Effects of Climate Change on the Alpine Forest: Needs for Research and Action

Position Paper

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Position paper on the
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Introduction

Measurements, observations and model calculations show that the European Alps are one of the regions most affected by climate change. There, the annual mean temperature has increased by about 1.5 °C over the last hundred years [1], which is twice as much as the global rise of 0.74 °C [2] and still much higher than the 1.0 °C increase for Europe [3].

For the end of the century, the IPCC projections for the scenarios B1, A1B, and A2 (which roughly may be described by low, medium, and high emissions) result in a further global rise of most likely 1.8 - 4.0 °C [2], estimates for Europe range from 1.0 - 5.5 °C [3].

A1B-based Regional Climate Models predict for Europe a further increase of 3.3 °C, while for the Alps a temperature rise of 3.9 °C is projected "with a particularly elevated warming of 4.2 °C in the high mountains above 1.500 m" [4]. Observed trends towards changing seasonal precipitation patterns and increased frequency and intensity of extreme weather are likely to continue or even accelerate [1], which all together severely will affect the alpine forests.

So far, the forests in the Alps grant ample and vitally important functions for men and nature, as they
- protect against floods, avalanches, erosion, mudflows, landslides, and rock falls,
- provide recreation space for the public and refuge for animals and plants,
- harbour a biological diversity of European significance,
- produce timber as work material, insulation material, and fuel,
- play a significant role in carbon sequestration,
- and serve the regional added value and the local people's livelihood.

They play a key role for nature conservation and protection, for the safety of settlements, infrastructure and traffic, for tourism and recreation, for water quality and management, and for material and energy supply, which services are not limited to the Alps, but extend far to the alpine foothills and forelands. Alpine rivers, for example, pass directly through several European major cities and have long-distance effects on 9 large agglomerations (Bern, Genoa, Lyon, Marseille, Milan, Munich, Turin, Vienna, Zurich) with a total of 16 Mio. people, not to mention the Rhine Basin with another 50-58 Mio. people.

Weather and climate have considerable influence on the alpine forests: higher temperatures extend the vegetation period and promote growth, whereas frequent extremes such as droughts, heavy rain and storms as well as climate-related humus loss and pest calamities present a substantial threat to forest vitality. The mountain forests will react with changes in the genetic structures of tree populations and tree species composition, the biodiversity of flora and fauna due to migration, and the composition of biological communities. Dimensions, speed and ecosystem consequences of these changes are however still largely unknown.
The European Alps extend across a 1.200 km long and 150-250 km wide arc covering an area of roughly 193,000 km², of which around 76,000 km² are forest land. Elevation, size and extent make the Alps not only an effective climatic divide, but also a region which itself is affected by different climates with maritime (in the West and North), mediterranean (in the South), and pannonic (in the East) characteristics. This results in different regional (and local) climates across the Alpine arc and therefore a great regional diversity in vegetation composition and growth conditions. Nevertheless, throughout the Alps forest is the predominant land cover occupying about 40 % of the total area.

**Basis characteristics of the Alpine Region**

<table>
<thead>
<tr>
<th>Country</th>
<th>Country Size (km²)</th>
<th>Total Area (km²)</th>
<th>Forest Area (km²)</th>
<th>Population (x 1000)</th>
<th>No. of Municipalities</th>
</tr>
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<tr>
<td>Austria</td>
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<tr>
<td>Slovenia</td>
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<td>6.690</td>
<td>2.790</td>
<td>889</td>
<td>91</td>
</tr>
<tr>
<td>Switzerland</td>
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<td>27.050</td>
<td>9.960</td>
<td>2.039</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.350.957</strong></td>
<td><strong>192.790</strong></td>
<td><strong>76.140</strong></td>
<td><strong>15.394</strong></td>
<td><strong>6.306</strong></td>
</tr>
</tbody>
</table>

* Total and forest area: MODIS data after CIPRA 2001 [5], population and municipalities: NORDREGIO 2004 [6]

Composed of 50 % coniferous, 23 % deciduous and 27 % mixed stands the alpine forest provides a timber stock of 1.5 billion m³ (conservative estimate [5]) fixing a total of 2.7 billion tons of CO₂. Every year at least another 37 million m³ of timber are produced of which about 75 % are harvested.

To further secure the sustainable use of the alpine forest and protect its multiple functions there is urgent need for research and action. The Center of Forestry Weihenstephan has identified the most pressing problems and priority fields, on which practice-relevant research should focus.

The paper is based on the Center's long-term and extensive involvement in forest-related climate change research and oriented on the respective European Guidelines, Directives and other important papers such as

- Communication from the Commission to the Council and the European Parliament on an EU Forest Action Plan;
- Communication from the Commission to the Council and the European Parliament - Reporting on the implementation of the EU Forestry Strategy;
- Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions (Thematic Strategy for Soil Protection);
- COP 9 Decision IX/5 (Forest biodiversity);
- DG Environment: Feasibility Study on means of combating forest dieback in the European Union;
• EU Biodiversity Action Plan;
• European Commission Green Paper on "Adapting to climate change in Europe - options for EU action";
• IPCC Report 2007;
• Natura 2000;
• "Progress towards achieving the Kyoto objectives" required under Article 5 of decision 280/2004/EC of the European Parliament and of the Council;
• Sustainable Forestry and the European Union;
• The Sixth Environment Action Programme of the European Community 2002-2012;
• United Nations Framework Convention on Climate Change (UNFCCC);
• White paper "Adapting to climate change: towards a European framework for action".

The document has been written in view of the situation of the alpine forests in the State of Bavaria, Germany. However, the vast majority of stated facts, conclusions and needs is relevant to all alpine forests. As climate change is not an isolated threat they all face equal or similar problems, which need to be attacked in a pan-alpine effort with multidisciplinary knowledge. The protection of the alpine forest and its functions and services is of existential importance to all alpine countries and therefore a task of European dimension.

Moreover, it is not only the forest in the Alps, which needs attention. Forest is also the predominant land cover in most other European massifs [6], be they high mountains such as Pyrenees, Romanian Carpathians and Southern Fennoscandia or lower massifs such as Black Forest, Bohemian Range, Massif Central, Vosges and Swiss Jura, to name but a few examples. Even though climate change will affect them in different ways and extent, their forest ecosystems will change. The European mountains are home to 94.3 million people who rely on stable forests and their vital functions for men and nature.

[1] Climate Change in the Alps, German Federal Environment Ministry, 2007
Forest Growth and Growth-specific Climate Extremes Indices

Tree growth patterns in the Alps clearly vary with altitude. The impact of climate change on growth patterns and tree species composition of mountain forests is supposed to be even more pronounced than in lowland areas. While present global climate change models usually are focused on mean values, climate extremes like thunderstorms, hail, torrential rain, and high winds may be of special importance for survival, distribution and yield of trees in the Alpine region.

However, our knowledge about the relationship between climate extremes and growth patterns is limited and does not allow sound predictions about the future role of mountain forests both for wood production and protection functions. The spatial resolution of the available climate models is too low for analysing the relationship between growth patterns and climate in the Alpine area, which is characterized by small-scale variations. Available yield data are insufficient to quantify increment rates, and the relationship between climatic extremes and tree behaviour remains more or less uncharted territory.

The lack of such information is not only a scientific issue but also has strong practical implications. Future growth rates and thus harvesting possibilities in the Alpine area may increase with rising temperatures. On the other hand climate change may reduce the resistance of forests against natural hazards. Reliable information about future increment and tree species composition are indispensable prerequisites for management decisions meeting the complex demands of tomorrow’s mountain forests.

There is a clear need to improve our understanding of growth patterns and their relationship with climate extremes. There are promising scientific developments in this field: Regionalisation of climate data, like in the INTERREG project "ClimChAlp", are based on statistical approaches and provide spatially high-resolved climate projections for the Alps. The new HISTALP database allows quantifying historical and recent regional climate change patterns in the Greater Alpine Region with a high spatial resolution. Improved climate data can be used to understand growth patterns and interspecies competition of tree species using dendro-ecological methods. Based on such results climate change driven growth models could be adapted to the alpine forests and, in a second step, validated using the comprehensive inventory data from the Bavarian State forests.

**Needs for Research and Action:**

- Definition of meteorological/climatic extremes indices and impact-related measures relevant to tree growth and competition, and testing the suitability of isotopes in tree rings in order to describe past climate (drought events);
- Dendro-ecological studies analysing growth patterns along vertical transects and correlation of tree growth, phenology and population dynamics with high resolution historical meteorological parameters;
- Simulation of growth performance and vertical distribution of the major tree species under future climate conditions;
- Management decision support concerning future behaviour of tree species by adapting existing management-orientated models to the Alpine area.
Forest regeneration in the Alps already represents a great silvicultural challenge. Due to strong vertical gradients, tree species and communities growing on the edge of their optimum area of distribution react much faster and more clearly to changing climate conditions than their lowland counterparts. The expected increase in weather extremes will particularly interfere with regeneration, which is especially sensitive to late frost, erratic rainfall, surface dehydration and insolation damage, although to what extent is still unknown. Largely unknown is also, what effect changes in snow movement and snow mould infestation due to less snowfall at higher temperatures will have. All in all there is great uncertainty about which stand and site-specific regeneration techniques to use in order to establish well-structured, functional mixed mountain forests.

From a genetic point of view, tree species in high elevated ecosystems are geographically clearly differentiated and seem to reveal a slight reduction in their genetic variation with increasing altitude. Genetic monitoring verified remarkable differences between species with respect to variation parameters and its dynamics. There is a need for species-dependent conservation measures with main focus on *Larix europaea*, *Abies alba*, *Pinus cembra*, *Pinus sylvestris*, *Pinus mugo* and *Pinus uncinata*.

In many cases, natural regeneration represents the respective mature stands genetically insufficient and exhibit a gene pool depletion which may reduce their potential to respond successfully to environmental heterogeneity under future climate change scenarios.

**Needs for Research and Action:**

- Concepts for and studies on
  - the conversion of even-aged, mono-layered and frequently non-autochthonous pure spruce stands of the mountainous zone into well-structured mixed mountain forests;
  - the site-appropriate re-afforestation of disaster areas originating from storm throws or bark beetle calamities;
  - the optimisation of the supply of reproductive material that is adjusted to the specific conditions for alpine forest restoration and conversion;
  - the natural regeneration of spruce and fir in mature mixed mountain forests.

- Genetically sustainable management by means of
  - revision of the primacy of natural regeneration over artificial regeneration with respect to in situ conservation of genetic variation in times of rapid environmental change;
  - identification of appropriate provenances in order to enrich the genetic potential of mountain forests, and re-stating of the regions of provenance with regard to climate change (altitudinal zoning); optional verification by translocation experiments;
  - avoidance of genetic loads (inbreeding and erosion of genetic variation) following small population sizes, lacking representativeness and isolation;
  - genetic certification of forest stands and seeds.
Water and Nutrition Balance, Humus Supply, Carbon Cycles

The growing of plants depends strongly on temperature, water and nutrients. The plants' water balance is determined by the precipitation amount and temporal distribution, the water storage capacity of the soil (which on mountain sites is often limited), the evapotranspiration, and the run-off. In general, the annual precipitation in the Alps is high, ranging in the Bavarian Alps, for example, from 1000 mm to 2500 mm. Nevertheless, model results for dry years such as 2003 show that drought stress lasting 1-2 weeks is possible on shallow soils. The continuing rise in temperature and changes in annual rainfall patterns let expect an increase in the frequency and duration of these situations. Present water balance measurements and models do not however describe the situation adequately. Normally, neither the mountain forest's special tree species mixture, nor their complex age structure is taken into account, and relief and soil-determined surface run-off and macropore flow, if considered at all, are included only insufficiently.

Besides the water balance also the nutrition balance needs to be looked at carefully. Compared to lowland measurements the nutrition status of the forests in the Bavarian Alps, especially in the Kalkalpin zone, gives reason to suspect deficiencies in N, P, K, Mn, Fe and B, which can only to a limited extent be compensated for by fertilizing. For a sufficient and well-balanced water and nutrient supply the humus pool is of crucial importance. Rising temperatures and more forest clearings due to increased pest infestation and storm damage lead to humus losses and therefore depletion of the nutrient pool and reduction of the root-penetrable soil layer. Particularly vulnerable is the humus fraction that is not stabilized by organo-mineral fixation. The probability of occurrence and the significance of such humus losses can be determined using multivariate statistical techniques that – once the soil humus reservoir is quantified in representative study areas – provide a georeferenced data basis for the regionalization of the humus supply and its change.

Humus losses may also have considerable effects on the soil's and forest's carbon storage ability. Temporary increased CO₂ emissions and a reduced sink strength of the mountain forests by direct and indirect impacts on growth and soil dynamics will therefore affect the regional and – considering the worldwide distribution of mountain forests – the global CO₂ balance.

Needs for Research and Action:

- Quantification of the water balance for important tree species (e.g. spruce, Swiss stone pine, mountain pine, beech, sycamore maple) at tree and stand level, taking into consideration the great variety of mountain sites and stand structures;

- Comparison of trial plots at different altitudes and/or experimental reduction of the water supply by artificially covering the soil to simulate the effects of rising temperatures and dry periods;

- Estimation of climate change effects on the humus supply and its stable and unstable fractions;

- Investigation of the nutrient supply, demand and uptake of alpine forests, and survey of the temporal and spatial co-incidence of nutrient and water deficiencies;

- Regional assessment of the complex reactions in the carbon cycle and of feasible silvicultural measures to preserve and enhance the alpine forests' storage function;

- Estimation of the consequences of regional carbon storage changes to the global CO₂ balance.
Vegetation and Tree Species

In mountain areas vegetation is arranged along altitudinal gradients. This is true for alpine grasslands as well as for forest vegetation. Most important site factors for vegetation differentiation are (i) temperature and (ii) precipitation. Both factors are predicted to change strongly in the future. Increasing temperatures will result in a general uplift of vegetation belts, and the combination of increasing temperature and independently changing precipitation will additionally affect forest communities by modifying species composition and changing the relation of indicator plant species. Therefore new species assemblages will appear and replace the former ones. The narrow vertical sequence of climatically determined life zones in the Alps makes their vegetation particularly suitable for research into the effects of climate change, and provides an excellent "outdoor" laboratory for studying the reactions of key tree species to climate change. It makes the forests of the Alps ideal for studying the processes of both spatial dislocation and internal re-arrangement of species assemblages.

Seen from the landscape management perspective forests and forestry are of particular relevance, because such changes will result in uncertainty respecting the timber production function of forests, but also concerning soil erosion, nutrient loss, snow avalanches, mudflows, and ground water quality. Forestry has to adapt quickly to these changes of the ecological basis of forest growth. In the Bavarian Alps, the present vertical distribution of tree species can be derived individually for tree species and regeneration layers from vegetation databases and forest inventory data, and then related to other site factors. The set of problems will generally affect the forests throughout the Alps, but in regionally differentiated ways.

Needs for Research and Action:

- Analysis of the ongoing floristic changes in mountain forests (tree species, but also the whole species pool), e.g. increase of thermophilous plant species; spatial change (uplift) of tree species and forest communities;
- Prediction of growth and regeneration reactions of key tree species to increased temperature/changes climate and proof of relevance by representative dendro-ecological and phyto-sociological random samples;
- Process studies of the vertical displacement of vegetation zones and causal analysis of the spatial displacement of individual tree species in order to assess implications for forestry and land use;
- Integration of the results into adapted forest and landscape management schemes.
Maintenance and Restoration of Protection Forests

As explicitly stressed in Article 6 of the Mountain Forest Protocol to the Alpine Convention, a legally binding treaty of the Alpine States, mountain forests that have a highly protective function must be conserved on site and have to be managed to that purpose. Those forests protect large economic areas and living space against natural hazards like avalanches, rockfalls, landslides and floods, secure their sites against soil erosion and preserve our natural livelihood such as drinking water. Protection forests are widely represented in the northern Alps: In Bavaria, for example, 60 % of the mountain forests are classified as protection forests.

From an economic point of view, there are no alternatives to protection forests as they protect much more comprehensively and – above all – cost-effectively against natural hazards than technical constructions. In the course of the climate change, protection forest management and restoration become even more important because of their high economic and ecological efficiency. Protection forest management will be important for the strategy for the security of our living space. However, investments in the protection forests often are effective not until after decades, and the benefits cannot be measured immediately. Diffuse or missing assessment categories and the complexity of the protection forest system with many outside influences such as natural events, intensify the problem.

In the Northern Alps protection forests are often dominated by spruce, which with increasing temperatures will lose vitality and – especially on shallow-soiled, sunny slopes – may even die off. Increasing risks of storms and temperature-caused improvement of breeding conditions for bark beetles make spruce even more susceptible to disasters. The combination of dry summers, wind damage and pest calamities is thinning the protection forests and, if spruce dies off entirely or even only partially, the mountain forests lose their protective functions. In future protection forests the share of spruce therefore needs to be reduced in favour of other evergreen coniferous species with similar protective functions.

Needs for Research and Action:

- Identification of the sites, where the protection forests are most vulnerable to climate change;
- Development of indicators for evaluating the long-term effects of protection forest management;
- Development of methods for a) assessing the benefits and b) fair compensation of owner-provided measures in protection forests;
- Establishing of monitoring systems to timely recognize undesirable developments in protection forests by, for example, improper silvicultural interventions;
- Research on the protection forests' prevention potential for landslides and mudflows in comparison to agricultural land use;
- Identification of evergreen coniferous species suitable to stabilize protection forests in the future, and development of management techniques to establish and increase their proportion in existing protection forests.
Global climatic change is expected to enhance the risk of pest outbreaks in the Alps. As predicted by climatologists, deficiencies of snowfall, drought periods and storms predispose trees to infestation by insect pests and pathogens. Low nutrition, drought susceptible and shallow stands will enhance the climatic impact. Especially cambiophagous and wood boring insects, particularly bark beetles, will benefit from these climatic constellations and damage particularly coniferous stands which are typical forests of the northern part of the Alps. Colonizing wind thrown trees, these pests are predicted to reach population densities high enough to attack standing trees in the near future. Wind blows cause new forest edges, which are susceptible to beetle attack. Proceeding pest outbreaks increase openings in the stands. Loss of canopy closure enhances the risk for further wind blows, which are followed again by bark beetle attack. Increasing temperatures predispose not only trees for pest attack, but enhance their development and generation frequency. Especially opened stands in the Alps will suffer impact from increasing temperatures. Global climatic change is suspect to cause self-accelerating processes leading to serious damages in alpine forests. Further on, due to global warming new pest will appear, those distributed in lower elevations will migrate to higher altitudes and secondary pests are suspect to turn into primary ones.

Up to now we have only vague ideas about efficient monitoring procedures and forecasting models, about frequency and patterns of outbreaks and about management strategies which can be applied in a landscape with a broad variability in stands and orography. On the other hand sound information on the occurrence and population dynamics of pests are urgently necessary to develop and recommend efficient techniques to minimize the impact on protection forests and stands for timber production.

**Needs for Research and Action:**

- Development of suitable monitoring techniques adapted to the orographic variability of the Alps;
- Intensified surveillance, particularly considering the migration of pest species or their appearance in higher elevations;
- Analysis of spreading and adaptation strategies of forest pests under changing climate conditions;
- Assessment of the risk to mountain forests from pest infestation as a result of disasters, drought stress, and nutrient deficiency;
- Adaptation of methods to avoid pest attack and development of action alternatives.
Biodiversity / Natura 2000

The mountain forests of the Northern Alps harbour a biological diversity of European significance. Here large, continuous forest areas with a comparatively low degree of fragmentation by settlements and infrastructure can still be found. Besides some of the most productive forest sites, there are extensive, inaccessible and often marginally productive forests that have been subject to minor human intervention. Therefore, even outside existing national parks and nature reserves, unusually high proportions of very old trees and dead wood have been preserved locally, of which fauna and flora yet await to be studied in depth. Forest vegetation is rich in endemic, prealpine plant species and communities (e.g. larch-stone pine forests, calcicolous Scotch pine forests, elm-sycamore ravine forests). The species-rich mixed mountain forests and subalpine spruce forests on limestone have their Central European centre of distribution here. These natural ecosystems are embedded in a rich cultural landscape, in which traditional land-uses connected to the high pasture system persist to the present. Thus, semi-open, extensive pasture forests are preserved to a degree that is unique in Central Europe. Likewise unique is the intensity of untrammelled geomorphologic dynamics (braided rivers, avalanche tracks, rockfalls) and the resulting succession processes.

These extraordinary biodiversity values have lead to the designation of very large areas protected under the FFH and SPA directives in Austria and Bavaria. Due to their sheer size and inaccessibility, monitoring poses a major challenge to the authorities in charge. Transnational harmonisation of monitoring and management plans remains yet to be developed. Due to the strong altitudinal climate gradients, significant shifts in the thermal limits of protected species and habitats are predicted. Detection of these shifts must be made a central feature of Natura 2000-monitoring. Management for biological diversity has to be harmonised not only between member states, but also needs to be weighed against interests of other land-uses. Apart from many synergies (eco-tourism, naturalistic silviculture, biological engineering in managing protective forest, extensive pasturing), undeniable conflicts are awaiting resolution based on the best available knowledge and on modern methods of moderation and mediation.

**Needs for Research and Action:**

- Vulnerability of biodiversity against climate change;
- Mitigation of and adaptation to the threats of climate warming;
- Risks and opportunities of structural and land-use change for biodiversity;
- Balancing biodiversity goals with other land-uses like hydropower, pasturing, tourism, forestry and protective forest management;
- Transnationally harmonised monitoring of Natura 2000 areas based on cost-efficient methods of remote sensing and habitat modelling;
- Systematic study of altitudinal and thermal gradients in the xylobiontic fauna and fungal flora of alpine forest communities;
- Harmonisation of protection strategies for threatened species and habitats across national and sectoral boundaries;
- Acceptance and marketing of Natura 2000 areas as an element of sustainable regional development.
In alpine regions, the manifold of forest ecosystem services, such as protection against floods, avalanches, erosion, provision of recreation, and supply of timber products, forms an enormous value that forests contribute to human welfare. As weather and climate have considerable influence on distribution, ecological stability and composition of alpine forest ecosystems, climate change has indeed an impact on the provision of ecosystem services as well. For example, the tree species Norway spruce becomes more prone to bark beetle attacks in alpine regions and the forest cover is lost at many places also by storms. In combination with lacking tree regeneration the surface water runoff is increased, floods become more frequent, and snow movements (snow gliding, creeping, avalanches) and erosion increase. The loss of permanent forest cover has also carbon emissions to the atmosphere and probably a loss of landscape beauty as a consequence. In conclusion, the ability of alpine forests to provide the variety of essential services is probably on the decrease, given the climate change ahead.

Many of the required services have (so far) no market value and thus no monetary incentives exist to increase (or at least maintain) the provision of non-market ecosystem services from alpine forests. A landscape view is also often missing in scientific studies. The question on how the alpine landscape is to be composed by forest, agricultural and touristic (e.g. skiing) areas to best provide ecosystem services under climate change, such as landscape beauty (recreational services), protection (including carbon pools) and production, is not even conceptually solved. It is open how the provision of ecosystem services should be integrated in scientifically sound land use concepts for alpine regions, if ecosystem services interact and compete. The impact that future uncertainties would have on ecosystem distribution and composition is unclear. How the provision of ecosystem services should best be financed is another open question. Moreover, the awareness of the importance of ecosystem services among the inhabitants of alpine regions is often not very developed. Thus, the local population often does not support restoration of protective forests. A need for participatory approaches is evident.

**Needs for Research and Action:**

- Estimation of shifts between ecosystems (forests and others) and of tree species and structural changes in forest ecosystems under climate change;
- Linking the provision of ecosystem services to the expected shifts under climate change;
- Identification of complementary and competing ecosystem services;
- Identification of measures to improve the provision of ecosystem services;
- Development of a comprehensive landscape model that considers effects of climate change, ecosystem services, monetary and uncertainty aspects;
- How to use landscape modelling and visualization in participatory planning processes;
- Testing various approaches to finance the provision of ecosystem services, such as taxes or the establishment of (voluntary or compulsory) markets for ecosystem services.
Social and Political Aspects 2, 8, 19

Climate change is perceived as a threat and a major issue to wide parts of the population. The media frame "climate change" is part of a frame of risk in general, with its implications for mobilization of the public. For this reason policy linked to climate change receives a high attention by the media, political actors, administrations, NGOs and the general public. Forest management is linked to climate change through several pathways:

1) Planting more forests is perceived as an important part of a successful mitigation strategy.
2) The destruction of forests in tropical countries is perceived as one reason of climate change.
3) Forests and their biodiversity are perceived to need protection against climate change.
4) Forests are subject to destruction events (storms, drought and fire), which are thought to be caused by climate change.

These connections establish a link between forest management and climate change. Therefore forest management decisions are part of public debate, and new actors participate in decisions. The current key actors of forest management (forest owners and the forest administration) have to integrate these new actors and the general public into the process of developing forest management strategies. Since new actors have a broader perspective, participative strategies should not be focussed on the forest sector only but include the whole range of land use possibilities to move from a pure "Forest Management" to a "Participative Land Use Management". In implementing a risk-sensitive participative land use management sustainable strategies should be developed to both mitigate climate change and adapt to it.

Needs for Research and Action:

- For the collaborative planning on the level of landscapes new methods of governance and participation have to be developed, integrated and evaluated.
- The integration of forest management in participative land use management needs cooperation by current key actors of forest management, their counterparts in other land use sectors (agriculture, urban development, ...) and new actors. This cooperation has to be moderated by a neutral actor.
- To understand the public's reaction to climate change debate and its links to land use management, risk perception plays an important role. Risk management has to be integrated into land use management more profoundly.
- An integrated land use policy has to be discussed, developed and implemented by the relevant actors as a framework for participative land use management.
Annex: The Center of Forestry Weihenstephan

History

The Center of Forestry Weihenstephan (ZWFH) is an institutional cooperation between three independent partners from forest academia and forest administration. Founded in 2003, it combines at one single place the School of Forest Science and Resource Management of the Technische Universität München (TUM), the Faculty of Forestry of the University of Applied Sciences Weihenstephan-Triesdorf (HSWT), and the Bavarian State Institute of Forestry (LWF).

Forestry and Forest Science however have a much longer history in Bavaria: Already in 1790 a School of Forest Science has been founded in Munich, the State Institute dates back to 1881. Following the State's idea of establishing a "Green Centre", they both moved in 1992 to Weihenstephan, where the HSWT (founded in 1970) had implemented in 1972 a Forest Faculty. By hosting the TUM Center of Life and Food Sciences with several faculties and research departments, further HSWT faculties and the State Research Center for Agriculture, the campus Weihenstephan provides a unique environment for interdisciplinary research and academic exchange (Table 1).

Table 1: Campus environment of the Center of Forestry

<table>
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<th>TUM Faculties</th>
<th>HSWT Faculties</th>
<th>Bavarian State Research Institutes</th>
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<tr>
<td>• Forest Science and Resource Management</td>
<td>• Forestry</td>
<td>• State Institute of Forestry</td>
</tr>
<tr>
<td>• Agricultural and Horticultural Sciences</td>
<td>• Agriculture and Food Management</td>
<td>• State Research Center for Agriculture</td>
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<tr>
<td>• Biosciences</td>
<td>• Biotechnology and Bioinformatics</td>
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<tr>
<td>• Landscape Architecture and Landscape Planning</td>
<td>• Horticulture and Food Technology</td>
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<tr>
<td>• Brewing and Food Technology</td>
<td>• Landscape Architecture</td>
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<td>• Nutrition</td>
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<tr>
<td>TUM Research Departments</td>
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<tr>
<td>• Ecology and Ecosystem Management</td>
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<td>• Plant Sciences</td>
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<td>• Life Science Engineering</td>
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<td>• Animal Sciences</td>
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<tr>
<td>• Biosciences</td>
<td></td>
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<tr>
<td>• Food and Nutrition</td>
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</tbody>
</table>

Structure

The Center comprises 45 units (chairs, institutes, divisions and sub-divisions) with a total of 400 people – university educated forestry personnel, scientists from other disciplines, experienced active foresters, technical staff and administrative personnel.

Basic guidelines, strategies and principles of operation for the Center's work are defined by a Coordination Board which consists of two members from each partner and a representative from the State Forestry Administration; its chairman, the Center's Head, is elected on a rotation principle between TUM, HSWT and LWF. The operational business is carried out by a Coordination and Support Office headed by a Managing Director.
Objectives, Key Competences and Major Fields

The Center's overall objective is to act as an interface between science, practice and the public, and to serve foresters, forest owners, forest industry, politics and society as central contact in all forest and timber related questions.

By combining its partner's individual expertise and resources in various disciplines (Table 2) and thus creating considerable synergies, the Center's core competences comprise

- Basic and applied research
- Long-term monitoring and inventories
- Development of skills and methods
- Consulting and knowledge transfer
- Academic and practice-oriented education
- Advanced training for professionals

The wide spectrum of key competences and their interlinking and mutual stimulation ensures the Center's ability to create, apply, pass and disseminate knowledge and experience, and makes it in size and coverage a unique "Forestry Competence Center", which meets the EU research policy intention of establishing central nodes through the aggregation of individual institutions.

Table 2: The Center’s major fields in research, education, and knowledge transfer

| Afforestation, Natural Regeneration | Geobotany, Forest Vegetation |
| Atmosphere/Biosphere Interactions | Inventories and Sustainable Use |
| Biometry and Informatics | Land Use and Landscape Planning |
| Carbon sequestration | Landscape Planning and Development |
| Ecology of Wooden Plants | Natural Forest Reserves |
| Energy Wood | Nature Conservation |
| Environmental Monitoring | Pathology of Forest Trees |
| Forest Access | Plant Ecophysiology |
| Forest and Environmental Policy | Protective Forests, Natural Hazards |
| Forest Ecology | Remote Sensing, GIS |
| Forest Economy | Resource and Energy Technology |
| Forest Education, Communication | Silviculture and Forest Planning |
| Forest Engineering and Ergonomics | Soil and Water Protection |
| Forest Genetics and Biodiversity | Soil, Site and Microclimate Conditions |
| Forest Growth and Yield | Timber Acquisition, Mobilisation, Transport |
| Forest Hydrology | Timber Composites |
| Forest Management | Timber Physics, Chemistry and Biology |
| Forest Nutrition and Matter Cycles | Wildlife Biology and Management |
| Forest Protection | Zoology, Animal Ecology |

Research

By cross-linking basic and practice-oriented research the Center generates the knowledge base for understanding how forest ecosystems work, their best possible protection and the optimum use of their ecological, economical and social functions. Because of the State’s high percentage of forest land (35 %), research on forest-related climate change had become the Center’s top priority: Presently more than 45 climate change mitigation and adaptation projects are being performed with state, national and international funding.

Often taking the Lead Partner or Coordinator function, the Center institutes participate in INTER-REG, COST, LIFE+ and EU Framework Programmes (Table 3) and run projects in North and South America, Africa, and Asia. On the other side, the Center offers scientists from all around the world excellent research conditions with over 140 year-old test and observation plots across the State’s vegetation zones, a 470 ha large University Forest Enterprise, the nearby ecological-physiological field station "Kranzberger Forest" and many special laboratories.
Table 3: Examples of the Center's involvement in European research projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Date</th>
<th>Programme</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAPTABILITY: &quot;Importance of regulation mechanisms for the climatic</td>
<td>12/00 - 05/04</td>
<td>FP</td>
<td>Partner</td>
</tr>
<tr>
<td>adaptation of tree species&quot;</td>
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<tr>
<td>ALPFFIRS: &quot;Alpine Forest Fire Warning System&quot;</td>
<td>09/09 - 08/12</td>
<td>INTERREG</td>
<td>Partner</td>
</tr>
<tr>
<td>BAFE: Biodiversity in Alpine Forest Ecosystems: Analysis Protection</td>
<td>02/97 - 04/00</td>
<td>FP</td>
<td>Lead</td>
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<tr>
<td>and Management&quot;</td>
<td></td>
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</tr>
<tr>
<td>CarbonPro: &quot;Carbon balance drafting and new resources management tools</td>
<td>04/06 - 12/07</td>
<td>INTERREG</td>
<td>Partner</td>
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<tr>
<td>according to Kyoto Protocol&quot;</td>
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<tr>
<td>CASIROZ: &quot;Carbon Sink Strength of Beech in a Changing Environment:</td>
<td>10/02 - 01/06</td>
<td>FP</td>
<td>Lead</td>
</tr>
<tr>
<td>Experimental Risk Assessment of Mitigation by Chronic Ozone Impact&quot;</td>
<td></td>
<td></td>
<td>Partner</td>
</tr>
<tr>
<td>&quot;CO₂ reduction potentials and application of climate protection</td>
<td>02/06 - 12/07</td>
<td>INTERREG</td>
<td>Lead</td>
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<tr>
<td>instruments in EFRE-Target 2-Regions&quot;</td>
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<tr>
<td>CONTROCAM: &quot;Sustainable control of the horse chestnut leafminer,...</td>
<td>12/00 - 02/04</td>
<td>FP</td>
<td>Lead</td>
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<tr>
<td>a new invasive pest of Aesculus hippocastanum in Europe&quot;</td>
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<tr>
<td>CYTOFOR: &quot;Measuring molecular differentiation of European deciduous</td>
<td>04/98 - 07/01</td>
<td>FP</td>
<td>Partner</td>
</tr>
<tr>
<td>forests for conservation and management&quot;</td>
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<tr>
<td>EPN: &quot;European Phenological Network – a network for increasing</td>
<td>01/01 - 12/03</td>
<td>FP</td>
<td>Partner</td>
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<tr>
<td>efficiency, added value and use of phenological monitoring, research,</td>
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<tr>
<td>and data in Europe&quot;</td>
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<tr>
<td>&quot;Establishing a European Phenological Data Platform for Climatological</td>
<td>05/04 - 04/09</td>
<td>COST</td>
<td>Partner</td>
</tr>
<tr>
<td>Applications&quot;</td>
<td></td>
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<tr>
<td>EUFORLA: &quot;Europe – Forest – Latin-America&quot;</td>
<td>06/05 - 06/08</td>
<td>ALFA</td>
<td>Lead</td>
</tr>
<tr>
<td>EUROISILVA: &quot;Forest tree physiology research&quot;</td>
<td>12/99 - 12/01</td>
<td>COST</td>
<td>Partner</td>
</tr>
<tr>
<td>EVOLTREE: &quot;Evolution of trees as drivers of terrestrial biodiversity&quot;</td>
<td>04/06 - 03/10</td>
<td>FP</td>
<td>Partner</td>
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<tr>
<td>Forest Focus: &quot;Monitoring of forests and environmental interactions in</td>
<td>01/03 - 12/06</td>
<td>Forest Focus</td>
<td>Partner</td>
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<tr>
<td>the Community&quot;</td>
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<tr>
<td>ForeStClim: &quot;Transnational Forest Management Strategies in Response</td>
<td>01/08 - 12/12</td>
<td>INTERREG</td>
<td>Partner</td>
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<tr>
<td>to Regional Climate Change Impacts&quot;</td>
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<tr>
<td>FutMon: &quot;Further Development and Implementation of an EU-level Forest</td>
<td>01/09 - 12/10</td>
<td>LIFE+</td>
<td>Partner</td>
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<tr>
<td>Monitoring System&quot;</td>
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<tr>
<td>KnowForAlp: &quot;Knowledge Network Forestry in the Alpine Space&quot;</td>
<td>07/04 - 08/07</td>
<td>INTERREG</td>
<td>Partner</td>
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<tr>
<td>MUFOMA: &quot;Multifunctional forest management - evaluation of policy and</td>
<td>01/99 - 12/01</td>
<td>FAIR</td>
<td>Lead</td>
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<tr>
<td>silvicultural means for mountainous regions&quot;</td>
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<tr>
<td>NAB: &quot;Natural space analysis for alpine mountain areas for a</td>
<td>10/03 - 12/06</td>
<td>INTERREG</td>
<td>Partner</td>
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<tr>
<td>cooperative development of a preventive safety and risk management</td>
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<tr>
<td>system for natural hazards&quot;</td>
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<tr>
<td>NMF: &quot;Network Mountain Forest&quot;</td>
<td>01/04 - 12/07</td>
<td>INTERREG</td>
<td>Partner</td>
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<tr>
<td>PARTS: &quot;Particles in the upper troposphere an lower stratosphere and</td>
<td>12/01 - 11/04</td>
<td>FP</td>
<td>Partner</td>
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<td>their role in the climate system&quot;</td>
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<tr>
<td>PAUR II: &quot;Photochemical activity and solar ultraviolet radiation&quot;</td>
<td>06/98 - 05/00</td>
<td>FP</td>
<td>Partner</td>
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<tr>
<td>POSITIVE: &quot;Phenological observations and satellite data (NDVI): trends</td>
<td>02/00 - 06/02</td>
<td>FP</td>
<td>Lead</td>
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<td>in the vegetation cycle in Europe&quot;</td>
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<td>&quot;Protective Forest Platforms and Forums in Tyrol and Bavaria&quot;</td>
<td>01/09 - 12/11</td>
<td>INTERREG</td>
<td>Lead</td>
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<td>&quot;Reduction of greenhouse gas emissions from lignocellulosic biogas</td>
<td>01/07 - 08/08</td>
<td>INTERREG</td>
<td>Lead</td>
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<td>production by optimised energy efficiency and energy use&quot;</td>
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<td>Partner</td>
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<tr>
<td>SMALLFORCE: &quot;Small-scale wood harvesting technology in European</td>
<td>03/00 - 08/02</td>
<td>FP</td>
<td>Partner</td>
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<tr>
<td>forestry and its contribution to rural development&quot;</td>
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<tr>
<td>STACCATO: &quot;Influence of Stratosphere-Troposphere Exchange in a</td>
<td>03/00 - 02/02</td>
<td>FP</td>
<td>Lead</td>
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<tr>
<td>Changing Climate on Atmospheric Transport and Oxidation Capacity&quot;</td>
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<td>&quot;The market position of privat small-scale forests and its improvement</td>
<td>10/06 - 06/08</td>
<td>INTERREG</td>
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<td>in the border region&quot;</td>
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<tr>
<td>&quot;Wildlife and Human in the Bavarian-Czech-Austrian border Region by</td>
<td>07/06 - 06/08</td>
<td>INTERREG</td>
<td>Lead</td>
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<td>example of the European Otter&quot;</td>
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<td>WINALP: &quot;Forest Information System Northern Alps&quot;</td>
<td>07/08 - 06/11</td>
<td>INTERREG</td>
<td>Lead</td>
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<td>Partner</td>
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</table>
Academic Education

TUM and HSWT offer the following Bachelor and Master Study Courses:

- "Forest Engineering" (B.Eng.)
- "Management of Renewable Energies" (B.Sc.)
- "Forest Science & Resource Management" (B.Sc.)
- "Forest and Wood Science" (M.Sc.)
- "Renewable Resources" (M.Sc.) and
- "Sustainable Resource Management" (M.Sc.), which programme addresses the full spectrum of natural resource management and takes students (from meanwhile 60 nations) well beyond the boundaries of forestry.

All study programmes include hands-on seminars, in-house and external training periods and excursions to enhance personal skills and knowledge and give detailed insights into forest practice.

Monitoring

The Center's observation, monitoring and sample facilities include 18 ICP Forests Level II stations, 56 permanent soil observation areas, and a 140 year-old net of yield sample plots with 980 parcels and 153 ha of measurement area. Periodic forest and soil inventories, and pest monitoring networks help track long-term developments, and generate a solid base to derive strategies and recommendations for forest management.

Consulting and Knowledge Transfer

The user-oriented preparation, dissemination and transfer of results and methods belong to the Center's key activities. Main clients are forest owners and practitioners, forest and timber related SMEs, and the public. They are informed in courses, seminars, workshops and conferences, by flyers, leaflets and brochures with target group oriented recommended courses of action, and in personal consultations. Specialist in, for example, "Wood Energy Consulting" or "Natura 2000 Management" get particular guidance and training. With "Regional Forest Owners Days", in which in 2008 more than 50.000 people have been informed on climate change effects and mitigation and adaptation measures, and "Forest Podcasts" also new ways in knowledge dissemination are being pursued.

Key Action "Weihenstephan Declaration on Forests and Forestry in Climate Change"

Stable forests and intelligent timber use play a key role in climate protection. The Center therefore initiated the "Weihenstephan Declaration on Forests and Forestry in Climate Change", in which the Bavarian State Government and 20 Bavarian Forest Associations and Organisations expressed their common and decisive will to adapt our forests to the challenge of climate change. By the holistic approach, the formulation of concrete strategies and measures, the stressing of the principle of solidarity and self-responsibility, and the broad alliance of the signatories, the declaration is a unique sign of unity and departure and goes far beyond previous memorandums.

Bridging the Gap to Practice

The integration of the State Forest Administration via the Institute of Forestry facilitates the Center's intensive exchange with forest practice and the transfer of developed skills and methods. Well-established platforms like the "Forest Owners Day" or the "Forest Entrepreneurs Day" and numerous meetings, often on site, serve to discuss practical solutions for the daily job routine and – vice versa – learn about the actual needs of forest practitioners. Forest owners associations and cooperatives get special attention by supporting them in marketing their goods and services by individual web presentations. Small and medium enterprises are especially cared of by the Center-based "Cluster Forest and Wood in Bavaria", a state-wide network cross-linking the sector's business and scientific potentials, and activating innovation and productivity: Generating an annual revenue of 30 billion euros the forestry and timber branch occupies a front-line position among the State's manufacturing industries.
Policy Briefing

The Center cares about an effective mutual exchange between science, forest practice and decision makers, and uses its expertise and knowledge to provide State Policy and Authorities with important information to facilitate economic and political decisions in forestry.

On the federal level, Center scientists are members of the German Advisory Council on the Environment, the Strategic Expert Group of the Federal Ministry of Education and Research, and the Policy-Science Council of the Federal Association for Bioenergy.

Functions and Posts

Center scientists are engaged in many state and national boards. On an international level, they hold among others the following posts and offices:

- Associate Editor "Folia Geobotanica"
- Chairman IPCC Forests Panel on Meteorology and Phenology
- Chief Editor "European Journal of Wood and Wood Products"
- Chief Editor "Wood Science and Technology"
- Coordinator IUFRO Unit 7.01.04
- Lead Author IPCC Working Group II
- Member "International Academy of Wood Science"
- Member "Scientific Council" of the Forest-Based Sector Technology Platform
- National Representative to "SynBioSys Europe"
- TUM-Representative to the European Plant Science Organisation
- Vice President "SILVA-Network"

The Center is a member of the European Forest Institute EFI.

External Evaluation

In the context of an evaluation of the development of the Agricultural Sciences Sector, the German "Wissenschaftsrat" (National Council of Science and Humanities) had also assessed neighbouring disciplines as Horticulture, Nutrition and Forest Sciences (WR, Dresden 2006). The Center of Forestry Weihenstephan was rated "an example for the successful formation of a regional cooperation… suited to play a leading part in European projects".

*) Empfehlungen zur Entwicklung der Agrarwissenschaften in Deutschland im Kontext benachbarter Fächer (Gartenbau-, Forst- und Ernährungswissenschaften), Dresden, 2006.
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