 4) suggest that the percentage of coniferous trees will decrease while broadleaf species will increase.

Adaptive options

It is assumed that the best way to prepare our forests for changing climatic conditions is to increase their stability and resilience by restoring disturbed forest ecosystems to more natural conditions.

Main implications of other sectors

Assuming that climate change will have an impact on the species composition in mountainous areas, the changes in climate patterns are expected to bring on extreme weather conditions, and therefore, higher risks for wind and storm damage, as well as avalanches and soil erosion.

Uncertainties and unknowns

Austrian forests are managed intensively. In some areas species composition has changed effecting the soil and humus. These areas are considered to be the most vulnerable regions in our country. These changes, combined with the uncertainties of a changing environment, have changed the research objectives from monocausal hypotheses testing towards “multiple stress hypotheses“ that focus on stress scenarios and stress profiles. While the reduction of air pollution is mainly a political issue, the renewal of devastated forest ecosystems is clearly a challenge within forest ecosystem research. Such ecosystems often suffer from severe heat and water stress as well as biotic and/or abiotic impacts. Thus, stand stability and resilience to additional stress factors such as potential climate change is limited within these stands. It is extremely important to improve our knowledge on this subject. Modern forest management must increase the resilience of such vulnerable ecosystems or, at least, maintain stability by reducing management induced stress factors.

Main policy implications

Public funding supports management strategies which promote uneven aged mixed species stands. These stands are diverse and, therefore, reduce the stress profile of stands.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–1	–2
High temperature	+1	+1
Drought (spring)	0	–1
Wind	–1	–2
Snow	0	–1
Fire	*	*
Insects	–1	–2
Fungi	–1	–2
Animals (deer)	–2	–1

remarks: * no fire

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change (increase)	+1	+2
Rate of precipitation change (decrease)	–1	–1
Rate of CO_2 concentration change	+1	+1
Extreme temperature		
Minimum (increase)	+1	+3
Maximum (increase)	0	–1
Length of the growing period (increase)	+1	+3
Changes in temperature and precipitation in (see remarks)		
Spring (higher temperatures no change in precipitation)	+1	+2
Summer	–1	–1
Autumn	0	0
Winter	?	?

Remarks: Changes in temperature and precipitation depends on what will become the limiting factor. As far as my analysis show precipitation is not the limiting factor in most parts of Austria. The limiting factors are temperature/growing season length combined with solar radiation. Growth responds very sensitively to minimum temperatures and drought in spring.

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Continental			
Scots pine	–1	–1	+1
Norway spruce	–2	–2	+1
Beech	+1	+1	+1
Oak	+1	+2	+1

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: +2 °C
Mean annual precipitation: +10–20%
CO_2: 30 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Continental			
Scots pine	low decrease	low decrease	low decrease
Norway spruce	low decrease	low decrease	medium decrease
Beech	low increase	low increase	medium increase
Oak	low increase	low increase	medium increase

The Czech Republic

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In the Czech Republic there are 2.63 million hectares of forested land (33% of the total land area). Forestry is responsible for 1% of the GDP. There are very diverse natural conditions, which alternate in a relatively small country area. The territory lies on the dividing line between an Atlantic and a continental type of climate. This area is relatively densely populated and there is pronounced interest in the non-wood-producing functions of forests. All forests are heavily affected by human activity (Norway spruce covers 55% of forest land, while only 11% of these forests was covered by spruce in the forests natural state), including the intensive effect of air pollution in the last five decades. As a result of these facts, over 60% of all the forests are damaged to some extent. First of all, however, there is very valuable and extensive information on the forest stands and site conditions (and their changes over the last forty years) for the whole forest area in the Czech Republic.

The most vulnerable regions

- the northern part of the country, because of continued atmospheric pollution with toxic products from industry, transport and intensive agriculture,
- higher elevations with extreme weather conditions,
- uniform forest stands, which are responsible for the decreased stability of forests, particularly during extreme climatic conditions. This uniformity also makes them more vulnerable to climatic extremes, insects, parasitic fungi, wind and snow,
- forest stands of tree species that occur near the bottom margin of their ecological amplitude.

Impact on management

It follows from the analysis of partial processes that more marked changes in the development of soils are not expected as a consequence of the effect of the eventual

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anticipated scope of changes in temperature and precipitation. Should they occur, they will have an effect on the condition of stands only after several forest generations. The supplies of overlying humus in the forests of the Czech Republic are considerable. Depending on current conditions and their changes, both decelerated decomposition and slower circulation of matter (in conditions of lower precipitation) and, on the contrary, accelerated decomposition of humus and more intensive matter circulation can be triggered by greater humidity and increased temperatures (especially at higher altitudes). The possible acceleration, however, caused by the release of some of the nitrogen and carbon will not mean dramatic changes because the process will be slow and a number of forest ecosystem processes will utilise the released substances.

For forest management it is necessary to:

- implement the proper methods of care for young forests (the use of traditional methods, rarely applied at present, because of their labour-intensity and low efficiency, should be encouraged.
- gradually change the species composition by increasing the proportion of broad-leaved species (especially those that stabilize and improve the soil) and in this way, to approach the natural species composition of the forests.
- use silvicultural procedures which are as natural as possible (this mostly concerns the shelterwood system), more planting space and spacing between seedlings during artificial regeneration, in the case of spruce, for example, intensive thinnings at a young age until approximately the half time of the rotation period, in places where middle-aged and older stands are stable enough to move relatively intensive thinnings into the regeneration phase.
- as for the issue of carbon, give preference to silvicultural systems that accumulate large amounts of biomass (forests with longer rotation periods, shelterwood system)
- with regard to the trend in the development towards a dryer climate all possibilities of water conservation in forest must be studied.
- another measure that can, amongst other things, contribute to the building up of carbon in biomass and, as far as CO_2 is concerned, secure the neutral cycle of this substance, is new afforestation. In the Czech Republic the establishment of new forest stands is possible as part of the afforestation of land separated – for economic and other reasons – from agricultural land resources, and the development of new forest stands on reclaimed land, especially that of disused mines.

Impacts on timber supply

A decrease in precipitation would be a great hazard to spruce. A combination of increased temperatures, increased evaporation and greater aridity could lead to a decrease in the growth of spruce as well as broad-leaved trees. On the other hand raised CO_2 concentrations will effect increase of WUE and biomass production. Allocation of biomass will be dependent on the actual soil content nutrients. We can expect an increase in demand, a large amount of smaller dimensions and less spruce timber.

Main adaptive options

In view of the number of unclear and vague points of further development, it is recommended for forest management to promote such changes in its management that comply with contemporary principles and implemented measures to improve the ecological stability of forests. The stability and function of forests in the Czech Republic is weakened and threatened today by the long-term development of civilization processes. Preliminary measures drawing on the principles of due caution vis-a vis possible global climate change are largely identical with measures for the safeguarding of stability and functioning even in the event that a global climate change of the kind that has been forecasted does not occur. Due to the long-term nature of processes in forest ecosystems forest preventive measures are very topical even today. That is why it is extraordinarily important, from the point of view of the forestry branch, that the decision-making sphere assesses and adopts a concept of these measures, including connected issues of forest economy and forest policy.

The conceptual measures primarily focus on:

- the overall enhancement of the ecological and mechanical stability of forests, especially by more variety in species composition (to increase the proportion of deciduous tree species), by adopting nature-friendly methods of management (to select tree species and their mixtures suitable for the kind of habitat and from the generic point of view, to apply corresponding methods and forms of management), by a more diverse spatial stand structure, by applying regeneration methods selected with regard to abiotic factors (e.g. wind), by care for forest edges, etc.
- the limitation of the effects of an unfavourable anthropogenic load on the forests, and that of both external stress factors (pollution) and internal loads (unsuitable management methods, techniques and technology, neglected stand-tending, inconsistent prevention against insect and disease outbreak, excessively large game population).
- the flexibility of forest ecosystems and the differentiation of management measures, taking into consideration changes in growth conditions as well as substantial public interests, and therefore, also, the design of solution variants.

Implications for other trends

Forests have important environmental functions (water management, soil protection, climatic function, etc.) which are not critically endangered by the anticipated changes. However, in the sphere of water and soil protection, there can be very detrimental effects unless there are improvements (optimalization) in the system of logging roads. Unfavorable effects, especially erosion, may increase with precipitation changes or with increased human economic activity in the forests. The anticipated climate change will increase the sensitivity of forest ecosystems to recreational use.

Uncertainties in biological knowledge

What will be the strategy of growth for trees within forest stands in relation to the changed competition and demand for light, water and nutrients?

Main policy implications

It is necessary to state that the awareness of risks ensuing from the possible impact on the public, including the professional forester community, from the anticipated climate change is still inadequate. There is no evident effort on the part of the departments that play an important role in this respect (especially the Ministry of Education) to change this situation to participate in an awareness-building campaign. The unavoidable change in the approach to the solution of long-term prospects of forest development should also be a concern of the state forestry administration for which the education of forest owners and consultations provided to them should be one of its key tasks. Education should be targeted for the governing political bodies so that decisions made in political consensus are not hindered by a lack of understanding of this new situation brought about by civilization processes. Legal and economic instruments of state forest policy ensue from the role of the forest as an asset with features of public goods, from the principle of its sustainable development, and from the irreplaceable role of forests as a factor in the landscape.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	0	0
High temperature	0	0
Drought (spring)	0	0
Wind	0	–2
Snow	0	–1
Fire	0	0
Insects	–1	–2
Fungi	–1	–2
Animals (deer)	–2	–1

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1	–1
Rate of precipitation change	–1	–1
Rate of CO_2 concentration change	+2	+1
Extreme temperature:		
Minimum	–1	–1
Maximum	–1	–1
Length of the growing period (increase)	0	0
Changes in temperature and precipitation in:		
Spring (higher temperatures no change in precipitation)	–1	–1
Summer	–2	–2
Autumn	0	0
Winter	0	0

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Norway spruce	–1	–2	+1
Beech	0	0	+2
Oak	+1	0	+2

Denmark

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Climate

A recent report on the expected climate change in Denmark (Christensen and Christensen 1998) proposes the following scenario (Table A). The scenario is a "warm" and "wet" scenario since it does not include the modifying effects of aerosols, which tend to reduce the changes caused by increased CO_2. The present precipitation in Denmark is, annually, about 650 mm. This means that we may expect an annual increase of up to nearly 20% over the coming 60 years. The increases in temperature and precipitation and carbon dioxide are expected to be exponential rather than linear.

Key sensitivities to weather

Sensitivities in Denmark are mainly related to weather extremes such as frost, drought and high wind speeds. Damage caused by biotic factors (insects, fungi) occurs frequently, but

Table A. Expected climate change in Denmark with a "warm" and "wet" scenario.

	CO_2 (ppm)		Temperature increase (°C)				Precipitation increase (mm)				
	Full yr		W	Sp	S	F	Full yr	W	Sp	S	F
1999	370	0	0	0	0	0	0	0	0	0	0
2020	410	0.4	0.3	0.4	0.4	0.4	13	4	7	–1	2
2040	470	1.5	1.2	1.6	1.4	1.8	52	17	29	-4	8
2060	550	3.3	2.6	3.6	3.2	4	118	39	65	-8	17

Remarks: W=winter, Sp=spring, S=summer, F=fall they are to a lesser extent climatically driven. Late spring frosts especially limit the regeneration of several species including *Fagus sylvatica, Abies alba, A. nordmanniana* and *Pseudotsuga menziesii*. There seems to be a special problem with *Picea abies* in relation to warm winters. After the extreme mild winters of 1989 and 1990 Norway spruce experienced a period of pronounced decline symptoms characterized by discoloration and needle cast ("red spruce decline"; Saxe 1993). Norway spruce seems to be at its limits regarding lack of dormancy during winter. With an average annual precipitation of 650 mm, water is the predominant limiting factor for tree growth in Denmark. Drought during the growing period can be fatal for newly established stands, whereas drought induced mortality in older stands seldom occurs. With intervals of 15 to 20 years Denmark experiences devastating storms, which cause heavy damage to stands with heights above 15 to 18 m. During the last 40 years, in 3 storms (1967, 1981 and 1999) a total of 10 mill. m^3 were blown down, which corresponds to an average wind throw of approximately 10% of the annual cut.

Key impacting aspects of climate change in the future

The expected moderate increase in temperature and precipitation is likely to promote tree growth in general. Those species which have their northern limit in southern Scandinavia (*Fagus sylvatica, Quercus spp., Fraxinus excelsior, Acer pseudoplatanus, Tilia cordata*) are, in particular, expected to profit from smaller increases in temperature and precipitation. Lime, which in Denmark is at its northern limit in respect to seed maturation, might additionally increase its reproductive capability significantly. Most exotic conifers of oceanic origin, especially those from the pacific Northwest (Douglas fir, Grand fir, Sitka spruce) might profit too. The only major species, which is expected to react adversely – especially to warmer winters, is *Picea abies* – unfortunately the most common planted tree species in Denmark. Models predict an increase in frequency and magnitude of storms over Denmark. Since storm, at present, is a very important damaging factor in Danish forestry, smaller changes in storm patterns might significantly affect forest stability.

Most vulnerable regions

The most vulnerable region in Denmark is the western part of Jutland, due to the combination of sandy soils with a low water holding capacity, frequent sea spray and wind exposure, and the predominant use of the basically unadapted *Picea abies* in monoculture. These systems have a very low resistance and resilience, thus being very susceptible to environmental perturbations (Larsen 1995a and 1995b). Other regions of potentially low robustness in relation to climatic changes are the ground water influenced, young moraine soils of central and eastern Zealand, which have a very high clay content and a poor drainage.

The impact of climate change on management and the main adaptive options available

Climate change will have a profound impact on forest management in Denmark. In fact, it already has. The main challenge is to develop strategies and operational practices in order to cope with uncertainties through risk alteration and to increase the stability of forest ecosystems in general (Larsen 1990).

The main management options available

- selection of site adapted species
- selection of species and provenances with a high adaptive potential
- breeding for physiological and evolutionary adaptability
- use of species mixtures instead of monocultures
- use of provenance mixtures
- promotion of stands with vertical structures (uneven aged)
- tending and thinning in order to increase species and structural diversity

In general, management has to change from the classical mono-species and even-aged management of stands into close-to-nature management characterized by more single tree management incorporation and supporting the natural processes such as regeneration and differentiation and aiming at structural differentiation.

Impact on timber supply and implications for other sectors

During the last century the productivity of the Danish forest has increased dramatically, mainly caused by more intensive management, the use of better provenances, nitrogen deposition and probably the already realized CO_2 increase. With the present climate change scenario wood production in Denmark tends to increase further, additionally promoted by the increasing atmospheric CO_2-concentration. Furthermore the Danish forested area grows by approximately 1% on an annualy basis, due to afforestation efforts aiming at doubling the forest area within 80 to 100 years. This increase in timber supply might to, at certain extent, be counteracted by setting aside areas for non-intervention forests and forests for other than timber producing purposes.

Since no dramatic change in the forest cover is being expected, the implications for other sectors might be small to insignificant. Conversely, the necessary change in management practices mentioned above in order to cope with the expected climate change might have positive side effects on other forests functions, such as recreational values, ground water protection, biodiversity conservation etc.

Main uncertainties and unknowns

The main uncertainties are founded in the limitations in the predictions of regional precipitation and storm patterns. Since Denmark is situated close to the limits of tree growth in respect to water, small deviations in rainfall, including the occurrence of extremes, might cause pronounced effects on tree growth and initiate dramatic shifts in vegetation. Further, rather small increases in the magnitude and frequency of storms over Denmark might lead to a total abolition of the storm sensitive conifers.

Other uncertainties are related to the lack of knowledge about species and provenance specific reactions to climate change, including their ability, physiologically, to buffer such changes. Further, the potential for breeding for physiological and evolutionary adaptability is limited (Larsen 1991). Another mainly unknown factor is the degree of interactions between climate change and the increase in atmospheric CO_2.

Results for beech and spruce seedlings indicate that a 2–3 °C increased temperature improve beech growth over one season, while 4–5 °C does not bring further improvements. For spruce, however, there is a continuos improvement at least up to a 5 °C temperature increase. For both species there are strong synergistic effects between elevated temperature and elevated carbon dioxide. In beech, elevated CO_2 is a prerequisite to real positive effects from elevated temperatures (Saxe et al. 1999). But CO_2 (Saxe et al. 1998) and temperature (Saxe et al. 2001) has profound effects on forest trees, stands and ecosystems by themselves.

Main policy implications

The probability of major climatic changes within the next 50 to 100 years should encourage policy strategies to promote general robustness of the forests. Emphasis should be laid upon supporting close-to-nature management and promoting structural diversity, including site-adapted species (especially broadleaves), species mixtures and uneven aged stand structures.

Further, research on the stability general aspects of stability of ecosystems under stress should be encouraged. Such studies should include biogeochemical, gene ecological, ecophysiological and systems ecological aspects (Larsen 1995b).

We conclude that the expected changes in climate could increase forest production, particularly if we plant and manage clones, provenances and species that we have no doubts about in relation to health responses to these changes.

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–1	–1
High temperature	0	+1
Drought (spring)	–3	–2
Wind	–1	–2
Snow	0	0
Fire	0	0
Insects	–1	–1
Fungi	0	–1
Animals (roedeer)	–2	0
Sea salt	0	–1
CO_2 increase since 1870	0	+1
Air pollution	0	–1 and +1

Remarks: sea salt with storms is mostly relevant 50–100 km inland from the West coast of Jylland. Air pollution particularly ozone probably inhibits photosynthesis and growth, while input of nitrogen improves forest growth on poor soils.

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	0	+1
Rate of precipitation change	+1	+1
Rate of CO_2 concentration change	0	+1
Extreme temperature:		
Minimum	–1	0
Maximum	0	0
Length of the growing period	+1	+2
Changes in temperature and precipitation in:		
Spring	1	1
Summer	0	0
Autumn	0	0
Winter	0	0
Synergistic response to temp. + CO_2 increase	+2	+2
Sea salt brought in by more frequent storms	0	–1
Increased air pollution O_3 and NO_x	0	–1 and +1

Remarks: The synenergistic response to temperature and carbon dioxide is found in several recent studies. Air pollution, particulary ozone, will probably inhibit photosynthesis and growth further, but input of nitrogen improves forest growth on poor soils.

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change	ALL change
Atlantic				
Norway spruce*	–3	0	2	–3 to +3
Beech**	1	1	1	2
Oak	1	0	1	2

Remarks: Norway spruce may suffer from warmer winters, while mature forests are not very wind and drought tolerant. The higher response by conifers than by broad leaved species is supported by Saxe et al. (1998). Other conifers and broad leaved species are preliminary expected to respond like Norway spruce and beech respectively.

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: +1–2 °C
Mean annual precipitation: +0–10%
CO_2: 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Atlantic	+4%	+18%	+40%
Norway spruce	+6% (or decline?)	+22% (or decline?)	+50% (or decline?)
Beech	+3%	+13%	+ 30%
Oak	+3%	+13%	+30%

Remarks: By 2050–2060 we will have 1–2 °C warmer annual temperatures, 0–10% higher precipitation and CO_2 will be at 530 ppm. As the climate changes non-linearly, so will growth. The figures are relative to current growth.

Estonia

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We mainly cover Estonia, but to some extent this assessment is also relevant to all Baltic countries. We do not have a good overview about forestry politics in other states. It is also important to understand that forest cover decreases and the importance of agriculture increases from north to south in the Baltic. There is also a shift in the species composition of forests.

Key sensitivities to weather

Current key sensitives to weather for forest growth and regeneration are mainly related to occasional extreme low temperatures during winter. In some areas (on sandy soils), drought may have a small negative influence on growth as well as on regeneration, but large forest areas in Estonia are relatively wet with a high water table and a low rate of infiltration, hence vulnerable to flooding. Forest fires are rare and have a marginal effect on forest growth. They are correlated with drought events in summer. The most important biotic restrictions in forest regeneration are large animals like moose and deer. Occasionally all pine plantations are damaged and very often spruce is planted instead. Some additional damage for forests is caused by root rot, spruce bark beetle and pine crown weevil. In some areas beaver causes some losses due to damaged trees and drainage systems (about 1/3 of Estonian forests have artificial drainage systems). As a total, approximately 10 thousand ha (from 1900 thousand ha of total stands), are damaged by biotic factors. Natural regeneration of pine and spruce is also influenced by competition from herbaceous plants and mosses.

Key impacting aspects of climate change in future

The expected rapid increase in temperature is likely to positively influence overall primary production. If winters will become too mild, then, the growth and competitive ability of spruce may be affected and other species may suppress it. It is difficult to assess the possible impact of increased precipitation. Although relatively small in area, Estonian forests have

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quite variable water regimes. Large areas are flat and have very low infiltration rates, an hence increase in wet forest areas with low growth is expected. As an average today, forest growth is positively related to the amount of precipitation during the vegetation period, but increased flooding in spring and autumn may shorten the active growth period and damage seedlings. The climate change is likely to increase forest damage by biotic factors. Snow cover and temperatures control an abundance of roe-deer in winter, low temperatures also regulates survival of spruce bark beetle. Humid and hot weather increases the risk of damage by root rot. It is likely that herbaceous plants will respond more rapidly to climate change and will substantially restrict natural regeneration of conifers.

Most vulnerable regions

Mires and peatlands cover 22% of Estonia and paludification is likely to increase in response to climate change. Additional risk factors appear because of changes in management and forest ownership investments into maintenance of drainage systems have been rapidly decreased. This leads to decreased forest production. Other vulnerable regions are coastal areas. The Estonian coastline length is estimated to be 3800 km and land loss in response to a 1m sea level rise is substantial in the western part of Estonia. However, only 15% of lost lands are forests, mainly with very low production potential, hence the total risk for forests from a sea level rise is not substantial.

Impacts of climate change on management

Changes in Estonian forest management are under way regardless of the climate change. Reorganisation of state forests and changes in forest ownership have lead to a decrease in thinnings, especially precommercial thinnings. Most of the private owners do not have enough knowledge and experience for proper management. The amount of clearcuts that are not regenerated by planting and hence remaining for natural regeneration is increasing, and this leads, most likely, to an increase in deciduous forests. Climate change will add to this shift in forest composition. Both improved growth and shift toward deciduous species will decrease the average rotation length in Estonian forests.

Impacts on timber supply

Changes in species composition will lead to a relative decrease in spruce and pine timber production. During the next decade, the absolute amount of timber production is increasing, so far, the present total harvest is less than annual growth increment of Estonian forests. Today, the main assortment categories are saw log, about one third, paper wood, one-third, and fire wood, one third of the total amount. There is no reason to think that climate change *per se* may change these proportions. These proportions in the future will depend on investments into Estonian pulp and paper industry. Today almost all paper wood is exported because there is little pulp industry due to out-of-date technology in Estonia. Additionally, fire wood prices are not competitive with coal and oil prices today but this may change if additional taxes on fossil fuels will be introduced. Consequently, we are expecting that changes in timber assortments are more vulnerable to changes in investments and the taxation environment.

Main adaptive options available

In order to maintain coniferous forests, efforts towards planting and precommercial thinnings have to be increased. Additionally, the improved selection of planting material should be applied. The selection of deciduous species is almost lacking today. Usually, thinnings are made from below method in Estonia. This practice seems to be appropriate for the uncertainties of the climate change because it does not overly influence natural processes.

Main implications for other trends

With increased investments into forest industry more timber is processed locally. The share of raw timber in export is steadily decreasing. During the last 80 years, Estonian forest area has almost doubled and is still increasing. Due to changes in agriculture a lot of agricultural land is abandoned and will be most likely forested. Perhaps, the most important implication of climate change to other sectors is related to agriculture. Today the highest productivity per land area is archived in livestock farming and dairying. It is possible that grain (wheat) growing will become profitable in the future and this may place limit on increase in forested areas.

Climate change may bring some new tree species (beech), but if climate change is too rapid then the overall plant species diversity is likely to decrease temporarily. Increased peat production and paludification in response to increased precipitation is expected. The groundwater table is expected to increase if precipitation increases and this will most likely lead to increased paludification. Because of flat landscape soil erosion is irrelevant in Estonia.

Main uncertainties and unknowns

There are two kinds of uncertainties when predicting the impact of climate change on Estonian forests. Transition in the Estonian economy is still very rapid and policy for supporting rural areas is not well settled. It is not clear how the timber and wood products market will change. The future of Estonian energy production and policy is also unclear. On the other hand, according to forest survey data, average site index (H50) has increased almost by 2 m during the last 50 years. It is partly attributable to intensive drainage of forests and perhaps, to deposition of nutrients, but it may partly be caused by ongoing climate change and an increase in the CO_2 concentration. If so, then the potential of growth improvement of existing forests may be exhausted and additional improvement in nearest future will be less than predicted. Additional uncertainties appear because actual genetic diversity, the potential of local species and the speed of the arrival of new species or genotypes is unknown.

Main policy implications

The importance of forestry in the Estonian economy is most likely steadily decreasing because other sectors, industry and transit services, are increasing more rapidly. Agriculture is not competitive today, but if climate change will lead to more favorable conditions and if supported by governmental policy, then possibly some forest land may be taken back for agricultural production. Very little research has been done concerning the impact of climate change on the Estonian economy and forestry. Possible risks have not been evaluated and understood because the first thing is to put some resources into such research.

Our judgement of the relative impact of climate change on forest growth is based on the assumption that the potential for growth improvement of existing forests will be rapidly exhausted and that new species and management practices settle very slowly so that the overall increase in production in 60 years is no more than 20%. Decrease in annual increment is also possible because most of our deciduous forests do not form stands with standing volume comparable to coniferous forests, hence the speed of changes in forest composition and arrival of productive genotypes of deciduous species may diminish any increased potential due to climate change.

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–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–1	–1
High temperature	–1	0
Drought (spring)	–1...+1	–1
Wind	+1	0
Snow	+1	0
Fire	0	0
Insects	–1	–1
Fungi	–1	–1
Animals	–2	0
Competition	–2	0

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1	0
Rate of precipitation change	–1	+1
Rate of CO_2 concentration change	0	+2
Extreme temperature:		
Minimum	–1	–1
Maximum	0	0
Length of the growing period		–1
Changes in temperature and precipitation in:		
Spring	–1	0
Summer	0	+1
Autumn	–1	–1
Winter	0	–1

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Boreal			
Scots pine	0	+1	+1
Norway spruce	–1	–1	+1
Birch	+1	0	+1

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: +2–4 °C
Mean annual precipitation: +0–15%
CO_2: 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Boreal	+10	+15	+18
Scots pine	+	+	+
Norway spruce	–0	–0	–
Birch	+	+	+

Estimate of the probability to occurence in general: low to medium.

France (Northern)

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Introduction

In this paper we consider northern France as the French area that is neither under Mediterranean nor under warm Atlantic (south-west of France) influence. Following this definition, this presentation includes approximately two thirds of the north of France. The forests of northern France are diverse and include several kinds of forest types corresponding to the Atlantic and continental climatic influences as well as to plain and mountain (Massif-central, northern Alps, Jura and Vosges mountains) conditions.

Deciduous broadleaved species (two thirds of the forested area in northern France) are predominant in plain regions, whereas coniferous species (one third of the forested area) are more frequent in mountain areas. The management system is mainly standard for coniferous species and is shared between coppice, coppice under standard and standard in broadleaved species. Forest management is primarily orientated towards timber, pulp- and ply- wood for managed forests or towards recreation purposes (mainly together with economic use).

We have considered here seven species of real area representativity and all are of economic importance, characteristic of the different forest types, the climate and the altitudinal ranges. The main characteristics of these species are presented in Table A.

The present limitations of forest growth and regeneration

Throughout the area considered, the forests are managed with various levels of intensification. Forest regeneration is mainly based on natural regeneration for broadleaved species and mainly on artificial regeneration (plantations) for *Picea abies* and *Pseudotsuga menziesii*. Both regeneration methods are used for *Abies alba* and *Pinus sylvestris*. Forest regeneration and growth are mainly limited by water availability which is mainly modulated (1) by the amount of extractable soil water in relation to soil characteristics and (2) the seasonal distribution of rainfall (the proportion of rainfall during the growing season shows an increasing trend from west to east). In some species (*Abies alba, Quercus, Pseudotsuga menziesii*), regeneneration (flowering and fructification) and growth of seedlings and

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saplings can be limited by late spring frosts. Winter frosts and high summer temperatures do not constitute a major limitation for forest species. Even though forests are mainly developed on soils with poor ability to sustain agricultural production, soil fertility is not a main limiting factor in the areas considered here. Furthermore, regeneration and growth limitations are important in areas characterized by hydromorphic soils in the centre and east of France. In these areas, forests are exposed to successions of anoxic and water shortage conditions. The impacts of fungi and phytophageous insects (namely defoliators) are also important, according to species, but their quantification is difficult.

The key impacting aspects of climate change in the future

The ARPEGE-IFS model (Déqué et al. 1998) forecasts a temperature elevation of 2 (winter and spring) to 3 °C (summer and autumn) for the north of France under double CO_2 concentration. This model also predicts an increase in rainfall of about 20% in winter and spring and a decrease of about 15% in summer and autumn. During these latter periods a decrease in soil water reserve of 5–10% is to be expected. Increasing winter and spring temperatures will induce earlier budbreak which is likely to increase the risks of late frost injuries (including effects on reproduction processes and regeneration) in some species (e.g. *Quercus* sp., *Picea abies, Abies alba* but not *Fagus silvatica*), according to our knowledge (Aussenac 1973). Beyond this effect, the earlier budbreak, together with an alleviation of autumn frosts will increase the duration of growing season in those situations where water limitations will not be important. Within this context, growth of species with long monocyclic or polycyclic shoot growth patterns would be stimulated. Increasing the winter temperature will also increase the winter photosynthesis of coniferous species, especially in eastern France and in mountain areas (De Vitry et al. 1995). Increasing summer water stress is likely to alleviate the stimulating effect of increasing CO_2 on growth. In these conditions, the stomatal sensitivity (stomatal closure leading to reduced transpiration) to increasing CO_2 may constitute a determining parameter (Picon et al. 1997). It has been suggested that, in contrast with *Quercus* species, stomata of *Fagus silvatica* would not be responsive to

Table A. Forest types and species in Northern France.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]

increasing CO_2, which may lead to a reduced potential of adaptation to drought in this latter species. In relation to enhanced summer and autumn droughts, the presently negligible risks of fire may become important.

The impacts of pathogens are likely to be modulated through three main effects: (1) A change in the distribution areas of pests. Several pests (e.g. *Phytophthora cinnamomi*, a fine root pathogen which induces decline in many hosts) are known to be limited by temperatures, so they could cause increased problems at higher mean temperature (Brasier 1996). (2) Many secondary pathogens could be favoured if drought becomes more frequent (*Sphaeropsis sapinea*, a canker inducing fungus, mainly on pines; *Armillaria* sp., fungi causing root rot on several hosts; *Agrilus biguttatus*, a bark insect on oaks). (3) Some pathogens are known to induce more disease on vigourous hosts (stem rusts as *Melanpsora pinitorqua*)

Most vulnerable areas

Areas with low soil water reserves will be generally most affected. This will particularly be the case in mountain areas. It is also worth noting that decreases in summer rainfall will be most pronounced in western France where the summer water deficits are already presently important. These hypotheses are reinforced by the statement that past diebacks in major forest species occurred precisely in such areas. Another potential important parameter may be in the enhanced windspeed, whose impacts are expected to be most pronounced in coastal and mountain areas and in shallow soil conditions.

Impacts on management and adaptive options available

The possible significant changes in regeneration processes and growth could lead to a necessity to redefine the classification of site fertility and could affect rotation lengths, thinning regimes and other forest practices. If necessary, and according to species and soil and climate conditions, the management of forests should be aimed at preserving the stand water status by using thinning and understorey control for managing the stand leaf area index, and lowering the root limit by deep ploughing in the case of reforestation. In the longer term a gradual species substitution may be undertaken in some areas by replacing species most sensitive to drought and to late spring frosts (e.g. *Fagus sylvatica, Abies alba, Pseudotsuga menziesii, Picea abies*) with *Quercus* species, or some Mediterranean mountain species (e.g. *Abies* species, *Cedrus* species). A gradual extension to the north of low elevation southern species (like *Pinus pinaster*) may also be considered as an option even though the occurrence of extreme winter frosts may be a limiting factor.

Timber supply

It is very likely that in the near future the trend of increasing growth and production, presently characterized in the major species under consideration here, will go on, leading to an increase in timber supply. In a further stage, if the predicted climatic changes and their likely impacts actually occur, disturbances in the wood market may appear in relation to anticipated harvests induced by dieback phenomena.

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–1	–1
High temperature	–2	–1
Drought (spring)	–2	–2
Wind	0	–1
Snow	+2	0
Fire	0	0
Insects	–1	–1
Fungi	–1	–1
Animals	–1	0

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1	+1
Rate of precipitation change	0	–1
Rate of CO_2 concentration change	+1	+1
Extreme temperature:		
Minimum	+1	+1
Maximum	+1	+1
Length of the growing period	0	+1
Changes in temperature and precipitation in:		
Spring	–1	0
Summer	0	–1
Autumn	–2	–2
Winter	+1	+1

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Atlantic			
Scots pine		–1	+1
Sitka spruce			
Oak		–1	+1
Continental			
Scots pine	+1	0	+1
Norway spruce	+1	0	+1
Beech	+1	–1	+2
Oak	+2	–1	+2

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Atlantic +1–2 °C, Continental +2 °C
Mean annual precipitation: Atlantic +0–10%, Continental +10–20%
CO_2: Atlantic and Continental 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Atlantic			
Scots pine		0	
Sitka spruce			
Oak		0	
Continental			
Scots pine		+1	
Norway spruce		+1	
Beech		0	
Oak		+2	

France (Southern)

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Introduction

The forests of Southern France are extremely diversified and include virtually all kinds of forest types which can be found under this climate: alpine forests, Mediterranean coniferous and broad-leaved, Atlantic coniferous and broad-leaved and continental forests. This area comprises three phytogeographic domains: Atlantic, Mediterranean and Medio European, plus the mountain area (Southern Alps, Pyrrenees, Corsica). Forest management is orientated toward a number of objectives, pulp-, saw,- and plywood production for intensively managed forests or soil fixation for littoral and mountain forests, or recreation forests. Coniferous and broad-leaved forests represent each one half of the forested area. The assessment of the possible impacts of climate change in this area is, therefore, complex. Having this specificity in mind, we have split the forests of Southern France into four species-types according to:

- the location of the main tree species in its geographic area (does the region considered, i.e. Southern France, correspond to the Northern, Centre or Southern part of its geographical area
- an altitudinal criteria: plain forest vs mountain forest
- deciduous versus coniferous species and representativeness in terms of surface area, standing volume and production.

Present limitations of forest growth and regeneration

Throughout the area considered, the forests are managed with various levels of intensification. Forest regeneration uses mostly artificial methods like seeding, plantation and coppicing. Tree growth and forest production are certainly limited by the water supply for all species, particularly in areas with shallow soils (e.g. mountains (south-exposed slopes), spodic soils). Nutrient supply is the second most important limiting factor in this area. Forests have been mainly developed on soils unable to sustain agricultural production:

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acidic spodic soils (e.g. *Pinus pinaster* Forest of South-western France), calcareous shallow soil (*Pinus sylvestris* in Southern Alps), and hilly terrain (e.g. *Fagus sylvatica* and *Pinus sylvestris*). For technical and-or economical reasons, not all these limitations can be removed using fertilisers e.g. the nitrogen deficiency. This limitation is less important for the areas recently converted from agriculture to forest. An additional abiotic limitation of forests growth in South-eastern France is fire. The impacts of fungi and phytophageous insects are also important but more difficult to quantify.

Key impacting aspects of climate change in the future

It is unlikely that climate changes could dramatically affect forest regeneration during the period under consideration (2000–2050) even if flowering, pollen and seed production and seed maturation could be locally affected. The ARPEGE-IFS model (Météo-France & ECMWF, Déqué et al. 1998, Déqué, 1998) forecasts a temperature elevation of 2–3 °C for the South of France under CO_2 doubling, with peaks at +4 °C in Southern Alps, Pyrenes and mediterranean shore in summer. While the winter and spring precipitation could be increased by 0.6 to 2 mm day^{-1}, summer and autumn precipitations will decrease by approximately the same amount. This will result in the soil water reserve being depleted by 10% in summer and fall.

An atmospheric CO_2 increase will increase forest growth, particularly before the canopy closure for forest regenerated by clear cutting. Interactions with the nutrient supply are a matter of debate: CO_2 effects will be diminished where strong nutrient limitations exist but they could improve root growth and nutrient capture to some extent.

Precipitation change is potentially a major impacting factor in Southern France but the available predictions for the rainfall regime are uncertain: even so they agree on the accentuation of seasonality in rainfall which could lengthen summer deficits and decrease forest production and tree growth. Increased summer drought will also increase fire risks. Precipitation change will interact with CO_2 increase. For instance, the comparison of water use and growth *of Q. ilex* between naturally CO_2 enriched areas and neighbouring control

Table A. Forest types and species in Southern France.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

areas demonstrate that water use efficiency and drought resistance will be enhanced in this species. Due to the uncertainty in climate scenarios, the extent to which the positive impact of the CO_2 increase will counteract the negative impact of reduced summer precipitation remains an open question.

Most vulnerable areas

Drier areas and forests growing on shallow soil with little prospect for potential increase in soil water reserves and nutrient supplies will be more affected. Depending on its severity, the decrease in summer will dramatically affect forest growth throughout this entire area, whatever the species. The forest tree species which are there in their southern range, i.e. *P. sylvestris* and *F. sylvatica*, are potentially more vulnerable to the impacts of precipitation and temperature change than those in their northern range like *P. pinaster*, and *Quercus* species. Mountain areas, which are refuges for the northern species, could experience a shift in species composition. Conversely, opportunities for extending the area of southern species limited by low winter temperatures could be considered.

Impacts on management

Climate itself will have no direct effect on forest management. However, the possible large changes in growth could lead to the refinement of classification of site fertility and affect rotation length, fertilisation, thinning regimes and other forest practices. The forthcoming restrictions in water could pose different problems concerning the percentage of land used as forests, their role and impacts on the hydrological cycle and the quality of surface water and finally lead us to consider the roles of forest other than wood-production.

Timber supply

At present, the timber supply is mainly controlled by users demand. This demand is generally increasing in quantity. It is very difficult to estimate future changes in the need for particular wood characteristics (fiber, mechanics) owing to the continuous evolution in wood transformation processes.

Adaptative options available

When necessary, i.e. in mountain forests, a gradual species substitution may be undertaken, replacing northern species (*Fagus sylvatica*, *P. sylvestris*) by their immediate southern variant, gradual extension of southern species should also be considered as an option for intensively managed forests (introductory trials of Eucalyptus sp.). Management of drier forests may aim at keeping the stand water use under an upper limit using thinning and understorey control for managing the stand LAI, and lowering the root limit by deep ploughing. The forest requirements in water should also be taken in account in the regional plans of water resource management. The general decrease in water table depth observed for the last ten years in the south-western forest of *Pinus pinaster*, due to excessive drainage and irrigation, negatively affects the growth of drier stands and may affect an increasing percentage of the *Pinus* forest in the near future.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Pinus pinaster		
Low temperature	–1	–1
High temperature	+1	0
Drought	+1	–2
Wind		–1
Snow	–1	–1
Fire	+1	–2
Insects	–1	–2
Fungi	–1	–1
Animals	–1	0
Pinus sylvesteris, 780 593 ha, 39% mountain, 61% plain		
Low temperature	0	0
High temperature	0	–1
Drought		–3
Wind		0
Snow		0
Fire	+1	–1
Insects	–1	–2
Fungi	–1	–1
Animals	–1	0
Mistletoe		–1
Quercus pubescens, 547 211 ha, 15% mountain, 85% plain		
Low temperature	–1	0
High temperature	0	0
Drought	–1	–2
Wind	0	0
Snow	–1	–1
Fire	–1	–1
Insects	0	–2
Fungi	0	–1
Animals	–1	0
Fagus sylvatica, 576 608 ha, 45% mountain, 55% plain		
Low temperature	–1	0
High temperature	–1	–1
Drought	–1	–2
Wind	0	0
Snow	0	0
Fire	–	–
Insects	–1	–1
Fungi	–1	–1
Animals	+1	0

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1	+1
Rate of precipitation change		–2
Rate of CO_2 concentration change	+1	+1
Extreme temperature:		
Minimum	?	?
Maximum	?	?
Length of the growing period		+1
Changes in temperature and precipitation in:		
Spring		0
Summer		–1
Autumn		–2
Winter		0

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Atlantic			
Scots pine	+1	–1	+1
Sitka spruce			
Oak	+1	–2	+2
Continental			
Scots pine	–1	–2	+1
Norway spruce			
Beech			
Oak			
Mediterranian			
Pinus halepensis	0	–1	+1
Pinus pinaster	0	–2	+1
Quercus ilex	0	0	+1
Quercus pubescens	0	0	+2
Pinus sylvesteris	–1	–1	0

Germany

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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.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–1	–1
High temperature	0	0
Drought	–2	–2
Wind / Storm	0	–2
Snow	+1	–2
Fire	0	0
Insects	–1	–1
Fungi	–1	–1
Animals	0	0

Remarks: It is difficult to make a general assessment for Germany. Most sensitivities vary considerably with geographic, topographic and geomorphologic conditions.

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change		1
Rate of precipitation change	2	3
Rate of CO_2 concentration change	?	2
Extreme temperature:		
Minimum	2	1
Maximum	1	2
Length of the growing period	0	2
Changes in temperature and precipitation in:		
Spring	2	2
Summer	2	2
Autumn	1	1
Winter	0	1

Remarks: This scoring is quite sensitive to the projected climate change (but it makes little sense to restrict the assessment to one scenario like the one in Table 4). Therefore we dropped the +/–, i.e. precipitation may decrease or increase and the response will be either negative or in some cases even positive.

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Atlantic			
Scots pine	–1	–1	+1
Oaks	+1	–1	+1
Continental			
Scots pine	–1	–1	+1
Norway spruce	–2	–2	+1
European beech	–1	–1	+1
Oaks	+1	0	+1

Remarks: Again, this scoring is quite sensitive to the projected climate change. In this case scoring is related to the scenario of Table 4. Different climate scenarios, e.g. with no or negative precipitation change, would lead to different scoring.

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Atlantic +1–2 °C, Continental +2 °C
Mean annual precipitation: Atlantic +0–10%, Continental +10–20%
CO_2: Atlantic and Continental 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Atlantic			
Scots pine	+5	+10	+10
Oaks	+5	+10	+15
Continental			
Scots pine	+5	+10	+15
Norway spruce	+5	+10	+10
European beech	+10	+15	+20
Oaks	+10	+15	+20

Remarks: Very speculative, see text! Estimate of the probability to occur in general: low.

Hungary

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Climatic and geographical background

The Carpathian Basin is located in Middle-East Europe at the border of the humid oceanic and drier continental large-scale climatic regimes. The Basin is crossed by a boundary line between the arid and humid areas along the river Danube. Analysis of long term observations for Hungary demonstrates a significant tendency towards decreasing amounts of precipitation and average moisture content in soil. In turn, drought frequency has also increased, especially over the last two decades. The last ten years (till 1998) have been the driest period in Hungary since 1881, that is, for the period for which already more or less adequate data sets from the regular observations are available. In particular, the amounts of precipitation in winter and spring show a significant decreasing trend. This process contributes to the subsidence of the water table, and as a result of this, the amount of water available in the soil is less. Therefore, it has an influence on plant growth with respect to drought periods in summer. The lack of precipitation in winter and early spring dried topsoil and frequent strong winds cause serious damage from deflation. Sometimes we can see roads covered by thick topsoil and ditches filled in by the same in dry autumns and winters.

There is a very dangerous decreasing tendency in the series of the ratio of annual precipitation to potential evapotranspiration (P/PE). Using the terms (P/PE less than 0.65) of 'The UN Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa', Hungary can be identified as a "danger zone", in particular the Hungarian Great Plain. In addition to that the frequency of some other extreme climatological events has also increased in recent years. Several climate modelling studies have pointed out, that the cumulative effects of greenhouse gases will cause a warming of 0.8–1.8 °C over Central Europe in the next 30 years, and indicate a considerable shift in seasonality

A short and variable spring would be followed by a longer but not considerably warmer summer. The autumn would begin in October and terminate in December and would be like the typical "indian-summer", while winter (between January and April) could be characterised as a "very temperate" one. Numerous GCM experiments have revealed that in summer a dramatic decrease in the level of precipitation and soil moisture content can be expected in Middle Europe. At the same time, in winter a small precipitation increase is

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predicted. Besides the warming a 0–10% precipitation increase in winter and 10–30% decrease in summer is predicted by statistical investigations. Significant reduction of soil moisture content would be expected as well.

Forest responses to the regional climate change

The ratio of forested lands in Hungary is rather low (18.9%), so the forests have high economic value and give us other important benefits. The forest ecosystems can be used as excellent indicators for description of climatic conditions. Hungarian zonal forest associations can be characterised by some climate indicator tree species; oak (here *Quercus petraea*) beech and hornbeam.

Impact on forest production

Although many tree species may benefit from a warming of up to about 1 °C, further warming combined with water deficiency may lead to poorer growth and even dieback. Due to an increase in temperature in the Carpathian Basin, an increase in the number of warm and dry days in summer can be expected. Those areas where some sensitive species (such as beech) grows well may be limited to the coolest and wettest areas in the western part of Central Europe, for instance, a yew (*Taxo fagetum bakonyicum*) forest died back in the Bakony Hills in 1939–40 and 1990. This period of dieback is supposed to coincidence with periods of high temperature, possible associated with summer drought, extreme soil drying and death of fine roots. In Hungary, 20% of the forests are Locust-tree. Hungarian foresters have observed the Locust decay during of ICP Forest surveying and in practice. The possible reasons of this decay are the increased soil surface acidity caused by acid rain and deteriorating nutrient uptake and the soil drought. In general, the positive perspectives of forest production are likely to be balanced, to some extent, by negative aspects associated with environmental change.

Impact on distribution of tree species

The distribution of trees in Central Europe is, in part, influenced by temperature during the growing seasons, when it must be warm enough to allow flowering, seed formation and ripening, and by certain winter conditions such as the frequency of frosts. Changes in climate have the largest effect on plant populations which are growing near the limits of their environmental tolerance. In the Carpathian Basin, an increase of about 2 °C is most likely to affect those trees whose present distribution shows that they are near the edge of their range here. The long life-cycle plants, such as hornbeam (*Carpinus betulus*), sessile oak (*Quercus petraea*), beech (*Fagus sylvatica*) or Scots pine (*Pinus sylvestris*) will probably suffer from water deficiency in summer because of increased assimilation activity and evapotranspiration. Less mushrooms can be a good indicator of drying, because many tree species grow well in a mychorryse environment and the mushroom-tree connection is interrupted by reduction in the water supply.

The climate will be favourable for those plants that can tolerate summer droughts and demand or eventually tolerate precipitation surpluses in spring and winter, therefore the appearance of plant species of southern character, such as eastern hornbeam (*Carpinus orientalis*), Turkey oak (*Quercus cerris*), Hungarian oak (*Quercus farnetto*) is expected.

Based upon the climatic scenarios mentioned above, the anticipated forest responses can be summarised as follows. A higher rate of assimilation can be expected from the vegetation due to warming and an elevated level of atmospheric carbon dioxide. The faster development would be more advantageous for the short life-cycle plants while the long life-cycle ones would likely suffer from water deficiency in the mid-summer period because of increased assimilation activity and evapotranspiration.

The effect of winter precipitation surplus would fade-off by the beginning of the vegetation season, while the altered light and heat conditions would create a dangerous situation for the trees, causing reduced yields in them. Although, agriculture may somewhat compensate for the summer drought damages of the irritable plants with a short life-cycle, this is not valid for the forests. Under the influence of the climatic factors the warmth demanding and drought tolerant plant species may be pushed forward at the cost of the more sensitive ones. The geographical extension of indigenous forest associations would also change: these ecosystems would become translocated in northerly direction and towards higher altitudes, respectively. These changes primarily affect the plant associations bordering each other in the transitional zone. In the middle part of the Carpathian Basin, the continental climate zone may turn into typical steppe climate, therefore the extension of the regions covered by forest steppe would be larger in horizontal and vertical directions, as well. The beech forests would also retire, whereas in the turkey oak-sessile oak forests the turkey oak may have a dominant role. The most disadvantageous climatic changes may be experienced by our lowland coniferous stands as we already can see in the black pine (*Pinus nigra*) forests of the Balaton hills. The living conditions of bush forests (*Cotino-Quercetum*) on dolomite rocks would be extremely restricted, however their presence on the erodible soil of steep slopes is very important. This soil would be set very strongly to summer warming, too. Higher temperatures and changed precipitation may well lead to an increased fire risk in the forested areas.

Pest and pathogens, in some cases, are expected to increase their ranges as a result of climate change and, in the case of insects, their population densities. Conditions that are more favourable for tree growth are likely to be more favourable for certain insects and diseases as well. Migration of pest or pathogen species from south could cause unforeseen losses as happened in some occasion in southern part of this area.

Influence on forest management and planning practice

As has been emphasised, the lands covered by forests must be preserved so as to avoid erosion in the Carpathian Basin. In consequence of this, it is essential to pay regard both to the exploitable age of different tree species (as for tree species growing slowly it can reach at least 100–150 years) and to the predicted climate changes which should be taken into account when we make any plan of afforestation works.

The method of gradual regeneration should be a widely used application instead of clear cutting. This reforestation method could moderate all kinds of harmful effects on forests: we will not face the danger of drastic impacts on soil biology, we need not cope with heat basins and as a result we will be able to save sensitive regrowth from unfavourable impacts. Some of these impacts can be moderated to a certain degree by using mixed stands.

Of course, we will have to continue to study how to mix different tree species and the results should be quickly adopted in practice. More attention will also have to be paid to the progenies and climate variants of propagating materials. In the case of a decreasing water table level, foresters are sometimes forced to use techniques at variance with custom, like deep boring planting, which can bring new forests with a good yield if buried humus layers can be found under the layer of moving sand.

Weather extremities also influence the year-to-year forest management practice. Unexpected meteorological events like heavy storms, rains or snow cover (as happened during the last three years) can cause serious damage and probably upset both the annual forestry schedules and the schedules used by the primary wood industry. If the probability of extreme precipitation increases, it will need to be considered by the watershed management of the forested hilly region. Keeping back running water by some mountain entrapments is beneficial to the forest's microclimate. Severe drought can cause considerable decay during the period of plantation and vegetation season especially in young forests and afforestations. The climatic trends mentioned above will have an influence on the seed trade and the practice of propagation. The lack of forest cover in the Carpathian region could contribute to the great scale floods in the Hungarian Great Plains and to the actual poisonous floods in the river Tisza region. The changes in the ownership structure of forest and the increased illegal deforestation in the watershed area strongly affect the lowland living conditions.

Influence on socio-economic conditions

The vulnerability of these systems is increasing parallel to the changing of other natural/ecological conditions. The most valuable agriculture lands in the Carpathian Basin are on the dry side of the dry/moist boundary line, and this line will move towards the North and the West because of the climate change. In this way, more and more areas will be getting into the unprofitable class, particularly if we consider the increasing costs of watering and the decreasing amount of good quality water.

It is not suitable to abandon these lands because both rich lands and the infrastructure are damaged by the deflation mentioned above, even if Hungary is constrained to reduce its agricultural production in the course of accessing the European Community. On the other hand, in these areas we have to save the population sustaining capacity in order to prevent migration from the country to the cities, which can cause several problems.

The anticipated drought-like climate will raise other problems, as well. Agriculture can change species considering the site conditions. In the practice of forestry, the production or growing cycle is very long; 40–150 years depending on the species. According to the climatologists, the inclination towards drought will increase considerably in the Carpathian basin and it will demand different management practices. In case of new forest plantations, we should select not only the indigenous ones, but also other species, which can tolerate unfavourable conditions. This raises another problem; the issue of nature conservation, which is opposed to planting of non-indigenous trees.

Considering the influence of forests on the soil, the surface and subsurface waters, the population, and their life quality and economy, we should establish forests which can grow well under the future conditions. It is not only a forest-related but environmental and socio-economical interest, as well.

Assessment of the potential impact of climate change has necessarily been based on shifts in present-day bioclimatic zones and associated geomorphological, hydrological and ecological processes. Major forest-type zones and species may also shift a tenth of a kilometre poleward over the next 40 years which primarily leads to an increase in the mortality owing to physical stress (enhance of susceptibility to infestations of insects and diseases) and a change in production and composition of species, as well. Although the potential environmental changes are certainly of a severe nature, it should be noted that the presumed warming could occur considerably faster than the migratory rate of most species.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–2	–1
High temperature	–3	–2
Drought	–3	–2
Wind / Storm	–1	–1
Snow*	±1/0	±1/0
Fire	2	–1
Insects	–2	–1
Fungi	–2	–1
Animals	–3	–1

*Snow, it depends on the level/scale of the snow cover and duration. Snow can break the trees and save the seedlings against animal and drying, frost damage. But the young seedlings can suffer from a lack of air under the iced-snow surface.

Notes to Table 1

In the Carpathian-Basin, up to +2 K (0.0073 °C) annual mean temperature change. The annual precipitation probably will change by –10%. The seasonality is more important than the annual mean. In this case the precipitation may increase in winter but considering the higher temperature it would be rather in form of rain than snowfall. This is important for the vegetation, because it means that the number of the snow-covered days may decrease. Due to a higher winter temperature more, and non-indigenous insects can attack seedlings.

During the summer period the growing season may increase 5–10 days, but the precipitation may decrease –30% at the same time. In this case, the drought frequency increases and the site conditions worsen for the forests, mainly for regeneration. In the dry summer, the wild animals look for water and moisture, what they found in seedlings and sprouts. The dried vegetation can suffer from potentially frequent fires, in this case regeneration is more vulnerable than the mature forest.

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change*	–3	–2
Rate of precipitation change	–3	–2
Rate of CO_2 concentration change	+1	+2
Extreme temperature:		
Minimum**	–2	–1
Maximum	–3	–1
Length of the growing period	+1	+2
Changes in temperature and precipitation in:		
Spring	–1	0
Summer	–3	–1
Autumn	–3	–1
Winter	0	0

Remarks: * the anticipated climate scenario is different for the Carpathian Basin than the Table 4 shows for the Continental areas. The annual precipitation won't be substantially higher than nowadays until the temperature change reaches the +4 °C. But till +2 °C temperature change the annual precipitation will decrease by about –10%.
** The minimum temperature is a main natural limit for the southern species to migrate or be introduced into the Carpathian Basin.

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Continental			
Scots pine	0	–1	+1
Norway spruce	–2	–2	+1
Beech	–1	–1	+1
Oak	–1	–1	+1

Remarks: Scots pine is rather resistent species in this area, Norway spruce is not really indigenous specie and its present distribution is larger than the real site possibility. Beech is not really montaneous beeches, but sub-mountan beeches (*Carpino-fagetum*) are in this area, with a lot of other species as *Ulmus, Tilia*, *Acer.* In this way the proportion of the "secondary" species will reach a higher level. Oak: This is very simple for us in this form, because we have *Q. robur* in the "close to water" site, *Q. petraea* with sub-humid site condition, *Q. cerris* mainly in drier sites and *Q. pubescens* in dry sites (because this basin is a mixture of the climate regimes).

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: +2 °C
Mean annual precipitation: +10–20%
CO_2: 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Continental			
Scots pine	+0–5	+0–10	+10
Norway spruce	–0–5	+0–5	+5
Beech	+0–5	+5–10	+10–15
Oak	+0–5	+5–10	+5–15

Estimate of the probability to occure in general: medium.

In the above cases I account with sites where the precipitation and air moisture will cover the demands of trees even if the higher CO_2 level may increase the effectiveness of the water consumption. There are many sites, mainly the southern ones, where the growth will decrease because of drought and because the soil- and air moisture is far less than that which could cover the increased demands, due to increased evapotranspiration.

Two scenarios are considered for the Carpathian Basin:

1. We accept the continental average changes of the annual mean temperature and annual precipitation totals, estimated for the year 2050. For the three other dates, given by you, we employ the qualitative feature of the scenarios elaborated by Dr. Janos Mika, Hungarian Meteorological Service, during the 1988–1998 period.

2. We apply his scenarios considering the 530 ppmv CO_2 concentration + the IPCC (1996) medium (92a) global scenario (1 Kelvin = 1/247 °C).

Scenario 1:

Year (Y)	Global change of temperature Y–1860, K	Regional change of annual mean temperature, K	Regional change of precipitation per annulum, %
2020	+1	+1.4	–10
2040	+1.5	+1.8	±0
2050	+1.75	+2	–10–20
2060	+2.0	+2.2	+20

Scenario 2:

Year (Y)	Global change of temperature Y–1860, K	Regional change of annual mean temperature, K	Regional change of precipitation per annulum, %
2020	+1.0	+1.4	–15–10
2040	+1.2	+1.8	–10–5
2050	+1.75	+2.0	–10–0
2060	+2.0	+2.2	–10–15

Italy, Malta, Greece and Albania

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Peculiar features of the Mediterranian region

As opposed to the other climatic types included in this assessment (Boreal, Atlantic and Continental), which can be considered to occur in rather well defined *macro-regions*, Mediterranean-type conditions are occurring in a variable landscape, that, in turn, makes the classification susceptible to further categorisation. In fact, due to the large geographical and topographical variability related to the presence of a variable coastline and many mountain ranges, the typical climatic bi-seasonality with dry and hot summers and moist and cool autumns and winters is locally influenced, creating a basis for a high diversity of plant and animal species and a rich variability of forest types (Scarascia Mugnozza et al. 2000). As a result, the number of tree species in the Mediterranean is quite large compared to the figure for central Europe (100 vs. 30, respectively).

The natural vegetation of the Mediterranean region also depends on altitude. The truly Mediterranean vegetation zone is represented by the plains and the low-elevation valleys all along the coast. It can be subdivided into *Thermo-Mediterranean* and *Meso-Mediterranean* belts and corresponds approximately to the area where olive trees are cultivated (Quézel 1985). As the elevation increases, we move from the *Supra-Mediterranean* to the *Montane-Mediterranean* and *Oro-Mediterranean* vegetation zones (Quézel 1985) with completely different forest types. Furthermore, latitude and topographic exposure affect this vegetational succession.

The Mediterranean region is characterized by a high proportion of broadleaf (approximately 60%) relative to coniferous forests. Broadleaf forests are composed of evergreen and deciduous oaks (*Quercus ilex*, *Q. suber*, *Q. pubescens*, *Q. cerris*), while pine species are the main component of coniferous forests (*Pinus halepensis*, *P. pinaster, P. pinea*). There is also a variety of mixed stands and low density, woody vegetation like the "macchia" and the "garrigue", often produced by the degradation of more complex forest types. In the low plains and along the rivers, in the absence of water limitation, forests of *Quercus robur*, *Fraxinus* spp., *Populus* spp. can thrive. As the elevation increases, other types of forests appear, partly made up of endemic Mediterranean trees but also with tree species that occur in other parts of the European continent, such as *Fagus sylvatica*, *P. sylvestris*, *Abies alba* and others (*Castanea sativa*, *Pinus laricio*, Mediterranean firs).

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The proportion of forest cover relative to the total land area is also quite different among sub-regions of the Mediterranean basin: it varies from nearly 30% in Italy to 50% in Greece and Albania, although in the latter countries only one third of the forests is utilized for wood and timber production, the remaining area being covered by under-stocked woodlands or by maquis-type vegetation.

Approaches used for expert judgement

Due to the peculiarities discussed above and in order to take into consideration the variability of climate and the diversity of forest types, for the present assessment the *Mediterranean* climate has been divided into three main types. These types are closely linked to the vegetation zones as defined by Quézel (1985) and can be summarised as follows:

a. *Thermo-Mediterranean* zone: plains and low-elevation valleys along the coast (0–300 m a.s.l.);
b. *Meso* and *Supra Mediterranean* zone: from the hills to the lower elevation of the mountain ranges (400–800 m a.s.l.). This belt can include also lower elevations and plains at distance from the sea;
c. *Montane* and *Oro-Mediterranean* vegetation zone: mountain ranges from 800 to 1600 m a.s.l.

For the Mediterranean region, five key species have been selected by EFI to be included in this assessment: *Pinus halepensis*, *P. pinaster*, *P. sylvestris*, *Quercus ilex* and *Q. pubescens*. According to the above reported vegetation zones, the key species occur as follows:

- *Thermo-Mediterranean* zone: *Pinus halepensis, P. pinaster, Quercus ilex*;
- *Meso* and *Supra Mediterranean* zone: *Pinus pinaster*, *Quercus pubescens, Q. ilex*;
- *Montane* and *Oro-Mediterranean* zone: *Pinus sylvestris*.

Scots pine is also present in one of the *Supra-Mediterranean* stations.

To quantify the climate situation for the years 2020, 2040 and 2060, we have used climate scenarios generated by the Potsdam Institute for Climate Impact Research (PIK) following the outputs of the Hadley Centre Global Circulation Model *HadCM2*. The *HadCM2* has a spatial resolution of 2.5° x 3.75° (latitude by longitude) that has been refined to a grid of 0.5° x 0.5° by PIK. PIK generated climate data for the period 1831–2100 for a number of sites, applying an exponential increase of [CO_2] from the year 1990 to the year 2100, when atmospheric [CO_2] will reach approximately 700 µmol mol^{-1}.

For the present assessment, we have used climate data and scenarios for 10 sites in Italy: four in the *Thermo-Mediterranean* zone and three for each of the other two zones.

Averaged over all sites, the changes in climate by 2050 compared to 1860 consist of an increase by 4.3±0.8 °C in mean annual temperature and by 10.2±3.6% in total precipitation (Table A). Both values are in the upper range of the reported figures for climate change in the Mediterranean indicated by EFI (see Table 4, top).

According to this approach, in Tables 1 and 2, three values have been included, one for each vegetation zone (a, b and c).

The relative impact of climate change on forest growth (Table 4) for the key species has been estimated using the outputs of the HYDRALL model (Magnani et al. 1999, 2000) for the coniferous forests and by expert judgement, corroborated by direct experimentation on *Quercus ilex* (Scarascia Mugnozza et al. 1996; De Angelis and Scarascia Mugnozza 1997), for deciduous and evergreen oaks. For coniferous forests, we have considered the effect on the current annual increment (CAI), averaged over 10 years, for 2010–2030, 2030–2050 and 2050–2070. Current growth refers to the 1950–1990 period. For each period, the increments of all age-classes in the range 10–110 years have been averaged.

Overall impacts and management options

According to the climate scenarios, in absolute terms, the largest temperature increase should occur in the *Thermo-Mediterranean* zone, followed by zone b and c, respectively (Table A). However, when the percentage change in temperature is calculated, the effect appears to be very important in the mountain zone (zone c).

Although predictions for precipitation are much more uncertain than those for air temperature, the predicted slight increase of rainfall (10%) might not cover the augmented evaporative demand driven by increased temperature in a changed climate, possibly causing harmful effects on the vegetation of the driest areas, that should be the most vulnerable to climate changes.

In relation to vulnerability, it must be stressed that a temperature change such as that predicted could have a strong impact on the forest tree species, whose altitudinal distribution is also linked to temperature conditions (both average and extreme temperatures). In this respect, we have calculated that a 4 °C change in temperature will significantly shift the present vegetation zones upwards (or northwards). Actually, it is not possible to anticipate what the precise effect of such a shift on vegetation distribution will be, but surely there will be an impact, particularly for important forest processes such as regeneration, species competition and overall stand stability. The impact should be more relevant in coastal and high elevation zones, where vegetation is already subjected to environmental extremes. A warmer climate could also increase the frequency of fires, with all their environmental consequences; this risk is very likely to occur because the increasing level of atmospheric CO_2 will increase the accumulation of woody biomass and litter in the Mediterranean forests.

For the Mediterranean region, another fundamental consideration pertains to the period in which the temperature increase will be more pronounced. In fact, if the increase will be concentrated in autumn-winter time, it will be more beneficial than detrimental to tree growth, while the reverse will be true in the case of a more pronounced increase in late spring or summer.

Table A. Temperature (°C) and precipitation (%) change in year 2050 compared to year 1860. The changes have been calculated from 20 year-means (1850–1870 and 2040–2060) of climatic data generated by PIK for 10 sites in Italy over the period 1831–2100. The values are means and standard deviations of the changes occurring in four (zone a), three (zone b) and three (zone c) sites. The average changes in temperature and precipitation are also reported for *P. halepensis*, *P. pinaster* and *Q. ilex* (7 stations in two zones) and *P. sylvestris* (4 stations in two zones)

Zone or tree species	°C	T, %	Precipitation, %
a) *Thermo-Mediterranean*	4.8±0.3	31.2±3.6	13.1±1.8
b) *Meso* and *Supra Mediterranean*	4.4±0.2	38.2±4.4	10.1±1.1
c) *Montane* and *Oro-Mediterranean*	3.7±1.4	73.5±43.1	6.4±3.7
Average	4.3±0.9	46.0±28.1	10.2±3.6
P. halepensis (a zone)	4.8±0.3	31.2±3.6	13.1±1.8
Q. pubescens (b zone)	4.4±0.2	38.2±4.4	10.1±1.1
P. pinaster, Q. ilex (a and b zones)	4.6±0.3	34.2±5.2	11.8±2.2
P. sylvestris (c and 1 station of b)	3.9±1.3	65.5±43.1	7.5±3.8

Apart from the general considerations above, critical for the correct understanding of climate change impacts in the Mediterranean basin, according to modelling results and the expert evaluation, the global effect of climate change on forest growth will be neutral or slightly negative for zone a (±10%, 3 key species), moderately positive in zone b (20–30%, 3 key species) and clearly positive in zone c (70–100%, 1 species). For *Q. pubescens,* the slight positive effect will be mostly due to the longer growing season; nevertheless, this effect is not so pronounced because of the expected increase of water deficit in summer. *Pinus pinaster* and *Quercus ilex* present an almost unchanged growth pattern under climate change conditions. The strong effect estimated for *P. sylvestris* is linked to the current growth limitations that this species suffers under cold climates. In particular for this species, the risk of vegetation shift is particularly high.

It is possible to propose some considerations on the management options that could help Mediterranean forest stands to cope with climate change. In a warmer climate with increased evaporative demand, forest regeneration after harvest will need to be assisted during the establishment period. Possibly, a tendency to shorter rotation lengths can be expected, due to the concurrent effect of increased CO_2 (predicted to be more relevant at the younger stage) and the increased temperature that could possibly lead to anticipated stand senescence. Thinnings should also be conducted to limit soil water depletion, particularly on dry sites. Nevertheless, a balance needs to be found in order to avoid soils exposure to direct evaporation.

For afforestation and reforestation purposes, the provenances of tree species with proper temperature and water stress adaptation should be selected and utilised for plantations. In this respect, a wise strategy should aim at selecting already in this present times the most suitable provenances and species.

The warmer climate with enhanced evaporative demand calls also for a more fruitful and efficient forest fire prevention and control activity. The implementation of these activities will obviously have an increased cost, and, hence will need a change in environmental policy priorities.

Forests in the Mediterranean area also have a relevant recreational function: in this respect, more stunted or less luxuriant forest stands are less likely to satisfy to the recreational needs of local and tourist populations.

A major concern is raised by the highly fragmented conditions of forest stands in the Mediterranean zone; the lack of “green” connections and corridors in the Mediterranean landscape may become very harmful in the future environment if the present forest vegetation may be required to migrate towards more suitable areas.

Relevant literature

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	0(a, b) –3(c)	–1(a, b) –2(c)
High temperature	–1(a) 0(b) +1(c)	–1(a) 0(b) +1(c)
Drought	–3(a, b) –1(c)	–3(a, b) –1(c)
Wind	0(a, b) –1(c)	0(a, b) –2(c)
Snow	0(a) –1(b) –3(c)	0(a, b) –1(c)
Fire	–3(a) –1(b) 0(c)	–2(a, b) 0(c)
Insects	–1 (a, b, c)	–1 (a, b, c)
Fungi	0 (a, b, c)	–1 (a, b, c)
Animals	0 (a, b, c)	0 (a, b, c)

Remarks: see text.

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1(a, b) +1(c)	–1(a, b) +1(c)
Rate of precipitation change	+3(a, b) +1(c)	+3(a, b) +1(c)
Rate of CO_2 concentration change	0(a, b, c)	+2(a, b, c)
Extreme temperature:		
Minimum	0(a, b) –3(c)	0(a, b) –3(c)
Maximum	–1(a) 0(b) +1(c)	–1(a, b) +1(c)
Length of the growing period	0(a) –1(b,c)	0(a) +1(b) +2(c)
Changes in temperature and precipitation in:		
Spring	0(a, b) –1(c)	+1(a, b) +2(c)
Summer	–3(a, b) +1(c)	–2(a, b) +1(c)
Autumn	0(a, b) –1(c)	+1(a, b, c)
Winter	0(a, b, c)	+1(a) 0(b) +1(c)

Remarks: According to most climate scenarios, we are considering for precipitation, an increase of the total amount and not a decrease (see text).

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Mediterranean			
Pinus halepensis	–3	+1	+1
Pinus pinaster	–2	+1	+2
Quercus ilex	–2	+1	+1
Quercus pubescens	+1	0	+1
Pinus sylvestris	+1	0	+2

Remarks: the impact has been estimated by considering the change of each factor in a climate change scenario and not with respect to the effect of temperature, precipitation, and [CO_2] as climatic factors *per se*.

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Mediaterranean +1–3 °C
Mean annual precipitation: Mediterranean –15–+10%
CO_2: Mediterranean 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Mediterranean	–2(a), 22(b), 75(c)	–8(a), 27(b), 73(c)	–27(a), 35(b), 109(c)
Pinus halepensis	13	–3	–43
Pinus pinaster	0	3	6
Quercus ilex	±10	±10	±10
Quercus pubescens	10	10	20
Pinus sylvestris	64	64	92

Remarks: For coniferous species, estimates of percentage change in the stand's current annual increment in the period considered, relative to the 1950–1990 reference, are derived from simulations of the Hydrall model (Magnani et al. 1999), using site-specific climatic scenarios produced by the Hadley Center. For broadleaved species, estimates are derived from expert judgement, corroborated by direct experimentation on *Quecus ilex*, for deciduous and evergreen oaks.

Norway

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Introduction

Prehistoric climate variations of significant magnitudes have occurred in Norway. The surface air temperatures in the period from about 6000 to 2600 years BC is comparable to those expected 50 years ahead. So, a notable change to a warmer climate, as such, is probably not a threat to our forests. The likely threat is the rapid changes, which are indicated by the climate scenarios. Trees are long living structures and cannot easily adapt to permanent changes beyond a certain level in periods much shorter than their normal lifetime. Evaluations of meteorological data have shown increased surface air temperature in the northern hemisphere of about 1 °C during the last 100 years. This change has obviously not been critical to our forests. However, a two- or three-fold change in the next 50 years might be beyond critical biological limits. As the magnitude of estimated changes are still uncertain, we must wait and see how the experimental factors of this gigantic global forestry test develop.

Forested areas and historical changes in timber production

Norway is dominated by large alpine areas, which is partly covered by unproductive deciduous forest, mostly birch. The productive forest land covers only 74000 km^2 or 24.1% of total land area (Table A). About one third of this area is “mountain forests” where climate restricts growth and reproduction either directly or indirectly. Low temperatures in the growing season and episodes of strong wind are the main restrictions to these forests, while availability of water is regarded adequate or in surplus.

The historical development of standing timber volume and increment under bark is summarised in Table B. From 1925 to 1995 timber volume and increment more than doubled and the rise has been most pronounced after 1970. Introduction of more effective silvicultural methods, considerable investment programs in primary production and less extracted timber volume than the increment are likely explanations. Examples of investments include the conversion of birch and pine forests in coastal areas to highly productive spruce forests, regeneration of spruce forests by clear-cutting and planting, systematic regeneration

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of pine forests with seed trees and afforestation of significant peatland areas by drainage and fertilisation. It is likely that the growth response is partly caused by warmer climate, especially in the last 25 years, but this effect is hard to prove by statistical means.

Predicted changes in Norway due to climate gases

Predicted climate changes in Norway from 1990 to 2040 are as follows:

- Surface air temperatures of about 2 °C higher in summers and 3–4 °C higher in winters. Less increase in the coastal zone compared to inland areas.
- Intensified hydrological cycles with more precipitation (5–15%). Showers will be more frequent and bring a larger fraction. Increased soil moisture in winter and decreased in summer.
- Increased wind speed, indicating higher frequencies of storm episodes.

Local and regional climate variations in Norway are quite large. Both orography, south-north variation from temperate to arctic and east-west variation from oceanic to continental explain the regional variations. The rather rugged landscape creates significant shifts of local climate over short distances. The mountain range from south to north has a profound effect on

Table A. Forested land area in Norway (km^2).

National land area on mainland		306808	100.0%
Productive forest land	74000		
Mountain forest	22200		
Lowland forest	51800		
Unproductive forest land	46000		
Deciduous forest above timberline	23000		
Impediments within productive forest	17000		
Peatlands with tree cover	6000		
Total tree covered land		120000	39.1%

Table B. Historical development of timber volume and increment under bark for productive forest land (million m^3).

Year of taxation	1925	1950	1958	1970	1984	1990	1995
Timber volume							
Norway spruce	165	197	206	227	251	273	300
Scots pine	91	113	121	140	168	186	212
Broad-leaved	56	57	58	72	88	123	137
Total	312	367	385	439	507	582	649
Increment							
Norway spruce	6.00	7.52	7.39	7.63	8.64	10.72	11.37
Scots pine	2.72	3.29	3.56	3.75	4.49	5.17	5.75
Broad-leaved	1.96	2.09	2.06	2.42	3.37	4.42	4.79
Total	10.68	12.90	13.01	13.80	16.50	20.31	21.91

precipitation pattern, as cyclones are often brought by westerly winds. Precipitation of more than 5000 mm has been measured at some distance from the coastal line in the fjords of the South-West Norway The precipitation is generally much lower to the east of the mountain range, at some locations even extremely low, only 200–400 mm. We expect that the climatic contrasts between coastal and inland sites of Norway will increase if the predicted climate changes come true. The large regional and local variations in climate are probably important for the discussion of likely impacts of climate changes on forestry.

Likely overall forestry changes

Table 1 lists the current statuses of regeneration and growth sensitivity to some key factors. If climate changes over the next 60 years reach the criteria presented, several physical and ecological shifts are probable. As delays in vegetation response and unforeseen interactions are difficult to judge, the evaluation of impacts in Tables 2–4 must be regarded as qualified guesses.

Higher growth season temperatures will cause a movement of the present forest geographic regions north or northwestwards. The existing boreonemoral zone will either partly or fully turn into a nemoral zone with dominance of broad-leaved species. This will include low altitude land in South-central Norway as well as coastal areas through Middle Norway (65 °N). The present south boreal zone will convert to a boreonemoral forest zone with a greater mixture of deciduous and coniferous species. It is likely that the southwestern extension of Norway spruce will be pressed northeast. The actual change in species composition will depend greatly on future silvicultural strategy. The timberline can be moved vertically upwards about 200 meters, less to the west of the mountain range and more to the east side. The mires, which have stump layers from the forests growing in the warm prehistoric period, are likely to become productive forests again.

There will be less snow cover in the current nemoral and boreonemoral zone with “green winters” and more winter run-off. This will cause less soil water saturation in spring, which should increase the frequencies of early summer droughts. This could become a problem especially in the Southeast on sites with shallow soil and, more generally, for shallow rooted species like Norway spruce.

More frequent storm episodes might cause damage to the forests, both directly and indirectly. Storm fellings are likely to increase, as well as indirect effects on root systems causing susceptibility to devastating insects and pathogens.

Higher winter temperatures can result in more frequent thaw/freeze episodes. This might affect the chilling period required by the trees. If the winter period is interrupted by warm episodes followed by freezing temperatures, then meristems, buds, foliage of coniferous and even the root systems can be hurt. This mechanism is documented in several events of forest damage.

Elevated CO_2 concentrations will generally increase the primary production through a mediation of many physiological processes. However, a full response depends on optimality of other growth factors. Our forests today have large-scale nutrient deficiencies, especially of nitrogen. It is likely that this restriction will continue, maybe somewhat modified, even at a changed climate. In addition, we expect more frequent water restrictions in the growing season, at least in South-Central Norway. This means that elevated CO_2 levels will not be fully effective and the forests will not achieve their potential growth capacity.

Warmer summers are supposed to initiate more flowering and better seed quality. This will be an advantage for natural regeneration, whereas the opposite will be true for timber production. The width of the year-rings in Norway spruce are often reduced by 50% in a year of heavy flowering, with autocorrelated effects in following years.

Conclusions

The overall effects of the predicted climate changes in the next 60 years are hard to evaluate. There are problems in settling the account because of many positive and negative elements. Even so, some consequences are more obvious than others. We do have large genetic variation in our forests, so the basis for natural selection should be fairly good. This guarantees proper successional processes with low probability of ecosystem collapse. Our forests have currently 19 natural tree species, 17 broadleaved and two coniferous and a warmer climate will probably cause more species to immigrate. Species requiring warm summers will expand at the expense of Norway spruce, while Scots pine, usually growing on shallow and nutrient poor soils, will be more competitive and stay more stable. The mountain forests will respond greatly resulting in improved growth and reproduction. The productive forest area is likely to expand considerably. A significant part of the present deciduous forests above the timberline will become productive as well as a major part of the treed peatlands. Altogether, this might increase the productive forest area by more than 30%. However, there will be considerable successional lags in the ecosystems. So, the full effects of the estimated climate changes will not eventuate in the projected 60-year-period. It is likely that successions must go on for several forest generations. Even so, the perspectives for increased timber production in the next 60 years are fairly good (Table 4). The estimates are given under the presumptions of continued current intensity of silviculture, investments in primary production and timber cutting.

It is difficult to imagine and look into the depth of the predictions of the climate changes. However, the predictions are not a reality so far, and there are still possibilities that feedback-systems might check the warming process more than expected. Even if the predicted case comes true, the overall effects on the forestry in Norway are likely to be positive in the end. When the forests have reached their dynamic stability, both forest productive area, genetical selection, species selection, timber production and ecosystem diversity will most likely be improved.

Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–2	–2
High temperature	+3	+3
Drought	–1	–1
Wind	0	–1
Snow	–1	–1
Fire risks	0	0
Insects	–2	–1
Fungi	0	–2
Animals*	–2	0

Remarks: * Moose feeding on regenerated Scots pine sites.

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	+3	+3
Rate of precipitation change	–2	0
Rate of CO_2 concentration change	0	+1
Extreme temperature:		
Minimum	–1	0
Maximum	0	0
Length of the growing period	+2	+3
Changes in temperature and precipitation in:		
Spring	+3	+3
Summer	–2	–1
Autumn	+1	+3
Winter	–1	–1

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Boreal			
Scots pine	+3	0	+1
Norway spruce	+3	–1	+1
Birch	+3	0	+1
Atlantic			
Scots pine	+2	0	+1
Sitka spruce	+3	0	+1
Oak	+3	0	+1

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Boreal +2–4 °C, Atlantic +1–2 °C
Mean annual precipitation: Boreal +0–15%, Atlantic +0–10%
CO_2: Boreal and Atlantic 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Boreal			
Scots pine	25	35	35
Norway spruce	25	35	35
Birch	40	50	60
Atlantic			
Scots pine	5	15	30
Sitka spruce	20	25	30
Oak	+	20	40

Remarks: Indicated relative impacts on forest growth is the sum of silvicultural treatments, investments in primary production, timber cutting strategy and climate change. Estimate of the probability to occur in general: medium.

Poland

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	0	0
High temperature	–1	–1
Drought	–3	–2
Wind	0	–1
Snow	0	–1
Fire	0	–2
Insects	–2	–3
Fungi	?	–1
Animals	0	0
High winter temperature	–3	+1

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Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	0	1
Rate of precipitation change	–3	–1
Rate of CO_2 concentration change	?	?
Extreme temperature:		
Minimum	0	0
Maximum	–2	0
Length of the growing period	+1	+2
Changes in temperature and precipitation in:		
Spring	–1	+1
Summer	–2	–1
Autumn	0	0
Winter	–2	+1

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Continental			
Scots pine	–2	–1	?
Norway spruce	–1	–2	?
Beech	+2	+1	?
Oak	+2	+1	?

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Continental +2 °C
Mean annual precipitation: Continental +10–20%
CO_2: Continental 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Continental			
Scots pine	+2	–1	–3
Norway spruce	+1	–1	–3
Birch	+1	+2	+2
Oak	+1	+2	+3

Estimate of the probability to occur in general: medium and high.

Slovakia

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Introduction

Activities focused on likely impacts of climate change on forestry in Slovakia were concentrated into two main projects: The U.S. Country Study Program and the Slovak National Climate Programme. This expert judgement is based on the results from these two projects, where several models were used (e.g. Holdridge model, Forest Gap model, Dendroclimatological model).

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

According to the inventory of injurious agent's impacts on forests in Slovakia, the most important abiotic factors are wind, snow and rime, drought and air pollution. The most important biotic factors are: insects (mainly spruce and pine beetles) and fungi. Analysis of temporal changes of injurious agents showed an increase of drought and insect damages over the last 15 years. Current key sensitivities to weather and the mechanisms limiting forest regeneration and growth are presented in Table 1.

Impacting aspects of climate change in the future

Key impacting aspects of climate change in the future with regards to regeneration and growth were identified according to the model results. Precipitation change in relation to water balance changes will be the key parameter for growth on more than 50% of forest territory in Slovakia. Because of unknown changes of temperature variability it is difficult to evaluate the role of extreme temperatures within the climate change impacts. Key impacting aspects of climate change are summarized in Tables 2 and 3.

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Most vulnerable regions

Because the tree species composition of the Slovakian forests do not correspond with their natural demands, the vulnerability of the regions depends on tree species occurrence. Table A gives some information about vulnerability to climate change in relation to altitude and three main tree species in Slovakia.

Impacts of climate change on forest management

Changes in wood production, regeneration, health status and injurious agents due to climate change must significantly influence the management of forest stands. In particular problems with higher tree mortality, higher frequency of outbreaks and problems with the regeneration of forests will be important factors for change of forest management system. The system of forest management should be based on anticipatory measures with the aim of mitigating negative impacts of climate change in the forests. At first, it is necessary to define the principles of an adaptation strategy, which should result from a profound scientific analysis of possible climate change impacts upon forest ecosystems.

During the years 1996–1998, the basic principles of an adaptation strategy for the forestry sector in Slovakia were defined and prepared for discussion with forest policy makers in Slovakia. At this moment we are preparing an expert analysis of possible climate change impacts for the preparation of “The new state forest policy in Slovakia”, where aspects of climate change impacts should be taken into account.

Impacts on timber supply

Timber supply can be influenced through the growth changes of forest trees due to climate change or through the change of forest harvest as a result of climate change impact on forests. Generally, during the coming years (up to the 2060), a slight decrease of timber supply is expected. Based on Forest Gap model analysis, changes in biomass production will be different according to altitudinal zones in Slovakia (see Table B).

Based on the analysis of impacts on tree species composition, biomass production change (model results) and current age class structure of Slovak forests we try to estimate the expected changes in timber supply suitable for harvest in the years 2030 and 2070, respectively. Table C gives information about expected changes in the timber supply suitable for the harvesting of Norway spruce, European beech and Oak species in Slovakia.

Estimation of changes in timber assortments and timber quality is very difficult and, at present, we do not have any scientific or expert analysis.

Main adaptive options available

- The enforcement of silvicultural principles proceeding towards the close-to-nature approach on the basis of site, species and genetic diversity based on the natural regeneration of forest stands.
- Tree species composition change, based on the anticipatory strategy measures.
- Maximum limitation of one-storey pure stands and the relevant clear-cutting system, creating a forest with low biomass and carbon accumulation. In spruce pure stands, there is also the risk of low ecological stability as an accompanying factor of climate change.

Table A.

Natural forest communities	Altitude (m a.s.l.)	Norway spruce	European Beech	Oak species
Thermophilous oak stands	200–300	***	***	**
Oak-beech stands	300–400	***	**	*
Beech stands	400–600	***	**	
Beech-fir stands	600–800	**	*	
Beech-fir-spruce stands	800–1200	**		
Mountainous spruce stands	1200–1500	*		
Upper tree limit	□1500			

*** most vulnerable **moderately vulnerable *less vulnerable

Table B.

Region	Main tree species at present	Change in biomass production
Upper tree limit	Norway spruce	50%
Spruce mountain forests	Norway spruce	10%–20%
Mid-mountain mixed forests	European Beech, Fir, Norway spruce	0%–10%
Submontane mixed forest	European Beech, Oak species	–40%–0%

Table C.

1990 = 100%	2030	2070
Norway spruce	140–180 %	10–60 %
European beech	110–130 %	60–100 %
Oak species	220–230 %	70–90 %

- From the 1st up to the 4th altitudinal zone (up to an altitude of 700–800 m a.s.l.), the small-area shelterwood system should prevail in the future. A certain proportion should cover the stands with the silvicultural system of long-term two-storey stands, which should include the light-demanding and shade-bearing deciduous tree species, the others, the light-demanding coniferous species (pine, larch) and shade-bearing deciduous tree species (beech).
- Regardless of the ownership relationships the enforcement of close-to-nature silviculture systems, i.e. small-area shelter wood system and both forms of selection system, which should have typical local characteristics and a high resistance potential in forests.

Main implications for other sectors

Changes in forests due to climate change will be connected with the water management sector in Slovakia. Sensitivity and vulnerability analysis of the surface water resources on possible climate change showed that most vulnerable regions for surface water resources and forests are very similar. Therefore, changes of forest stands can bring additional problems into the water management sector such as higher differences between maximum and minimum runoffs, higher potential soil erosion and a decrease in the total water supply.

Main uncertainties and unknowns

The main uncertainties and unknowns regarding climate change impacts on forest ecosystems are:

- CO_2 effects on biomass production in relation to temperature and water balance changes, carbon and nitrogen cycles,
- soil mineralisation processes and nutrient availability,
- outbreaks and extended ranges of pests and pathogens.

Main policy implication

Because of the long life span of a forest it is reasonable and necessary to consider implementing the principles of adaptive strategy into the state forest policy. Results and resolutions from the "Ministerial Conferences on the Protection of Forests in Europe" (e.g. H4 resolution) could be a good basis for policy implication at the national level. The main problem for policy makers in forestry is to take into consideration climate change impacts on Slovak forests as important problems, which should be included in the state forest strategy and policy.

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Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	0	0
High temperature	–1	–1
Drought	–2	–1
Wind	0	–1
Snow	0	–1
Fire risks	0	0
Insects	–1	–2
Fungi	–1	–1
Animals	–2	–1
Air pollution	–1	–2

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	–1	–1
Rate of precipitation change	–1	–2
Rate of CO_2 concentration change	0	+1
Extreme temperature:		
Minimum	–1	0
Maximum	–1	–1
Length of the growing period	0	+1
Changes in temperature and precipitation in:		
Spring	0	+1
Summer	–1	–1
Autumn	0	+1
Winter	–1	0

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Continental			
Scots pine	0	–1	+2
Norway spruce	–2	–2	+1
Beech	–1	–1	+1
Oak	–1	–1	+1

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Continental +2 °C
Mean annual precipitation: Continental +10–20%
CO_2: Boreal and Atlantic 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Continental			
Scots pine	0%	–5%	–10%
Norway spruce	–10%	–20%	–30%
Beech	0%	–5%	–10%
Oak	0%	+5%	+10%

Remarks: These numbers are the average values for individual tree species on the whole forest area of Slovakia.

Switzerland

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Most vulnerable regions

For the Alps the most vulnerable regions concerning temperature change and associated change in the species composition are:

(a) low-elevation belts on low-elevation Plateaus and xeric inter-alpine valleys that undergo the risk of steppification,
(b) high elevation sites due to terrain instability (retreat of permafrost, avalanches).

Climate change impacts

For the Alps timber production is decreasing in its commercial value. For protection functions timber assortments do not play a vital role. For timber production on the Plateau we calculated commercial losses due to a long-term species shift from beech to hornbeam-beech forests that amount up to 25% for a warm-dry scenario but gains of up to 5% in the case of a warm-wet scenario (Kienast 1997). Warm-dry conditions will likely increase overall biodiversity since species rich-communities are enlarging (Kienast et al. 1997). Groundwater depletion is a serious problem, as well as soil erosion and retreat of permafrost.

Adaptive options available

No precautions were taken except a choice of tree species (beech-hornbeam instead of conifers in the lowlands) We simulate that under the current climate conditions, approximately 25–30% (depending on the model version used) of all Forest Inventory Points (FIP) must be considered as poorly adapted, i.e. less than 20% of the actual basal area consists of tree species that are expected as dominating taxa. This definition applies to trees with a DBH = 12 cm. Moderate warming increases the percentage of poorly adapted FIP by 5–10% (relative to all FIP considered), strong warming leads to a 10–30% increase of poorly

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adapted FIP (relative to all FIP considered). If trees with a DBH < 12 cm are considered, the percentage of FIP that have to be classified as poorly adapted is reduced significantly. (Kienast et al. 1996).

A CO_2 tax will be launched in 2000 in Switzerland.

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–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	0	–1
High temperature	0	0
Drought	–2	–2
Wind	0	0
Snow	0	0
Fire risks	+1	+1
Insects	–1	–1
Fungi	0	0
Animals	–1	0

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	+1	+1
Rate of precipitation change	–2	–2
Rate of CO_2 concentration change	0	0
Extreme temperature:		
Minimum	0	0
Maximum	0	0
Length of the growing period	+1	+1
Changes in temperature and precipitation in:		
Spring	+1	+1
Summer	0	0
Autumn	0	+2
Winter	0	0

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Continental			
Scots pine	0	0	0
Norway spruce	0	–1	0
Beech	–1	–3	0
Oak	+1	–1	0

Table 4. The relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:
Climate by 2050 mean annual temperature, compared to 1860: Continental +2 °C
Mean annual precipitation: Continental +10–20%
CO_2: Continental 530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Continental			
Scots pine	+10%		
Norway spruce	+5%		
Beech	+10%		
Oak	+10%		

United Kingdom

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Productivity and timber supply

Conifer plantations in the northern part of the UK have been increasing in growth rate in recent decades at a rate equivalent to an increase in yield (harvested at the time of maximum mean annual increment) of about 1 m^3/ha per decade. That is, young forests are growing faster than older ones growing on the same site types and in the same climates. Physiological models suggest that about half of that increase in growth may be attributed to the increases in atmospheric CO_2 and N deposition that have occurred this century, with a small additional affect of increased temperatures (Cannell et al. 1998). If this is true, then these forests may be expected to increase in growth further during the next century – maybe by 20–30% by 2050. Separate analyses of the relationships between temperature and the growth rates of these forests suggest that warming alone might increase growth by about 20–30% by 2050 (Worrell and Malcolm 1990; Proe et al. 1996).

This prediction of increased growth of conifer plantations in northern Britain may be expected to increase the supply of home-grown timber. At present, about 15% of the timber used in the UK is supplied from UK forests. However, this assumes that there is no increase in the frequency of high winds, which restrict the size and age of timber that can be grown in the UK. Any increase in storm frequency or severity would disrupt timber supplies and possibly negate the benefit derived from other changes in climate.

By contrast, drier conditions in the south of Britain are likely to have an adverse impact on the growth and maybe the survival of broadleaved woodlands, such as beech and oak. These woodlands showed signs of decline following summer droughts in 1976, 1984 and 1995. Therefore there may be decreased production of high quality hardwoods and greater reliance on imports of this type of timber (Parry et al. 1996).

Management strategies

Increases in the growth of conifer plantations will require repeated revision of yield predictions, harvesting schedules and forest values. Timber supplies per hectare will be

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increased, but the growth in total supply will also depend on the rate of continued forest expansion, which will depend on agricultural and other land use policies.

Adaptation may occur by using different tree species or provenances – bearing in mind that most of the timber grown in the UK is from exotic species already. Thus, more drought tolerant species such as Douglas fir and Corsican pine may be grown in southern Britain and more southerly provenances of Sitka spruce may be grown in the north.

Environmental policy

In the north, faster forest growth will have little impact on environmental policy, which is already finely tuned to take account of the effects of afforestation on biodiversity, recreation, water supplies and acidification. In the south, the decline of some tree species in heavily populated areas could have adverse effects on the flora, fauna and landscape. The recreational value of woodlands and urban trees would decline and have knock-on effects on the quality of life. Such forest decline could force a radical review of forestry and woodland conservation policy in southern Britain.

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–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature	–2	–2
High temperature	+1	+1
Drought	–2	–2
Wind	0	–3
Snow	0	–1
Fire	0	0
Insects	–3	–2
Fungi	–1	–2
Animals	–2	0
N deposition	0	+1

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change	0	+1
Rate of precipitation change	0	0
Rate of CO_2 concentration change	0	+1
Extreme temperature:		
Minimum	–1	–1
Maximum	–1	–1
Length of the growing period	+1	+1
Changes in temperature and precipitation in:		
Spring	0	+2
Summer	–1	+1
Autumn	0	+1
Winter	+1	0
Nitrogen deposition	0	+1

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Atlantic			
Scots pine	+1	0	+1
Sitka spruce	+2	0	+1
Oak	+1	–2	+1

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Appendices

Appendix 1: Content of the assessment (writing task):

Note that the maximum length is 3 pages + tables + list of 5 main publications relevant to your assessment.

- current key sensitivities to weather and the mechanisms limiting forest regeneration and growth (like drought, low temperature, wind and snow damage, fire risk, insects and fungi);
- key impacting aspects of climate change in the future;
- most vulnerable regions (like coastal areas, high elevations etc.), give a listing and why a region is vulnerable;
- impacts of climate change on management (soil management and preparation, species and provenance selection, precommercial thinnings and thinnings (timing and intensity), rotation length, harvesting methods and conditions);
- impacts on timber supply (timber assortments and amount: species and dimensions, quality);
- main adaptive options available (what are already in use and what should be applied: like management patterns, shelterbelts etc, land-use policy);
- main implications for other sectors (how the changes in the forests and forestry e.g. will effect forest industry, agriculture, ground water resources, recreation, management of biodiversity, and other sectors);
- main implications for other trends (e.g. climate change may aggravate near-term issues such as groundwater depletion, biodiversity, soil erosion, acidification etc.);
- main uncertainties and unknowns (in biological knowledge, in socio-economic understanding, future management systems, time and scale issues etc.);
- main policy implications (adaptation and risk management: changes in management policy, changes in forests and forestry in environmental policy, possible changes in the role of forestry in economics);
- your expert judgement of the relative impact of climate change on forest growth: percentage change (at least plus or minus, but preferably the estimate of the percentage) in growth by 2020, 2040, 2060;
- other issues you may want to discuss;
- list of 5 main publications relevant to your assessment.

Table 1. Current sensitivities to weather and the mechanisms limiting forest regeneration and growth. Provide your estimate of the importance of the following sensitivities to regeneration and growth. Scoring is:

–3	large negative impact
–2	moderate negative impact
–1	small negative impact
0	no effect
+1	small positive impact
+2	moderate positive impact
+3	large positive impact

Key sensitivity	Regeneration	Growth
Low temperature		
High temperature		
Drought		
Wind / Storm		
Snow		
Fire		
Insects		
Fungi		
Animals		
Other, specify		

Remarks:

Table 2. Key impact aspects of climate change in future (which changes will have most substantial impacts on regeneration and growth). Scoring is the same as in Table 1.

Key aspect	Regeneration	Growth
Rate of temperature change		
Rate of precipitation change		
Rate of CO_2 concentration change		
Extreme temperature:		
Minimum		
Maximum		
Length of the growing period		
Changes in temperature and precipitation in:		
Spring		
Summer		
Autumn		
Winter		
Other, specify		

Remarks:

Table 3. Key impact aspects of climate change for the future on some key tree species (which changes will have the most substantial impacts on regeneration and growth). Scoring is the same as in Table 1. See map indicating in which region your country is and provide your estimate for those species selected for your country.

Tree species	Temperature change	Precipitation change	CO_2 concentration change
Boreal			
Scots pine			
Norway spruce			
Birch			
Atlantic			
Scots pine			
Sitka spruce			
Oak			
Continental			
Scots pine			
Norway spruce			
Beech			
Oak			
Mediterranean			
Pinus halepensis			
Pinus pinaster			
Quercus ilex			
Quercus pubescens			
Pinus sylvestris			

Table 4. Relative impact of climate change on forest growth in general (in the region column) and by some key species (in the species columns): % change (at least plus or minus, but preferrably % estimate) in growth by 2020, 2040, 2060 compared to current growth. Climate scenario is as follows:

	Climate by 2050, mean annual temperature, compared to 1860	Mean annual precipitation	CO_2
Boreal	+2–4 °C	+0–15%	530 ppmv
Atlantic	+1–2 °C	+0–10%	530 ppmv
Continental	+2 °C	+10–20%	530 ppmv
Mediterranean	+1–3 °C	–15–+10%	530 ppmv

Tree species	Change by 2020	Change by 2040	Change by 2060
Boreal			
Scots pine			
Norway spruce			
Birch			
Atlantic			
Scots pine			
Sitka spruce			
Oak			
Continental			
Scots pine			
Norway spruce			
Beech			
Oak			
Mediterranean			
Pinus halepensis			
Pinus pinaster			
Quercus ilex			
Quercus pubescens			
Pinus sylvestris			

Remarks:
Give your estimate of the probability to occur in general: low/medium/high

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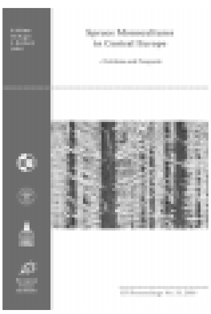

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