Draft version 1.0

COST action FP0703 – ECHOES

Country report

Austria

26 October 2009

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Content

1 Austrian forests

Austria has part in 3 biogeographical regions, Alpine, Continental and Pannonian, the last one being of minor importance in respect to area. This division between the Continental lowland part and the Alpine regions has to be taken into account when studying climate change impacts as well as when implementing adaptation and mitigation strategies.

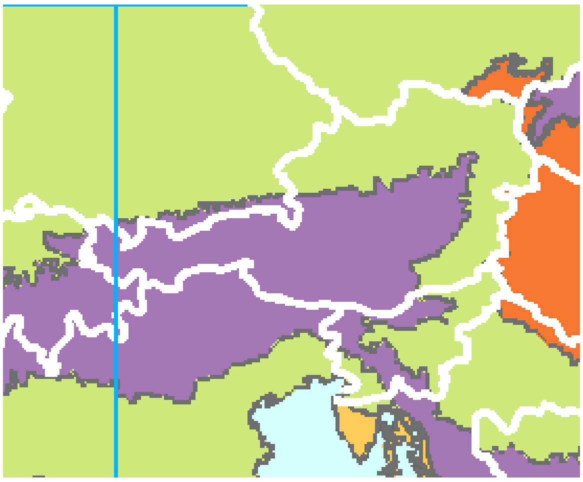

Figure 1. Biogeographical regions of Austria (from European Environment Agency, 2001).

Austrian Forests cover 3.6 million hectares, these are 47.2 % of the Austrian state area. From these 3.31 million hectares are productive. The federal provinces of Styria (61.1 %) and Carinthia (60.6 %) have the highest percentage of forest land, even the capital territory of Vienna has more than 21% of its area covered by forests.

The Austrian forests are dominated by conifers (81% of growing stock). The dominating tree species is Norway spruce, comprising 61.5% of growing stock. Most abundant broadleaved species is Common beech with 9.3%. Mean stock is 325 $m^3.ha^{-1}$, the annual mean increment being 9.3 $m^3.ha^{-1}$. Only 5.6 $m^3.ha^{-1}$ are harvested.

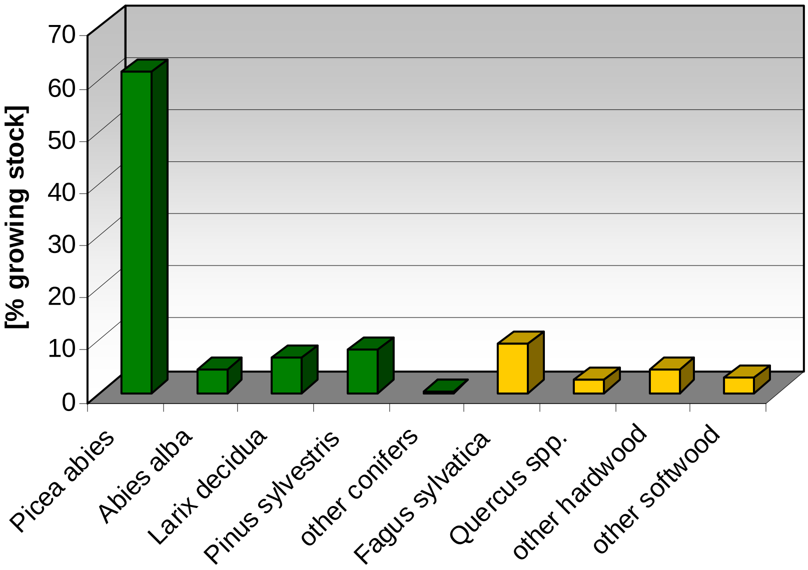

Figure 2. Share in growing stock for major species in Austrian forests. Source: Austrian Forest Inventory 2000/2002.

The Carbon stock in 1990 was an estimated 320 ± 42 Mt in the biomass and 463 ± 185 Mt in the Ectohumus and mineral soil, thus resulting in a total Carbon stock of 783 ± 190 Mt in the forest land. (Weiss et al. 2000). The mean annual increase of the Carbon stock in the biomass was estimated as 2.527 Kt between 1961 and 1990.

About 75% of the Austrian forests are private property and are managed by the owners. About one third of the forest land is managed by major forest companies. About 50 % of the forest land fall upon private properties of less than 200 hectares. The ÖBF AG (Austrian Federal Forests AG) manages the state forest, about 16% of the forest land, 9% are community forests, 2% communal forests and 1% is owned by the federal provinces.

The Austrian forest comprises 93 different forest biotope types, 53 are types are considered as endangered (f.e. floodplain forests, marshland forests). 22 types are not considered as endangered; further 18 types are classified as not specifically worthy of protection. The Austrian forests are considered to be of highest importance for the conservation and promotion of biodiversity. About 50% of the Natura2000 sites in Austria are forests.

In Austria almost no virgin forests are remaining (appr. 2% of forest area). Most of wooded lands have been used more or less intensively by men since the the last ice-age. Nevertheless, depending on the province up to almost 50% of forest area are classified as natural or near-natural (Figure 3).

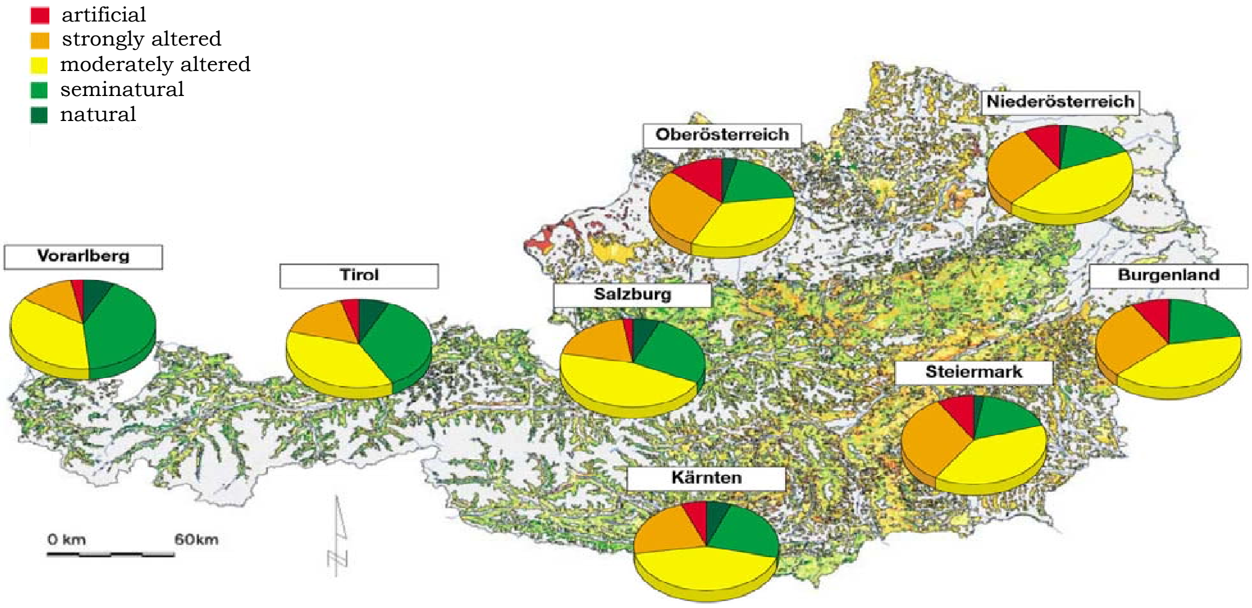

Figure 3. Naturalness of Austrian Forests in 8 provinces (province of Vienna not shown on map). Source: Federal Ministry for Agriculture, Forestry, Water and Environment.

Preservation of forests and its multifunctional effects by sustainable forest management are the focus of the Austrian forest law. Beyond a general habitat function it differentiates four forest functions: timber production, protection, recreation and social services (protection against climate, water production). As a typical landscape element of Austria forest forms a basis of recreation and hunting. The fores based sector is of great importance to the economy of Austria. The multifunctional effects of the forests depend on vitality, stability and ecological diversity. The Austrian Forest Programme of 2005 focuses amongst others on:

- stabilising of forest ecosystems in regard to climate change and carbon sequestration
- increasing use of biomass as renewable regionally produced energy and wood products
- maintenance and improvement of the protection effect of forests in regard to natural hazards
- maintenance and sustainable use of biological diversity and prevention of further losses
- reduction of immissions.

2 Impacts

2.1 Climate research, climate impact research

Climate change is currently intensively studied bei ZAMG (Zentralanstalt für Meteorologie und Geodynamik, Central Institute for Meteorology and Geodynamics), a multitude of projects mainly focussing on the preparation of climatological time series (f.e. ALOCLIM: preparation of a multiple, homogenized climate data set, which describes climate variability in Austria for the period since 1767 (beginning of measurements with instruments, ALPIMP: Reconstruction of climate variability within the Alpine region for the last 1000 years, CLIVALP climate variability within the Alpine region, FORALPS Climate change in the Alpine region and changes in the frequency of climatic extremes) *inter alia* used for climate change simulations.

Within a national research programme projects will be implemented which are focussed on regional and sectoral impact scenarios with their consequences on economy, ecology and social issues. The starting point is the inter-disciplinary research programme StartClim (www.austroclim.at) which looks into climate change and climate change impacts in Austria. Within this framework up to now the following themes were covered: Analyses of extreme events and their impacts, analyses of heat and drought and their impacts, clmate change and health, impacts on economy.

2.2 Observed Climatic Change

From Austrian long-time time series Auer et. al. (2001) have homogenized 9 meteorological parameters for Austria and neighbouring alpine countries (EU-project ALOCLIM). The homogenized time-series show a temperature increase of 1.8°C since the middle of the 19th century (Figure 4). In an earlier study Böhm et al. (1998) could show, that temperature trends are rather uniform in Austria, i.e. the trends north of the Alps, south of the Alps, in the eastern and western parts etc. do not differ significantly. All altitudinal zones are affected, temperature increase even being more pronounced in higher altitudes (Figure 5). There are indications for locally differing trends, which could not be verified up to now, however.

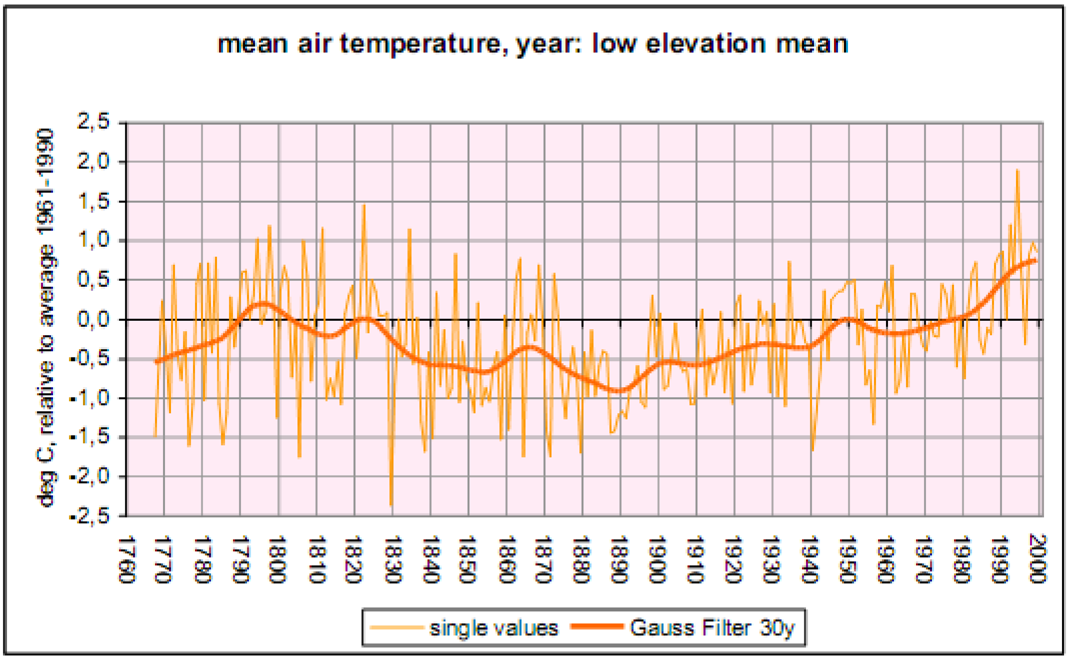

Figure 4. Mean annual temperature of the last 240 years for Austrian lowland meterological stations (single years and 30 years' filter). (Auer et. al 2001).

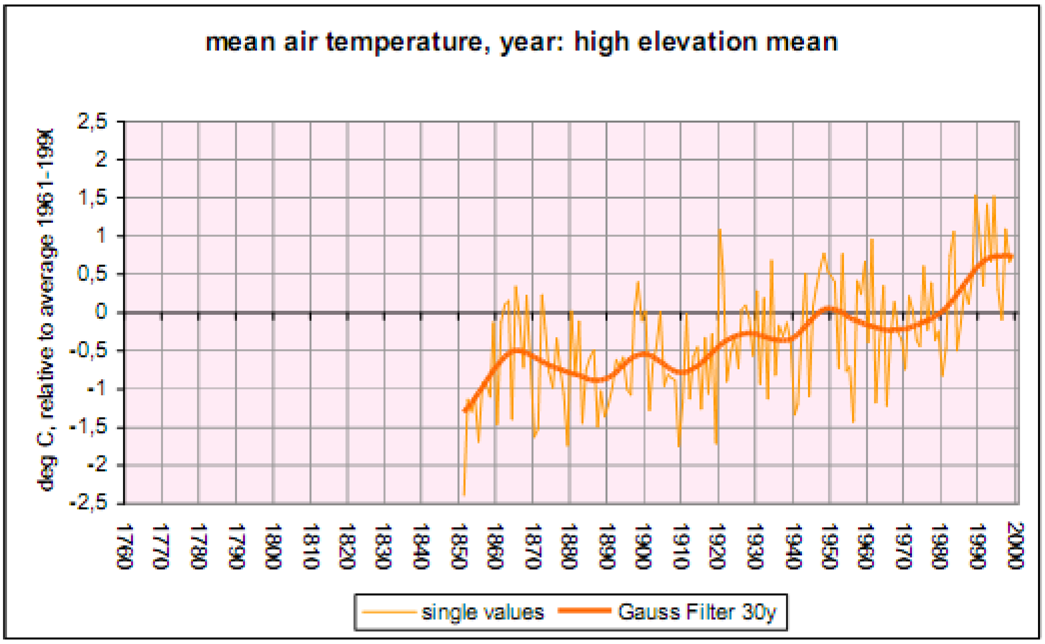

Figure 5. Mean annual temperature of the last 240 years for Austrian Alpine upland meterological stations (single years and 30 years' filter). (Auer et. al 2001).

Precipitation sums have altered, too, the spatial and temporal variation being even larger as with temperature. Trends have got more distinct in the last decades only. Mainly in winter an increase of precipitation in the middle and high latitudes of the northern hemisphere were found. In the European Alps this is true above all fort he western part (Northern and Western Switzerland). In the southern parts of the Alps in Austria as well as the eastern parts of Austria a decrease of precipitation was observed (Auer & Böhm, 1994).

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2.3 Extreme events

Currently, a generally increasing frequency of extreme events in storms, precipitation and drought cannot be proven in Austria. This may be partly due to the rarity of such events compared to the available time series of reliable data and in some cases may be attributed to lack of data (e.g. avalanches are recorded only if causing damage). However, in Switzerland an increase of heavy precipitation events was found in the Alps (Figure 6).

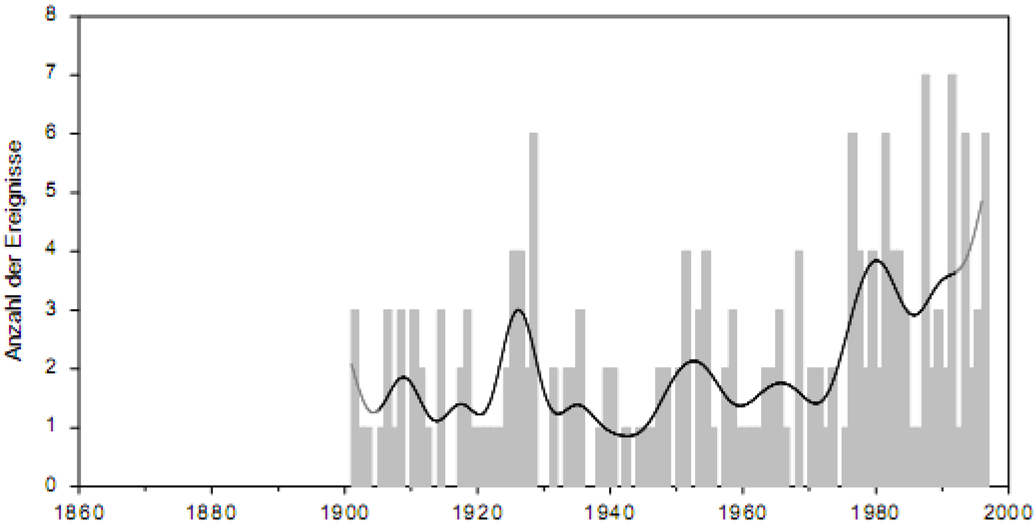


Figure 6. Frequency of heavy precipitation (> 70 mm per day on a minimum area of 500 km^2) at the northern side of the Alps and the inner Alps of Switzerland for the period 1901 to 1996 as well as in the Alpine Region (Baumgartner et. al. 2000). x-Axis: frequency of events.

2.4 Observed impacts on ecosystem dynamics and functioning

2.4.1 Phenology of vegetation

Scheifinger & Koch (2009) found a tendency to earlier phenological spring phases from the mid 1980’s (Figure 7) in the Alpine region. In Central Europe 90% of the variability of the beginning of phenological phases are explained by the variability of near-ground air temperature. A temperature increase of 1°C in spring results, for instance, in an earlier blooming of hazel and cherry by 1 week. In autumn, phenological phases show a slight tendency for delayed occurrence. These findings are in line with studies using the whole European phenological network (Menzel et al. 2006).

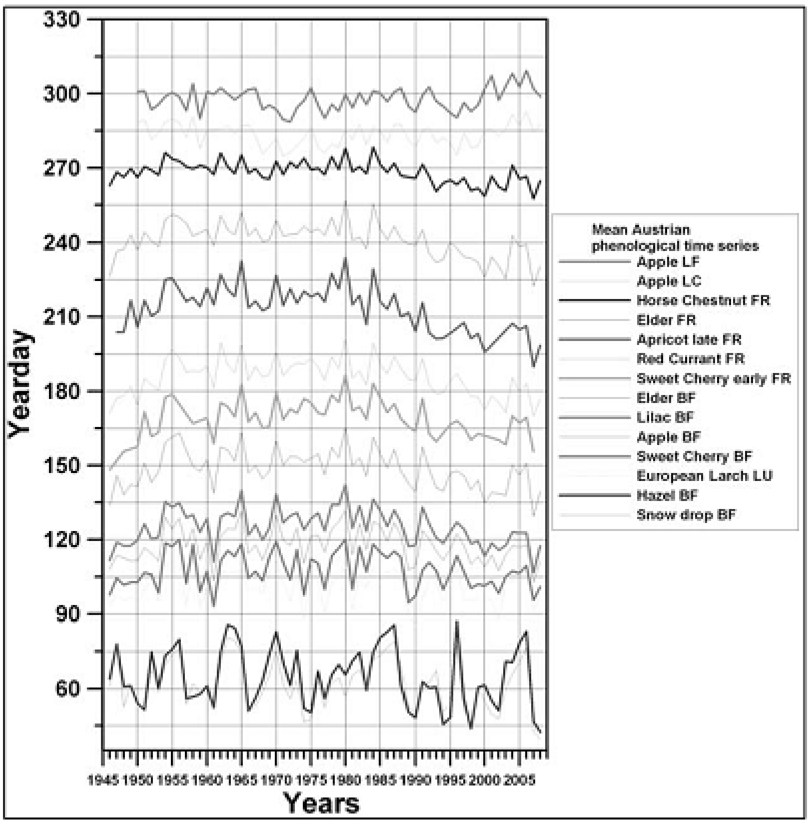


Figure 7. Mean Austria time series of selected phenological phases (BF = Beginning of bloom, LU = foliation, FR = Fruit ripening, LC = Leaf colouring and LF = Leaf fall).

2.4.2 Change in distribution areas of plants

Due to the morphology of Austria upward shifts of the occurrence of plants are discussed primarily. High mountain ecosystems being defined by low temperatures and therefore considered to react sensitively to climate warming are currently in the focus of climate change research.

Grabherr et al. (1994) calculated (upward) moving rates for typical nival plant species on the basis of 12 very precise historical recordings, which have an age between 70 and 90 years. They found maximum rates of 4 m per decade, most values being lower than 1 m per decade. According to the meteorological data the mean annual temperature has increased since that time by 0.7°C. Taking into account an average decrease of 0.5°C per 100m of increasing altitude, this warming should theoretically lead to a shift in the altitudinal vegetation belts at a rate of 8-10 m per decade. The empirical values are clearly far lower than this. Grabherr et al (1994) conclude that there is no doubt that even moderate warming induces migration processes, an that this process is underway.

On Schrankogel, an alpine-nival ecotone (between 2900 and 3450m altitude), which is a GLORIA master site in the central Tyrolean Alps, Austria, Pauli et al. (2007) observed an average change in vascular plant species richness from 11.4 to 12.7 species per plot, an increase of 11.8% (or of at least 10.6% at a 95% confidence level). The increase in species richness involved 23 species (about 43% of all taxa found in that ecotone), comprising both alpine and nival species and was pronouncedly higher in plots with subnival/nival vegetation than in plots with alpine grassland vegetation. Species cover changed in relation to altitudinal preferences of species, showing significant decline of all subnival to nival plants, whereas alpine pioneer species increased in cover. Recent climate warming in the Alps, which has been twice as high as the global average, is considered to be the primary driver of the observed differential changes in species cover. Results of Pauli et al. (2007) indicate an ongoing range contraction of subnival to nival species at their rear (i.e. lower) edge and a concurrent expansion of alpine pioneer species at their leading edge. The projected acceleration of climate warming raises concerns that this phenomenon could become the major threat to biodiversity in high mountains.

Erschbamer et al. (2008) studied short-term changes in plant species number, frequency and composition along an altitudinal gradient crossing four summits from the treeline ecotone to the subnival zone in the South Alps (Dolomites, Italy). After 5 years, a re-visitation of the summit areas revealed a considerable increase of species richness at the upper alpine and subnival zone (10% and 9%, respectively) and relatively modest increases at the lower alpine zone and the treeline ecotone (3% and 1%, respectively). At the lowest summit, competitive displacement of alpine species is predicted for the near future to result from shading by young trees and dwarf shrubs and enhanced frequency of competitive clonal graminoids.

Nicolussi & Patzelt (2008) found an increase of the upper limit of occurrence of trees and rejuvenation of stone pine (Pinus cembra) in the Tyrolean Central Alps (Kaunertal, Figure 8) in the last 150 years.

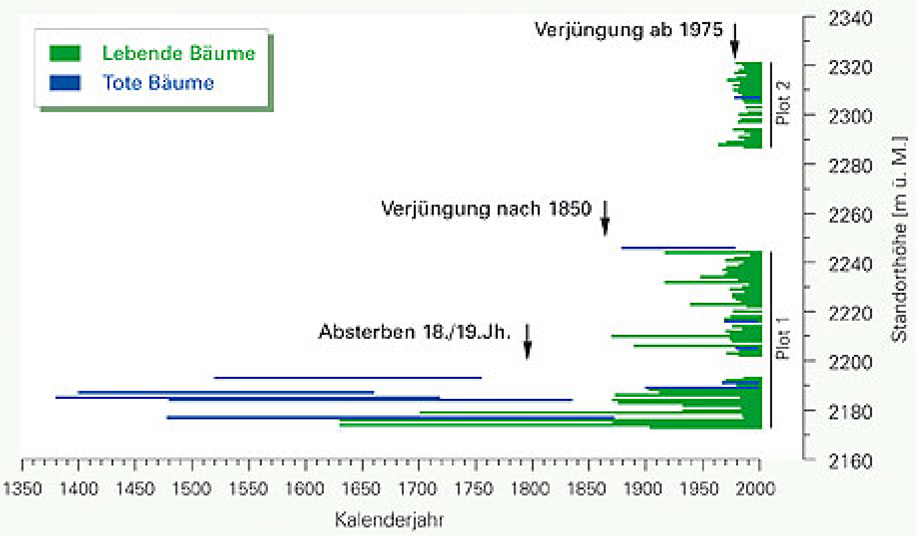


Figure 8: In the mid of the 19th century tree and timber line in Kaunertal (Tyrolean Central Alps) was at an altitude of 2180 m, currently young trees are found in altitudes up to 2370m. Source: Nicolussi & Patzelt (2008).

The increase of the tree line and the establishment of stone pine and larch at the current tree line were not continuous, but mainly synchronous to the melting of Alpine glaciers after a maximum in 1855. Especially during the last 25 years successful establishment of rejuvenation was found in the Tyrolean Central Alps. Especially stone pine reacts directly to improved climatic conditions. If the current temperature regime continues Nicolussi & Patzelt (2008) predict an increase of timber and tree line of 100-150 m compared to the mid of the 19th century. This is somewhat contradictory to observations in Switzerland, where a slight upward shift of the tree line that is much smaller than would be expected based on the temperature data (Zimmermann et al. 2006, Gehrig-Fasel et al. 2007).

2.4.3 Insect pathology and distribution area

Increasing temperatures are expected to affect the population dynamics of insects and pathogens in forests via increased development and reproduction rates (Tomiczek 2008, Wermelinger & Seifert 1998, 1999). In Austria and other parts of Central Europe the spruce bark beetle (Ips typographus) has caused extensive damage to Norway spruce following the storm Vivian (February 1990), foehn storms in November 2002, the storms “Cyrill” in 2007 and “Paula” and “Emma” in winter 2008. Starting with the foehn storms of 2002 and the following drought year of 2003 annual salvage harvests never decreased under 1,9 million m^3, partly due to the storms in the following years (Steyrer & Krehan 2009; Figure 9).

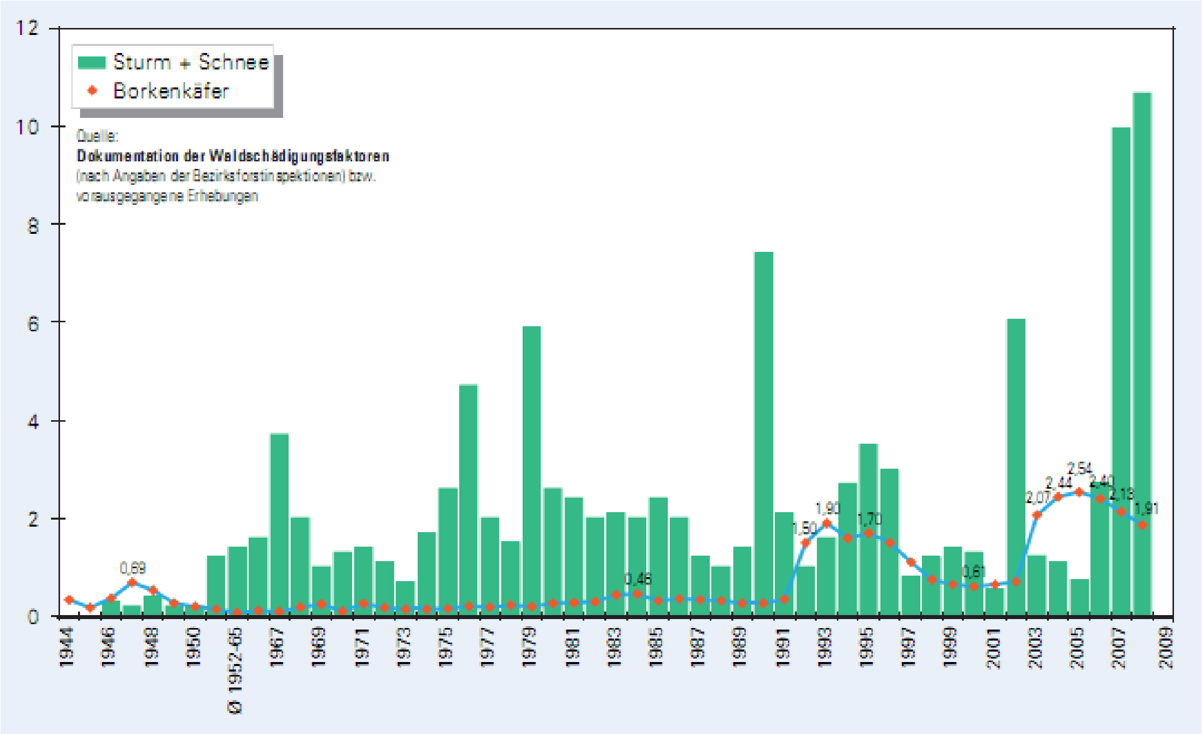


Figure 9. Time series of damages in million m³ by bark beetles, wind and snow breakage. Source: Steyrer & Krehan (2009).

In many cases outbreaks of *Panolis flamea, Bupalus piniarius* (Schopf 1997), *Rhyacionia buoliana* (Bejer-Petersen 1972) and *Cephalcia arvensis* (Marchisio et al. 1994) are linked with warm-dry periods and high temperature sums in summer. From 1985 on an extension of the damage area of *Pristiphora abietina* into altitudes of 800 m a.s.l. and more was documented. There are indications that the increased occurrence of *Thaumetopoea processionea* in the eastern parts of Austria may be caused with an optimisation of temporal coincidence of insect development and tree susceptibility (Baaske & Plattner 2004).

A study about neobiota in Austria (Essl & Rabitsch 2002) has shown that the predominant number of non-domestic animal and plant species come from geographically adjacent regions (Mediterranean, SE-Europa) or climatically similar regions (North America). Therefore the anthropogenic climate change might be interpreted as an indirect support to the occurrence of thermophilous species into formerly non accessible regions. Further temperature increase benefits the occurrence and the establishment of these species.

2.4.4 Change in productivity

Several studies in Austria have recorded increased tree growth in recent decades (e.g., Hasenauer et al. 1999). The causes of this increased forest growth are not known, but have been generally attributed to a combination of change in forest management (including decrease in nutrient removal from forests), nitrogen deposition and temperature increase. The European-wide study RECOGNITION found increased tree height growth of Scots pine, Norway spruce and European beech of 25% over the last four decades (Kahle et al. 2008). Most of this change was however attributed to nitrogen deposition and only a smaller portion to an increase in temperature.

In a recent European study Laubhann et al. (2009) showed the influence of temperature change and nitrogen and sulphur deposition at European scale, using 654 plots of the European intensive monitoring program (Level II plots) with 5-year growth data for the period 1994–1999. The analysis was done for common beech (*Fagus sylvatica*), oak (*Quercus petraea* and *Q. robur*), Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Increasing temperature showed a positive effect on growth for all species except Norway spruce. Nitrogen deposition showed a positive impact on growth for all four species. This influence was significant with $p < 0.05$ for all species except common beech. For beech the effect was nearly significant ($p = 0.077$). An increase of 1 kg N ha^{-1} yr^{-1} corresponds to an increase in basal area increment between 1.20% and 1.49% depending on species. Considering an average total carbon uptake for European forests near 1730 kg per hectare and year, this implies an estimated sequestration of approximately 21–26 kg carbon per kg nitrogen deposition.

Hasenauer et al. (1999) studied forest growth response to changing climate between 1961 and 1990 in Austria by means of the ecosystem model FOREST-BGC. Using climate records from 20 weather stations the influence of temperature and precipitation as well as the length of the growing season on annual net primary production were studied. A significant increase in mean annual temperature of 0.72°C, mean annual minimum temperature (0.80°C), winter temperature (2.36°C) as well as an increase in the length of the temperature-controlled growing season by 11 days, resulting in a significant increase in diameter increment obtained from 1179 cores of Norway spruce across Austria were found. The trends in simulated NPP were consistent with observed increment rates validating the use of biogeochemical modeling as a diagnostic tool to search for possible causes on changing environmental conditions. Between 1961 and 1980, only winter temperatures have increased significantly by 2.8°C. In the 1980s, however, all investigated climate and growth parameters increased. NPP model estimates showed an increase of 6.3% between 1981 and 1990 vs. −1.0% between 1961 and 1980. The mean annual increment index, calculated from 1179 increment cores, increased between 6.8% and 8.0% during 1981–1990 vs. −0.9% and 1.9% during 1961–1980. The results are consistent with the previous findings of Myneni et al. (1997), who estimated an 11% increase in plant growth for the northern latitudes (45°–70°N) during this time span. Significant changes in growing season length found in this study may have profound effects on the functional aspects of ecosystems.

The timberline shifts upwards due to climate change and changes in land use. The effect is well documented since several decades. The effects of the shift from dwarf-shrub communities to stone pine (Pinus cembra) forest was investigated by soil analyses at a site that was intensely monitored and well documented during the 1950s. The experimental site Poschach near Obergurgl, Ötztal, has been subject to detailed plant physiological and meso-climatic research. At that occasion vegetation, geomorphology and soil typology were assessed on a small scale. Upon a repeated assessment of vegetation and soils the change of these site properties within half a century was documented. In Obergurgl the advancing forest replaces dwarf-shrub communities, dominated by Calluna and Rhododendron. These dwarf shrubs yield a poorly degradable litter and are renown for their closed nutrient cycle. Soils under dwarf shrubs were richer in carbon as soils under now 50 year old stone pine forests. That has far reaching implications for the carbon balance: Although a large carbon pool establishes in the aboveground biomass, the usually more stable carbon pool of the soil is reduced.

Representative soil samples from four positions along an elevational gradient were incubated in the lab at five temperature steps (5, 10, 15, 20, 25°C) in order to quantify how much carbon is released as CO2 as a consequence of the temperature increase. Soils under dwarf shrubs hardly responded to the temperature increase, indicating the high chemical stability of soil organic matter at these sites. The measured values were below the values of most other previously investigated forests in Austria. Soils under stone pine responded much stronger to the temperature increase. The implication for the Austrian carbon balance is that the changing vegetation implies the formation of a soil carbon pool that strongly responds to increasing temperatures. Large differences were found with respect to the total microbial biomass. Soils under dwarf shrubs are obviously a poor substrate with a low microbial population density. Soils under stone pine are biologically active. Organic matter that enters the soil via litterfall (needles, roots) is quickly mineralized and released to the atmosphere as CO2. In conclusion we state that the rise of the timberline leads to significant changes in the soils that are linked to a higher release of carbon.

Global warming has the potential to increase soil respiration (R_S), one of the major fluxes in the global carbon (C) cycle. R_S consists of an autotrophic (R_A) and a heterotrophic (R_H) component. Schindlbacher et al. (2008) combined a soil warming experiment with a trenching experiment to assess how R_S, R_A, and R_H are affected. The experiment was conducted in a mature forest dominated by Norway spruce. The site is located in the Austrian Alps on dolomitic bedrock. We warmed the soil of undisturbed and trenched plots by means of heating cables 4°C above ambient during the snow-free seasons of 2005 and 2006. Soil warming increased the CO_2 efflux from control plots (R_S) by □45% during 2005 and □47% during 2006. The CO_2 efflux from trenched plots (R_H) increased by □39% during 2005 and □45% during 2006. Similar responses of R_S and R_H indicated that the autotrophic and heterotrophic components of R_S responded equally to the temperature increase. Thirty-five to forty percent or 1 t C ha^{-1} yr^{-1} of the overall annual increase in R_S (2.8 t C ha^{-1} yr^{-1}) was autotrophic. The remaining, heterotrophic part of soil respiration (1.8 t C ha^{-1} yr^{-1}), represented the warming-induced C loss from the soil. The autotrophic component showed a distinct seasonal pattern. Contribution of R_A to R_S was highest during summer. Seasonally derived Q_{10} values reflected this pattern and were correspondingly high (5.3-9.3). The autotrophic CO_2 efflux increase due to the 4°C warming implied a Q_{10} of 2.9. Hence, seasonally derived Q_{10} of R_A did not solely reflect the seasonal soil temperature development (e.g. Schindlbacher et al. 2008).

2.5 Expected impacts

2.5.1 Expected climate change

Climate change scenarios for Austria (ECHAM4/OPYC3), based on the trace gas only or trace gas plus sulphate scenario IPCC IS92a) show increases from +1.4 to +4.0ºC (trace gas only integration) and from +1.1 to +2.9ºC (trace gas plus sulphate integration) for a period of about 55 yr relative to the 1961–1995 climatology (Matulla et al. 2001). The regionalized recipitation changes are both negative and positive. Values range from –44 to +26% (trace gas

only integration) and from –29 to +26% (trace gas plus sulphate integration). The explained variability for temperature being higher than for precipitation, both temperature and precipitation were better reproduced for winter than for summer (Matulla et al. 2001).
Predictions for future extreme events from the ACACIA project (in: Formayer et al. 2001) include an increase of hot spells in summer, increases in summer drought and heavy precipitation events, especially in winter as well as an increased frequency of storm events.

2.5.2 Expected impacts on ecosystem dynamics and functioning

2.5.2.1 Phenology of vegetation

Further warming will shift the spring and summer phenology, i.e. bud burst, leaf development and flowering to earlier dates, while the impact on autumn phenology, i.e. leaf discoloration and leaf fall will depend on the possible effect of increased or more frequent drought on leaf senescence.

2.5.2.2 Expected impacts on distribution and suitability of tree species

A warmer climate should in general lead to a migration of plants to higher altitudes and to the establishment of new species at lower altitudes.

Changes in the hydrothermal regime influences site properties and vegetation dynamics. Shifts of temperature and precipitation may generally lead to improved or worsened suitability of a certain tree species to a site. Depending on site and species changes in the climatic properties may lead to a transgression of ecophysiological tolerance, decreasing competitiveness of a species or an increasing loss of species, or on the other hand increased growth and competitiveness. Both cases lead to a change in natural stand composition (Potential Natural Vegetation).

Computer simulations predict a strong shift of tree species composition in Austria under realistic climate change scenarios (Umweltbundesamt 2007). Generally deciduous species will gain in contrast to conifers. Especially conifers with a narrow eco-physiological tolerance (e.g. silver fir) or low tolerance to heat and drought (e.g. Norway spruce) will be affected. Within the dominating tree species in Austria Norway spruce shows the highest susceptibility to climate stress. The suitability of this species is supposed to decrease in low and medium altitudes. Currently Norway spruce dominates due to anthropogenic promotion in regions where natural occurrence of this species would be sparse (Eastern and South Eastern lowlands. These secondary stands are especially susceptible to calamities and disturbances (drought stress, bark beetle, wind throw), a sustainable management being questionable.

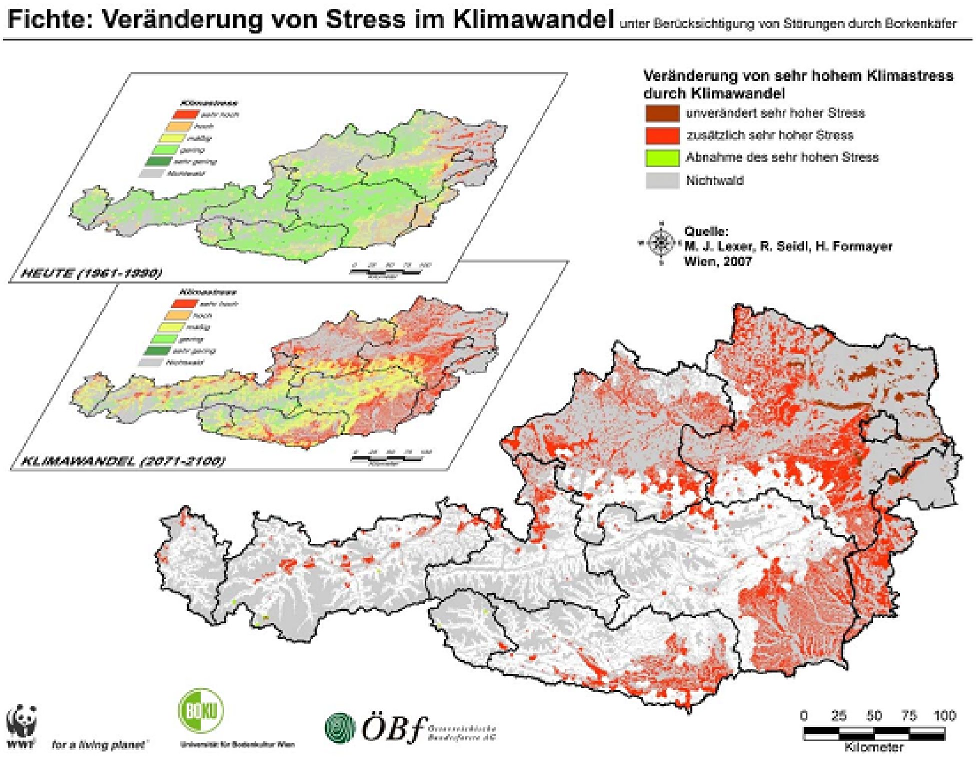


Figure 10. Change of stress for Norway spruce induced by climate change (including bark beetle disturbances) In the insert 2 maps of climate stress categories (current climate, climate change: +4.5°C, -35% precipitation in summer season) are shown. The main map shows regions of high stress induced by climate change (Niedermair et al. 2007)

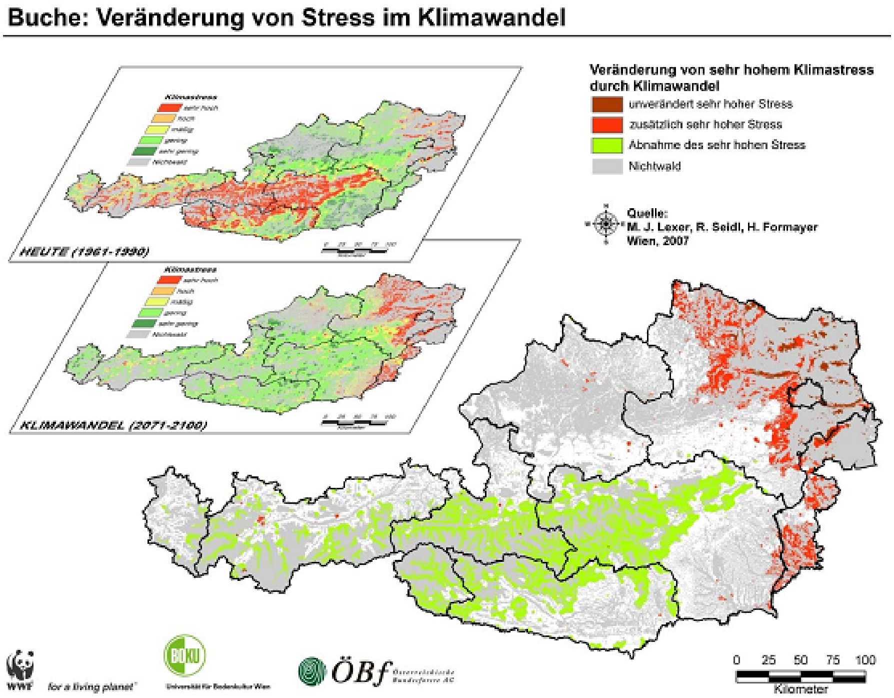


Figure 11. Change of stress for beech induced by climate change. In the insert 2 maps of climate stress categories (current climate, climate change: +4.5°C, -35% precipitation during summer season) are shown. The main map shows regions of high stress induced by climate change (Niedermair et al. 2007).

Fagus sylvatica, the most common deciduous species in Austria will gain area within the Alps, while losing area in the East of Austria due to insufficient water supply. In general the potential are of beech will increase in Austria.

A large-scale climate change impact assessment study for Austrian forests based on dynamic modelling approaches investigated the sensitivity of the Austrian forests to scenarios of climatic change (Lexer et al. 2001). Major findings of the risk assessment were:

(1) Severe short-/midterm impact of a moderate warming scenario (+0.8 °C by 2050) on existing forests with substantial tree mortality was simulated for appr. 3% of the forest inventory plots included in the study. However, stands not well adapted to site conditions showed substantial periodic tree mortality even under the baseline scenario (current climate represented by the conditions of the period 1961-1990). Under conditions of stronger warming (+2.0 °C by 2050) the proportion of sample points showing severe impacts due to the changing climate increased to 12%, while under a third scenario (+2.0°C, decrease of precipitation during summer season -15%) just a slight additional increase of such severe impact stands to 14% occurred. Particularly Norway spruce stands at low elevations in the eastern and partly in the southern parts of Austria responded rather sensitive to small variations in soil moisture supply.

(2) Short-/midterm impact indices representing the transient response of currently existing forests as recorded by the Austrian Forest Inventory from 2000 to 2050 differed strongly from long-term indices derived from PNV. At lower elevations (today's colline and submontane vegetation belt below 900 m a.s.l.) with frequently occurring secondary Norway spruce forests at sites naturally supporting broad-leaved species mixtures increased tree mortality compared to current climatic conditions was simulated due to increased frequency of drought periods and subsequent bark beetle infestations. While this was an expected response of current forests which are known to suffer from periodical mortality events even under current climatic conditions, the simulated potential natural vegetation at such sites in general showed only minor indications of climate change impacts. The opposite holds true for high altitude sites. At these sites the substantial increase of temperature under scenarios scB and scC resulted in a major shift of the simulated PNV species pool towards broad-leaved species. Thus, despite no indications for immediate adverse effects of a changing climate (as indicated by low impact categories of short-/midterm indices), the long-term implications of the applied climate change scenarios for the competitive interrelationships of tree species might be substantial.

(3) Under the marked warming conditions (+2 °C by 2050) the potential impact derived from short-/midterm (2000-2050) as well as from long-term indices (derived from simulated shifts in PNV) was significantly larger compared to the moderate warming conditions (+0.8°C by 2050). According to a sensitivity index based on both, short-/midterm and long-term measures, the share of sample points with low expected climate change impacts decreased from 67.3% to 18% under strong warming, and finally to 15.5% under scenario conditions of strong warming and reduced precipitation. From these simulation results it might be concluded that climate change conditions as represented by the moderate warming scenario seemed to characterise some kind of threshold beyond which the severity of potential climate change impacts might increase substantially.

2.5.2.3 Changes in productivity

Increased annual mean temperatures, higher minimum temperatures and longer vegetation periods have potential positive effects on the productivity of forests. Possibly climate induced growth increase of trees were documented in the 20th century within the Alpine region (Spiecker 1999). Probably this increase was furthered by anthropogenic nitrogen immissions as well as an increased photosynthesis and lessened transpiration losses due to increased atmospheric CO_2-concentrations. Potential increases in productivity are variable and are depending on tree species and site conditions. However, insufficient water supply is a limiting factor for productivity increase (ClimChAlp 2008b). Decreasing water supply, which is expected with progressive climate change may invert the CO2 fertilization effect resulting in productivity losses; especially for Norway spruce productivity losses are expected (Umweltbundesamt 2007, Lexer et al. 2005). Furthermore disturbances and calamities due to climate change (biota, drought periods) may increase forest management costs.

2.5.2.4 Possible impacts on nutrient cycling and storage

Jandl et al. (2007) studied the impact of a shifting of the tree-line as response to climate change and changes in land use which is well documented since several decades in respect to carbon and nitrogen cycling as well as on the release of greenhouse gases. The effects of the shift from dwarf-shrub communities to stone pine (Pinus cembra) forest were investigated at site Poschach near Obergurgl (Tyrol) that was intensely monitored and well documented since the 1950s. The experimental site has been subject to detailed plant physiological and meso-climatic research as well as soil and site research on a small scale. Dwarf shrubs yield a poorly degradable litter and are renown for their closed nutrient cycle. Soils under dwarf shrubs were richer in carbon as soils under now 50 year old stone pine forests. That has far reaching implications for the carbon balance: Although a large carbon pool establishes in the aboveground biomass, the usually more stable carbon pool of the soil is reduced.

Representative soil samples from four positions along an elevational gradient were incubated in the laboratory at five temperature steps (5, 10, 15, 20, 25 °C) in order to quantify how much carbon is released as CO2 as a consequence of the temperature increase. Soils under dwarf shrubs hardly responded to the temperature increase, indicating the high chemical stability of soil organic matter at these sites, while soils under stone pine responded much stronger to the temperature increase. The implication for the Austrian carbon balance is that the changing vegetation implies the formation of a soil carbon pool that strongly responds to increasing temperatures. Large differences were found with respect to the total microbial biomass. Soils under dwarf shrubs are obviously a poor substrate with a low microbial population density. Soils under stone pine are biologically active. Organic matter that enters the soil via litterfall (needles, roots) is quickly mineralized and released to the atmosphere as CO2. In conclusion Jandl et al. (2007) state that the rise of the timberline leads to significant changes in the soils that are linked to a higher release of carbon.

A soil warming experiment was conducted by Schindlbacher et al. (2008) in a mature forest dominated by Norway spruce, located in the Austrian Alps on dolomitic bedrock. Global warming has the potential to increase soil respiration (R_S), one of the major fluxes in the global carbon (C) cycle. R_S consists of an autotrophic (R_A) and a heterotrophic (R_H) component. Schindlbacher et al. (2008) combined a soil warming experiment with a trenching experiment to assess how R_S, R_A, and R_H are affected. In the experiment soil of undisturbed and trenched plots was warmed by means of heating cables 4°C above ambient during the snow-free seasons of 2005 and 2006. Soil warming increased the CO_2 efflux from control plots (R_S) by □45% during 2005 and □47% during 2006. The CO_2 efflux from trenched plots (R_H) increased by □39% during 2005 and □45% during 2006. Similar responses of R_S and R_H indicated that the autotrophic and heterotrophic components of R_S responded equally to the temperature increase. Thirty-five to forty percent or 1 t C ha^{-1} yr^{-1} of the overall annual increase in R_S (2.8 t C ha^{-1} yr^{-1}) was autotrophic. The remaining, heterotrophic part of soil respiration (1.8 t C ha^{-1} yr^{-1}), represented the warming-induced C loss from the soil. The autotrophic component showed a distinct seasonal pattern. Contribution of R_A to R_S was highest during summer.

2.5.3 Expected impacts on insect pathology and distribution areas

To study potential consequences of climate-induced changes in the biotic disturbance regime at regional to national scale Seidl et al. (2008) integrated a model of Ips typographus (L. Scol. Col.) damages into the large-scale forest scenario model EFISCEN. Simulations of a transient climate change scenarios for the 21st century resulted in a strong increase of bark beetle damages under business as usual management, rendering sustainable forest management in Norway spruce dominated stands virtually unfeasible at low elevations. Simulation results also showed a marked increase of damages in Alpine areas as a result of the extended range of Ips typographus (Figure 12). Increasing damage levels at higher altitudes have been documented by Krehan & Steyrer 2006) in recent years. Consequent effects of the expansion of biotic disturbances may lie in the (partial) loss of the protective function of forest in Alpine areas as well as a negative impact on the carbon storage of forests and forest soils. While increasing temperature may further increase the potential of population growth of insects and their capacity to shift to higher altitude, it is currently not clear how inter-species competition and possible decrease of precipitation will affect insect populations and their distribution.

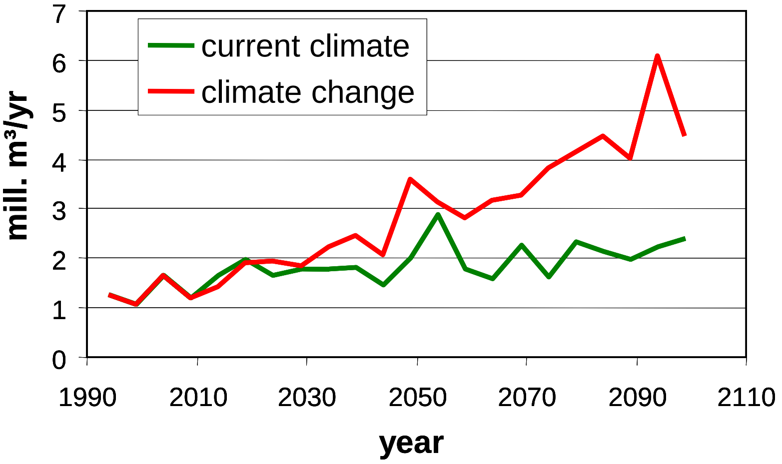


Figure 12. Simulated development of bark beetle damage in Austrian forests under current climate and conditions of climate change (scenario B1; +2.4°C 2070-2100 compared to 1961-1990). Source: Seidl et al. (2008).

3 Adaptation

3.1 General adaptation strategy and policy

In Austria the process of establishing a national climate change adaptation strategy has been started in late 2007, its completion is planned for 2011. To that end, the process included a series of informal workshops with invited stakeholders comprising, among others, representatives from federal and provincial administration services and practitioners, experts and scientists from agriculture, forestry, water management, tourism and the energy sector. During the process the focus has been compiling and discussing the current state of knowledge on climate change, climate change impacts, the implementation of a preliminary qualitative vulnerability assessment for these sectors as well as on the identification of potential adaptation measures (Haas et al. 2008).

Reports and documents are available at http://klimaanpassung.lebensministerium.at. Currently in ongoing consultations next steps are prepared. It is planned to assess climate change vulnerability of additional sectors (building, natural risks and hazard mitigation, infrastructure, traffic and spatial planning, public health, natural ecosystems and biodiversity) until late 2010.

Complementary to these activities and processes in the technical domain a consultation and participation process has been initialized in June 2009 where, among others, administration services, chambers of labour, agriculture and commerce, environmental and social NGOs, etc. contribute with feedback, additional expertise and the discussion of recommendations as well as the input generated by a broad public consultation process via the internet.

In parallel there are also strategic and operational policy and administrative activities at provincial level. Targeted research into climate change issues (climate scenarios, impacts, mitigation and adaptation) is funded at federal as well as at provincial level (e.g., http://www.climchalp.org, http://www.adaptalp.org/, http://www.klimafonds.gv.at, http://noe.gv.at/Umwelt/Klima/Klimawandel-limaschutz/klimawandelschutzuebersicht.html).

3.2 Vulnerability of Austrian forests and forestry

Forests are playing a major role in alpine environments. A multitude of goods and services is provided by forest ecosystems like timber, non wood forest products, biodiversity, clear drinking water and protection to mention but a few. In densely populated mountainous regions like, for instance, in Austria the protection against natural hazards is of high importance. The protection against natural hazards is also a vital factor when thinking about tourism, a major source of income in the European Alps and other mountainous areas around the world, as it is also sheltering tourism infrastructure and recreation areas.

Both the observed and the projected climatic changes will strongly alter alpine ecosystems as well as communities depending on forest goods and services. Increasing temperatures and changing precipitation patterns will affect forest ecosystems as well as the occurrence of natural hazards.

Vulnerability assessments are needed as a crucial prerequisite to successful climate change adaptation. This is also stressed by the IPCC (e.g. Schneider et al., 2007) by underlining the importance of regional vulnerability assessments in the Fourth Assessment Report.

In the regional to national attempts to operationalize climate change vulnerability for Austrian conditions Haas et al. (2008) as well as Lexer and Seidl (2009), Seidl et al. (2009) and Maroschek (2009) all set back to the definition of the IPCC (2007):

- **Exposure**

Exposure is the nature and the degree to which a system is exposed to climate change containing mean climate characteristics, climate variability and frequency and magnitude of climatic extremes. Currently available regional climate change scenario information is briefly presented in section 1.2 ("Potential impacts")

- **Sensitivity**

Sensitivity is the degree to which a system is affected (adversely or beneficially) by climate change exposure. The climate change induced effects might be direct like increasing tree growth due to higher temperatures in mountain forests or indirect like increased tree mortality due to changing abundance of pests.

- **Potential impact**

The potential impacts are a function of sensitivity and exposure. It subsumes all climate change induced impacts on an ecosystem function (e.g. timber production or like in this case protection against natural hazards) without consideration of human intervention. Current expectations are presented in section 2 ("Potential impacts")

- **Adaptive capacity**

is the ability of a socio-ecological system to adjust deliberately to climate change including climate variability and extremes. Furthermore it enables the system to moderate potential damages, utilize opportunities or to cope with the consequences via planned anticipatory or reactive adaptation.

- **Vulnerability**

is defined as the degree to which a system (i.e. an ecosystem function) is susceptible, or unable to cope with, adverse effects of climate change, again including variability and extremes. Vulnerability is a function of potential impact and adaptive capacity.

- **Adaptation**

refers to deliberate human interventions in the system, aiming at counteracting negative climate change impacts or taking opportunity of positive impacts in an anticipatory or reactive way (according to IPCC, 2001).

Within the process of developing the Austrian national climate change adaptation stratgey Haas et al. (2008) conducted a qualitative sectoral vulnerability assessment. They used the categories low, moderate and high vulnerability, complemented by the category "no judgement possible due to knowledge gaps/high uncertainy". Table 1 shows the results for forestry.

Table 1. Summary of the vulnerability assessment of Austrian forests and forestry. Time horizont for forestry is the period 2080-2100 due to long production and planning periods.Source: Haas et al. (2008), modified.

Thematic issues	Vulnerability category	Comments
Productivity	High	Short-term: opportunities to increase production; long-term: without adaptation highly vulnerable; thematic and regionally explicit assessments needed.
Drought stress	High	Water supply is very likely a key factor for low-elevation forests in Austria under climate change
Biotic disturbances	High	Increase in habitat range as well as well as in reproduction rates/generations per year for poikilothermal organisms such as bark beetles will lead to intensified disturbance regimes
Abiotic disturbances	no judgement	Future storm climate uncertain; but highly relevant for forestry.
Change in species composition	High	In mountain forests broadleaves gain in competivity relative to conifers; at low elevations oak species gain at the cost of beech and off-site conifer plantations
forest services	High / no judgement	In mountain regions protective functions of forests are vulnerable due to intensified disturbance regimes; currently difficult to judge. (see also Maroschek 2009)
Carbon storage	Low	Under a warmer climate the sink strength may decrease on the long run

In a vulnerability assessment of 160000ha production forests of the Austrian Federal Forests (AFF) in the second half of the 21st century timber production within a multifunctional framework of sustainable forest management in about 40% of the assessed forests were considered highly vulnerable while vulnerability was judged as low for just 20% of the forest area (Lexer and Seidl, 2009; Seidl et al. 2009). Before 2050 just negligible shares of the assessed forest area were classified as highly vulnerable. Figure 13 displays vulnerability under current “business as usual” management and under adaptive management with regard to three time horizonts. Adapting forest management (management intensity, tree species change, change in silvicultural system) to the changing climate reduced the vulnerability of timber oriented multi-functional forestry substantially.

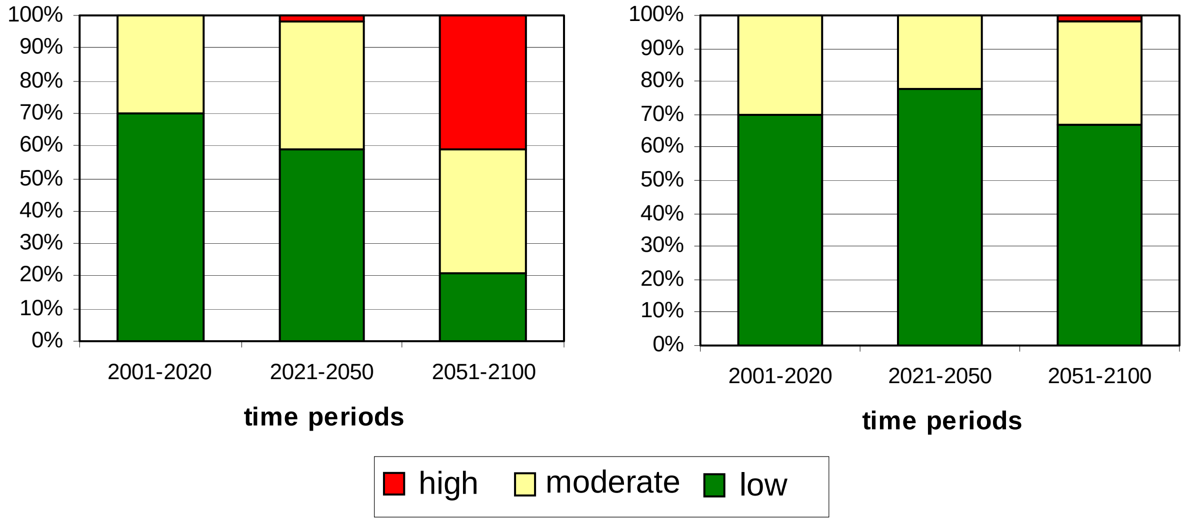


Figure 13. Vulnerability of 160000ha multifunctional production forests of the Austrian Federal Forests Ltd. Under current management regimes (left side) and under an adaptive management regime (right side). Climate change scenarios used in the assessment: A1B, A2, B2 (Formayer and Haas, unpublished).

To specifically address the protective function of mountain forests against avalanches, rockfall and mudflow Maroschek (2009) developed a qualitative regional vulnerability assessment scheme and demonstrated its use by means of three different districts (see Figure 2) of the Austrian Service for Torrent and Avalanche Control (WLV). It was shown that the regional vulnerability may strongly differ depending on initial forest state and the estimated adaptive capacity (Table 2).

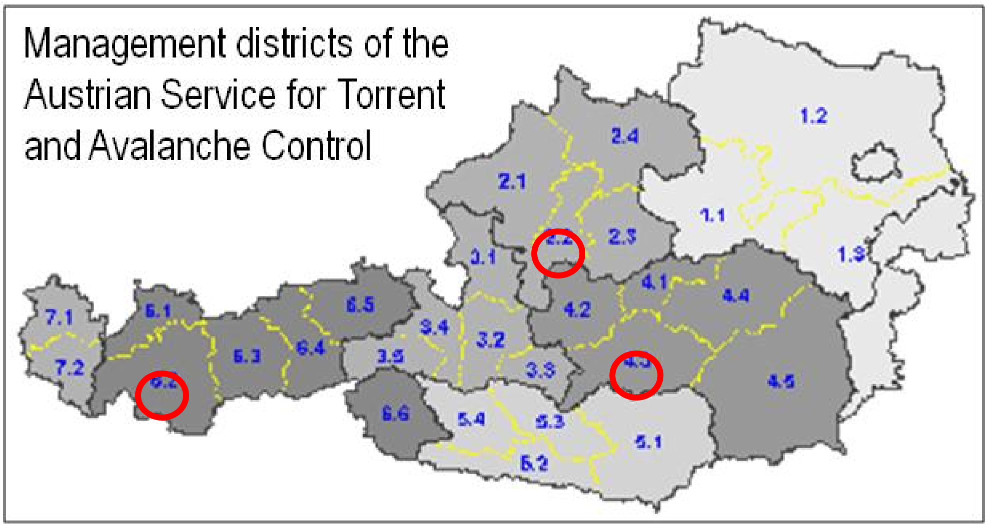


Figure 14. Management districts of the Austrian Federal Service for Torrent and Avalanche Control (WLV), the case study regions, highlighted by the red circles, are the Upper Mur Valley (4.3), the Upper Inn Valley (6.2) and the Salzkammergut (2.2).

Table 2: Vulnerability of the protective functions for three case study regions. (1 = low vulnerability, 2 = medium vulnerability and 3 = high vulnerability).

Protective function	Upper Mur Valley		Upper Inn Valley		Salzkammergut	
	2021-2050	2071-2100	2021-2050	2071-2100	2021-2050	2071-2100
Flooding	2	2	2	3	2	3
Debris flow	2	2	2	3	2	2
Rock fall	1	1	2	3	3	3
Landslide	1	2	2	3	3	3
Avalanche	1	2	2	3	1	3

3.3 Forest adaptation measures

3.3.1 Political level

The **Austrian National Forest Programme** was approved in 2005 (http://www.walddialog.at/filemanager/list/16026/). The main part is composed of 7 thematic areas which are related to the 6 "pan-European Criteria for Sustainable Forest Management" identified by the Ministerial Conference on the Protection of Forests in Europe. The seventh thematic area on "Austria's international responsibility for sustainable forest management" has been added. For each thematic area the current state and related trends are described and general principles and goals have been developed. Sets of measurements have been elaborated for each thematic area. Climate change is directly addressed within thematic area "health and vitality of Austrian forests". Current state and trends are mainly based on an impact study by Lexer et al. (2001). In the section on principles and goals no reference is made to climate change and adaptation. Goals include reduction of pressures on forest health and vitality such as browsing by game and lifestock and air pollutants as well as general goals fostering sustainable forest management. However, due to manifold cross-relations between thematic areas, principles and goals measures recommended in other thematic areas may support adaptation to climate change as well.

An example for policy documents at provincial level which address climate change and adaptation is the **Forest Strategy 2018** of the **Province of Vorarlberg** (Amt der Vorarlberger Landesregierung 2009). Climate protection is listed as one of five strategic objectives. Some general principles are listed which include the stabilisation of forest ecosystems in view of climate change.

In the **Province of Tyrol** first attempts have been made to adapt the site classification system which is based on the notion of (potential) natural forest types, currently the main planning tool for tree specie choice and recommended silvicultural systems, for conditions of climate change. Research and networking activities within the Interreg domain are utilized intensively (e.g., WINALP).

Within the process of developing the **Austrian National Climate Change Adaptation Strategy** Hass et al. (2008) have summarized some preliminary principles. According to this intermediate report adaptation measures should meet the following requirements:

(i) robustness (i.e., based on reliable projections of future conditions or increasing the flexibility to respond to future changes)

(ii) increase the adaptation potential of forest ecosystems

(iii) based on integrated approaches for the design of adaptation measures (minimize the externalisation of problems to other sectors and areas such as nature protection, down-stream industries; prefer measures with synergies)

General recommendations in Haas et al. (2008) which go beyond operational forest management and clearly address regional to national scale activities include:

(a) Improved disturbance management (crisis plans, infrastructure such as wet and foil storage, warning and monitoring systems, improved accessability of mountain forests)

(b) Reduce damage by game species (browsing, bark peeling)

(c) Improve value chains in broad leaves to foster broadleaved silviculture

(d) Research in effects of climate change and climate extremes on timber quality along the forestry wood chain

(e) Maintain and improve forest monitoring systems (e.g. National Forest Inventory)

(f) Consider risk zoning (e.g. storms)

(g) Establishment of an information system on climate change and adaptation

(h) As precondition for successful adaptation regional vulnerability assessments are required, science-based case studies for demonstration and training purposes, knowledge base on climate change and forest management.

3.3.2 Management level

First recommendations for operational forest management from the National Climate Change Adaptation Strategy include (Haas et al. 2008):

(i) Choice of suitable tree species (robust species compositions; addressing economic and ecological criteria)

(j) Fostering diversity (genetic, structure, tree species composition, habitat types) as a means to increase stability and resiliene of forst ecosystems

(k) Priority for regenerating mature and aging forests (particularly in protective forests)

(l) Enhancing soil protection in forest operations (prevent soil erosion, provide water storage, sustain nutrient cycling)

(m) Improved disturbance management (crisis plans, infrastructure such as wet and foil storage, warning and monitoring systems, improved accessability of mountain forests)

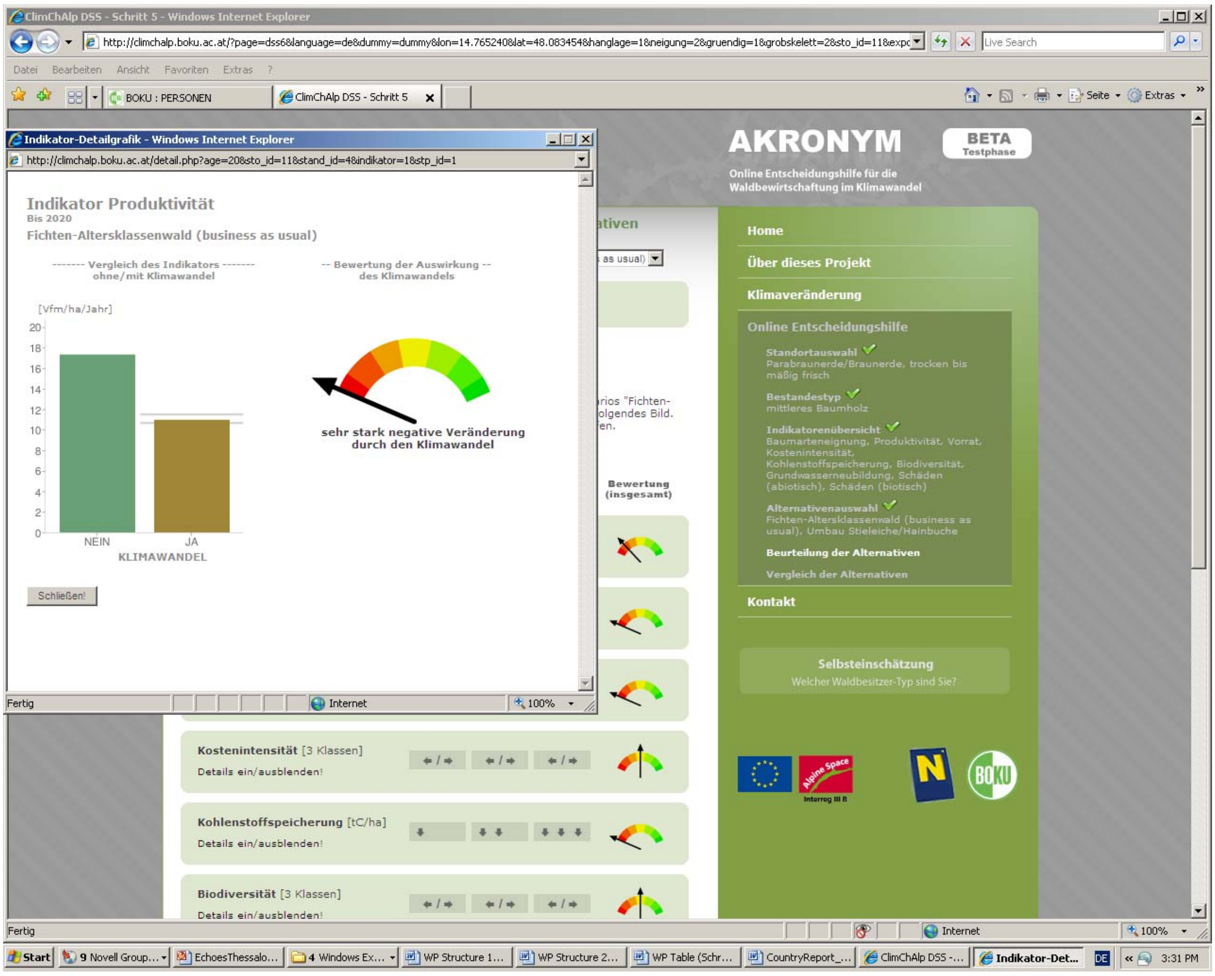
(n) Reduce damage by game species (browsing, bark peeling)

Summarizing, these preliminary recommendations combine activities and measures to

1. cope with intensified disturbance regimes
2. increase stability, resilience and the autonomous adaptation capacity of forests
3. reduce additional pressures on forest ecosystems

The forest administration service of the province of **Upper Austria** has published a **guideline to support tree species choice** at lowland sites which is particularly motivated by adapting current Norway spruce (*Picea abies*) dominated forests to a changing climate (Anonymous 2009). The booklet provides a simple site classification and suitable tree species including recommendations for spacing and mixture types. Focus is on promoting broadleaves for production of valuable timber. In paralell a network of demonstration plots in broadleaved stands has been established to provide practical training facilities and to demonstrate the potential for production of valuable sawn timber assortments.

The province of **Lower Austria**, also located in the eastern lowland parts of Austria follows a similar approach. Within the Interreg domain Alpine Space the ClimChAlp Project had been utilized to develop a **web-based decision support and information tool** to support experts of the forest administration service in advicing small scale forest owners with regard to tree species choice. The tool will be online by end of 2009 (Figure 15).



http://climchalp.boku.ac.at/?page=dss6&language=de&dummy=dummy&lon=14.765240&lat=48.083454&hanglage=1&neigung=2&gruendig=1&grobskelett=2&sto_id=11&expc

http://climchalp.boku.ac.at/detail.php?age=20&sto_id=11&stand_id=4&indikator=1&stp_id=1

Indikator Produktivität
Bis 2020
Fichten-Altersklassenwald (business as usual)

------- Vergleich des Indikators -------
ohne/mit Klimawandel

-- Bewertung der Auswirkung --
des Klimawandels

sehr stark negative Veränderung
durch den Klimawandel

Online Entscheidungshilfe für die
Waldbewirtschaftung im Klimawandel

Standortauswahl ✓
Parabraunerde/Braunerde, trocken bis mäßig frisch

Bestandestyp ✓
mittleres Baumholz

Indikatorenübersicht ✓
Baumarteneignung, Produktivität, Vorrat, Kostenintensität, Kohlenstoffspeicherung, Biodiversität, Grundwasserneubildung, Schäden (abiotisch), Schäden (biotisch)

Alternativenauswahl ✓
Fichten-Altersklassenwald (business as usual), Umbau Stieleiche/Hainbuche

Beurteilung der Alternativen

Vergleich der Alternativen

Kostenintensität [3 Klassen]

Kohlenstoffspeicherung [tC/ha]

Biodiversität [3 Klassen]

Figure 15. Screenshot of the web-based decision support system for the forest authorities of the province of Lower Austria.

Within the research project ADAPT adaptive silvicultural concepts for 160000 ha production forests of the **Austian Federal Forests** (AFF) were designed and tested in a simulation-based scenario analysis (Lexer and Seidl, 2009, Seidl et al. 2009). Structured into three broad site categories (Flysch sites, sites on limestone and silicatic bedrock) for the most abundant site types of the AFF the following main recommendations were derived:

(1) avoid spruce dominated mixture types at shallow calcareous sites, particularly at low elevations

(2) at sites along the northern ranges of the eastern Alps with high precipitation mixture types dominated by Fagus sylvatica, Acer pseudoplatanus, Fraxinus excelsior, Abies alba are an alternative to current Norway spruce (Picea abies) stands

(3) particularly for calcareous sites reduced rotation length for Norway spruce ageclass stands should be considered to reduce risk of storm and bark beetle damages

(4) at productive silicatic mountain sites increased productivity at higher risk from bark beetle damage may also be utilized through shorter rotations and adapted thinning regimes

(5) at low elevation Flysch sites in the eastern parts of Austria Picea abies dominated stands are unsuitable due to extremely high risk from bark beetle damages. Fagus sylvatica in general is a suitable alternative to stabilize stands. However, increased stress from drought and heat waves is to be expected. Therefore, at suitale sites oak (Quercus robur) is recommended as admixed or dominant species.

3.3.3 Research studies related to forest adaptation

The Austrian Climate Research Programme (ACRP) was created in 2008 under the auspices of the Austrian Climate and Energy Fund (Klima- und Energie-Fonds), which is a broad policy initiative that promotes climate-related and energy-related research in Austria. The ACRP pursues two interconnected activities. It supports and funds climate research by issuing regular calls for research proposals. In addition, the ACRP is planning to initiate a platform – the ACRP Forum – to assure the integration, mutual cooperation, external visibility and international outreach of ACRP-funded research activities. ACRP activities are guided by an international steering committee. The first call of the Austrian Climate Research Programme (ACRP) has been launced in March 2009. It is to be expected that several projects will be funded which directly address adaptation in forestry.

In Austria the community of forest management-related research is relatively small. However, with the increasing importance of mitigation in climate change research other scientific disciplines run research projects which are related to forests and forestry as well. Thus, a complete overview of all climate change related research activities into forests and forest management in Austra is beyond the scope of this report. Below a number of ongoing or recently completed research projects are listed which are closely related to adaptation.

MOTIVE (Models for adaptive forest management)
FP7-ENV-2008-1
Start: 01.05.2009
End: 30.04.2013

MOTIVE developes and evaluates strategies for forest resource management as affected by changing landuse and global climate change under multiple objective management. The project covers major biogeographical regions of Europe via a series of case studies representing different ecological and socioeconomic environments. Particular attention is paid to disturbance regimes and how these may change under changing climate and adaptive management. Key target of MOTIVE is to create new know how, data and models for improved decision making under conditions of climate change. Enduser of MOTIVE output are policy makers as wellas strategic and operational forest resource managers. Main deliverable of MOTIVE is a decision support tool box to support forest management planning.

ccTAME (Climate change – terrestrial adaptation and mitigation in Europe)

FP7-ENV-2007-1
Start: 2008
End: 2011

The project will assess the impacts of agricultural, climate, energy, forestry and other associated landuse policies, considering the resulting feedbacks on the climate system. Geographically explicit biophysical models together with an integrated cluster of economic landuse models will be coupled with regional climate models to assess and identify mitigation and adaptation strategies in European agriculture and forestry. The role of distribution and pressures from socioeconomic drivers will be assessed in a geographically nested fashion. Crop/trees growth models operating on the plot level as well as on continental scales will quantify a rich set of mitigation and adaptation strategies focusing on climatic extreme events. The robustness of response strategies to extreme events will further be assessed with risk and uncertainty augmented farm/forest enterprise models. Bioenergy sources and pathways will be assessed with grid level models in combination with economic energylanduse models. The results from the integrated CCTAME model cluster will be used to provide: quantitative assessments in terms of costefficiency and environmental effectiveness of individual landuse practices; competitive LULUCF mitigation potentials taking into account ancillary benefits, tradeoffs and welfare impacts, and policy implications in terms of instrument design and international negotiations. The proposed structure of the integrated CCTAME model cluster allows us, to provide an evaluation of policy options at a great level of detail for EU25(27) in a postKyoto regime, as well as to offer perspectives on global longerterm policy strategies in accordance with the principles and objectives of the UNFCCCC. Close interactions with policymakers and stakeholders will ensure the policy relevance of CCTAME results.

CC-WaterS (Climate Change and Impacts on Water Supply)

INTERREG SEES (South East European Space)
Start: 2009
End:2012

The stability of vegetation cover within drinking water protection zones is of crucial importance, especially in the context of climate change. In the case of forest vegetation, the possibilities of silviculture are requested to influence stability of forest stands in a way, that their protection functionality can be maintained under climate change conditions.

Therefore research goals of ccWATERs are to investigate the effects of changing climatic conditions on vegetation succession and forest management (focus on conversion to continuous cover forestry) within the water protection zones in selected case study regions. Within this context, stability and also risk-potential of single tree-individuals, forest stands, hydrotopes and whole water protection areas will be assessed. Implications for water protection purposes will be described in a comprehensive way.

iLand (A framework for individual-based forest landscape modeling under changing climate and disturbance regimes)

FP7-PEOPLE-IOF-2008
Start: 01.04.2009
End: 31.03.2011

Climate change is a major challenge for sustainable forest management. Impacts on the disturbance regime are particularly relevant in this regard. In a sound science-based sustainable forest management/ ecosystem management approach potential changes in climate and disturbance regimes need to be considered explicitly. Disturbance dynamics, however, are still poorly understood especially in ecosystems with interacting, climate-sensitive disturbance agents. Currently, most available model approaches suffer either from a limited spatial extent to address large scale interacting disturbance regimes (i.e. stand models) or from a coarse structural resolution with regard to the information needs in forest management (i.e. landscape models). The objective of the project is to bridge this gap in (i) developing an integrated, individual-based landscape modeling framework; (ii) adopting process-oriented, climate sensitive disturbance modules and utilizing existing ecological understanding to model disturbance interactions, and (iii) testing the behaviour of the model framework in two case studies in the temperate forest biome. To successfully address (interactions between) disturbances as emerging property of the modeled system as well as to provide relevant levels of information in the context of SFM an individual-based, process-oriented landscape modeling approach is proposed. The development will bring together recent advances in forest landscape modeling with efficient algorithms of modeling individual-based tree competition and process-based production. Existing disturbance models for selected agents will be adopted focusing on interactions and climate sensitivity. The framework will be parameterized and evaluated for two cases studies in the Eastern Alps (Austria) and the Pacific Northwest (USA), focusing on wind - bark beetle and fire - bark beetle disturbance interactions respectively. Overall, the integrated modeling framework aims at contributing to questions of sustainable forest management under changing climate and disturbance regimes and facilitating a landscape perspective in forest resource management.

ADAPT (Vulnerability of production forests of the Austrian Federal Forests Ltd under conditions of climate change and options for adaptation in silviculture)

Funding: AFF, Austrian Ministry of Agriculture, Forestry. Environment and Water Management
Start:2007
End: 2009

A vulnerability assessment for 160000 ha of production forests of the Austrian Federal Forests (AFF) under conditions of climatic change is conducted. Based on the results of this assessment adaptive silvicultural management strategies for vulnerable ecosystems are developed and compared with regard to a set of indicators. ADAPT playes particular attention on a sound knowledge management concept within the project including strategic and operational domains.

Currently a follow-up project is in preparation which will focus on forests of the AFF with nature conservation priority.

ClimChAlp

Interreg Alpine Space
Start:2006
End: 2008

In this research project a computer based decision support tool is developed for selected regions in Lower Austria which aims at:
(1) identifyinga specific site in the knowledge base of the DSS
(2) identifying a specific stand type in the data base of the DSS
(3) predicting likely consequences of a changing climate under several silvicultural treatment schemes
(4) indicator-based risk assessment
(5) classifying the potential for broadleaved timber production
(6) based on risk assessment and production potentials derive management objectives and related treatment schemes.
(7) provide links and info on related trial stands.
The project aims at contributing to the extension services of the regional forest authorities in Lower Austria, and thus contribute to the development of rural areas.
The DSS will be online by end of 2009.

IFORCAM (Integrated forest carbon management at FMU-level)

Funding: Federal Ministry for Agriculture, Forestry, Water and Environment
Start: 12/2004
End: 05/2006

Numerous studies have analysed the carbon sequestration potential of forests and forest management. However, most studies either focused on national and supra-national scales or on project level in context to the flexible mechanisms of the Kyoto Protocol. Few studies are available which analyse the effects of alternative silvicultural strategies on carbon sequestration, timber production and other forest services and functions at the operational level of the forest management unit (FMU). The present study investigates effects of four alternative management strategies (Norway spruce age class forestry; continuous cover forestry; conversion to mixed broadleaved forests; a "conservation" variant without any active management) for secondary Norway spruce forests (*Picea abies* (L.) karst.) on C sequestration in situ, in wood products and through bioenergy production at the level of a private FMU in Austria, and analyses the interrelationships with timber production and key indicators of biodiversity. The hybrid patch model PICUS v1.41 and a wood products model are employed to simulate forest ecosystem development, timber production, carbon storage in the forest and in wood product pools. Results show that in situ C sequestration is sensitive to forest management with the highest amount of Carbon stored in the unmanaged strategy, followed by the continuous cover regime. Actively managed strategies store substantial quantities of C in the wood products pool. Considering alternative biomass utilization focused on bioenergy production substantial C offsets could be generated from potential substitution of fossil fuels. Opportunity cost estimates for C sequestration reveals that C sequestration through forest management can be a cost efficient way to reduce atmospheric CO_2, however, achievable quantities are limited due to biological limitations and societal constraints. The study emphasizes the importance of developing sustainable forest management strategies that serve the multiple demands on forests in the future. Special attention was devoted to the effects of including/excluding bark beetle infestations on the performance of the analysed management strategies.

4 Mitigation

4.1 Relevance of forests

The Austrian commitment is to reduce the GHG emission between 2008-2012 by 13% below the emission rates of 1990. The Austrian ‚climate change mitigation‘ strategy rests on three pillars (i) using the reduction potential by increasing the efficiency of energy use and by using natural resources to increase energy supply, (ii) developing new technologies that will be effective in later commitment periods, (iii) and by using the flexible mechanisms of emission trading. Currently 2/3 of the Austrian electricity production is generated by hydro-power. The ambitious target is to cover the total energy consumption until 2020 by 34% by renewable energy, including biomass (BMLFUW 2008b). Generated electricity can be fed into the national grid (Ökostromgesetz). Afforestation and reforestation projects play a role in the flexible mechanisms (JI and CDM) where Austria invests in mitigation projects. Austria invested 73 Mio Euro until 2006 and will invest 36 Mio Euro per year until the end of the first commitment period. The country intends to cover approx 42% of its emission reductions by trading AAUs (BMLFUW 2007).

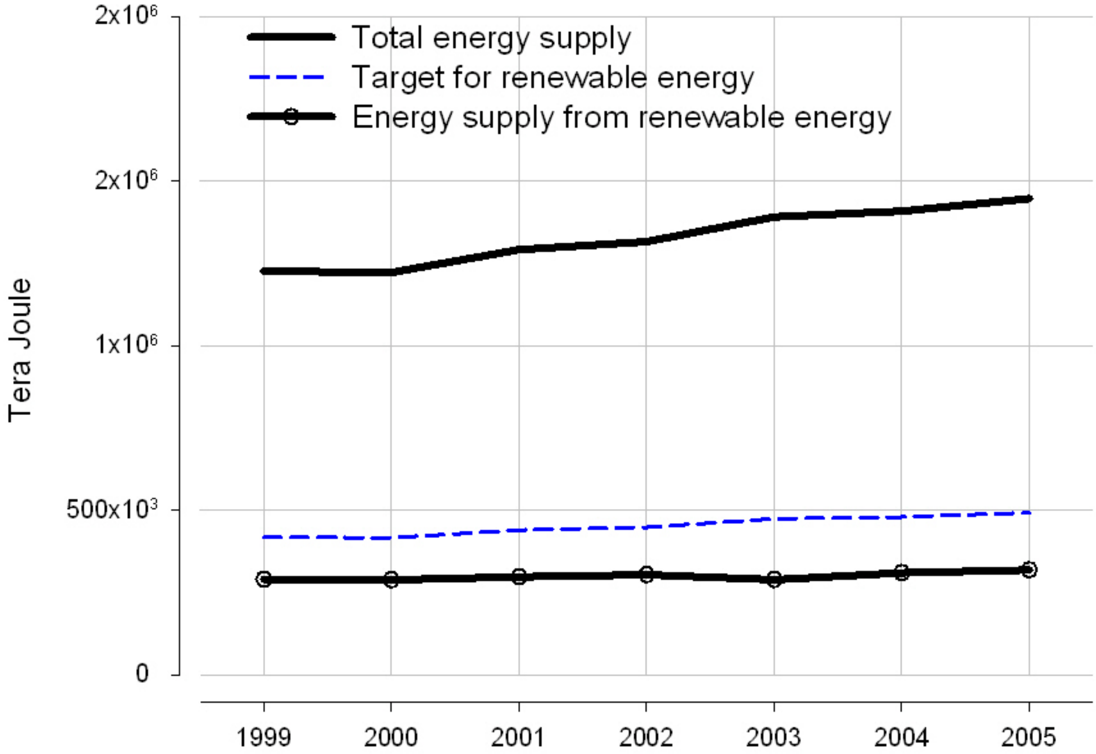


Figure 25. Temporal trend of energy production in Austria, the political target of the share of renewable energy, and the energy supply by renewable energy (Source: BMLFUW 2009).

Figure 15 shows the challenge of producing increasing amounts of energy from renewable sources. Due to the gradual increase in the energy demand the target for 2010 of covering 34% of the energy by renewable forms of energy proves to be ambitious (BMLFUW 2009).

Forest resources play an important but not necessarily the central role in using and developing new technologies. In accordance with the sequence of abatement measures with increasing costs as given by Enkvist et al. (2007) and Stern (2009) measures such as improving the

insulation of old and new buildings, use of solar energy for domestic use, fuel efficient vehicles are even commercially more viable than afforestation projects.
The need to reduce GHG emissions meets the Austrian forestry sector in the following situation (BMLFUW 2008a):

- the forest area is increasing, mainly due to the afforestation of marginal agricultural land
- infestation by pests is a threat that requires the constant attention of forest owners. Among driving factors are the existence of secondary spruce forests in low elevation that are particularly vulnerable and the migration of stable bark beetle populations into mountain forests that have so far been considered to be outside their range. Climate change plays a role in both situations.
- the productivity of forests is increasing since many years. Even though the demand for forest products increases the standing stock of forest biomass is rising.
- Renewable energy (hydropower and other renewable energy in Figure 16) supplies 21% of the total energy demand, 11% stems from biomass. Forests are the main source of biomass.

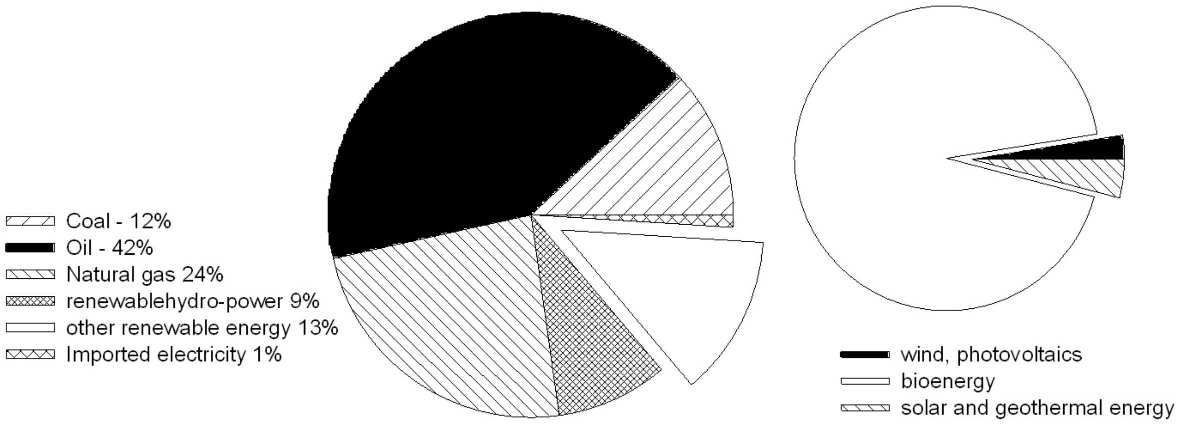


Figure 16. The Austrian energy supply system. Left: Total energy supply (1450 PJ), right: contribution of ‘other renewable energy’ (Source: BMLFUW 2009).

The energy demand is slowly increasing and was 1450 PJ in 2005. Renewable sources of energy ware mostly hydropower (130 PJ) and bioenergy (176 PJ) (Figure 16). Bioenergy comprises unprocessed wood (41%), combustible waste, pellets, biofuels, bark, industrially processed wood, gas from fermentation processes, and residues from the paper production (BMLFUW 2009).

A challenge for forest politicians is to mobilize the available forest resources. Combating climate change with a national afforestation programme is not on the political agenda. With a forested area already comprising more than 47% of the countries’ area a further increase is not immediately desired. Even the gradual increase of the standing stock of forest biomass has problematic aspects. The under-utilization of the forest resource is an indication that the current form of forest management is not sustainable. In areas with high harvesting costs such as mountain forests the age structure of forests shifts towards higher age classes and complex infrastructures are provided by the Forest Administration to manage these forests in a commercially meaningful way (e.g., Stöhr, 2009). The second reason for the under-utilization is the segregation of 50% of the Austrian forests between many private land owners, each owning only a small forest area. These farmers' forests often belong to agricultural enterprises (farms) and forestry is often of minor importance in the overall economy of land management. These small-scale private forests are often managed intermittently and market developments for forest products do not necessarily lead to strong reactions by forest owners.

The political challenge is providing incentives for the sustainable use of the forest resource. Several programmes (BMLFUW 2008c) have the objective to mobilize the forest resource. The climate change debate offers an important argument, because biomass from forests can substitute for fossil fuels and can directly reduce the national GHG emissions. An increase in thinning operations can supply fuel wood for energy production, can shift the mean forest age towards the point of the culmination of the growth rate and can increase the economic value of the remaining forest (Cannell, 2003, Schlamadinger and Marland, 2000, Assmann 1961). However, besides convincing forest owners of the benefits of marketing biomass the government needs to ensure the existence of energy plants that can absorb the flux of forest biomass to the newly emerging energy market. – It remains to be seen how much forest biomass will supply the energy sector. In the immediate future large areas of immature forests have the potential for thinning operations. In the long run the competition between the pulp & paper industry, an emerging chemical industry that is based on wood (e.g. Lyocell, http://www.lenzing.com/), and the energy sector will regulate how much fossil fuels can be substituted by the mobilization of so far postponed forest management actions.
A somewhat peculiar situation in Austria is that short-rotation tree plantations for the production of biomass for energy are stocking on agricultural land instead on forest land. The Austrian Forest Act (Forstgesetz 1975) requires a minimum rotation period that is much longer than the production cycle of energy plantations.

The potentially available agricultural area that is available for energy production has been estimated by several authors. The estimates range from 200 000 ha to more than 800 000 ha. A cautious estimate based on a thorough discussion among stakeholders is to manage by 2010 between 210 000 and 235 000 ha of agricultural land for the energy production and to produce 20.6 to 25.6 PJ (BMLFUW 2009).

4.2 Kyoto Article 3.4

For the forest sector the climate change debate offers new business opportunities (Sommerauer, 2005). Among the repeatedly addressed options is the increase in the rotation period. This strategy assumes that forests maximize the total carbon pool when they mature. Evidence has been provided in several experiments and modeling exercises (Knohl et al., 2005, Liski et al., 2000, Schulze et al, 2000). With hindsight to the intended mobilization of forest resources the Austrian Governments decided not to opt for Article 3.4 of the Kyoto Protocol, even though the cap, i.e. the accountable amount of GHG emission reductions due to forest management, would have been worth several Mio Euros. It was argued that the need to maintain the already high carbon pool in the standing biomass would deprive the forest sector of its flexibility in responding to opportunities on the timber market. Further uncertainty was introduced by the high amount of forest damages by storms that later on led to regional aggradations of bark beetle (BMLFUW 2008a). Storm damages and insect outbreaks are clearly outside the control of forest managers. The concern was that these ecosystem disturbances can suddenly turn the national forest resource from a minor carbon sink into a major carbon source (Körner, 2003).

4.3 Specific mitigation measures in forest management

The usual suspects in the realm of forestry that are rounded up for mitigating climate change can be divided into measures either affecting the soil carbon pool or the aboveground biomass. The incomplete and partially controversial state of knowledge for the soil carbon pools has recently been summarized by Schils et al. (2008). Under the high uncertainty and slow rate of carbon accretion in forest soils most forest management strategies need to aim far beyond single commitment periods.

Sustainably increasing the aboveground biomass can be achieved by the selection of appropriate tree species compositions and measures to increase the productivity (fertilization, irrigation). These strategies have been listed various times (Seidl et al., 2007; Seppälä et al., 2009, Lindner et al., 2008). Under Austrian production conditions these forms of forest management will not be implemented for the sake of mitigating climate change because they would require a considerable intensification of forest management that is not profitable under the current market prices for timber. There is general agreement that establishing forests that can withstand the increasing pressure from disturbances is the best option. This objective is fuzzy and takes into account that the current understanding of climate change effects is insufficient to offer general solutions.

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