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Global change in Mountain Sites (GLOCHAMOST) –
Copying strategies for Mountain Biosphere Reserves

Implementing the GLOCHAMORE Research strategy into the Biosphere Reserve Berchtesgadener Land

Global change in Mountain Regions (GLOCHAMORE)
a Project of the UNESCO's Man and Biosphere Programme

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Nationalpark Berchtesgaden

Content

Abstract

Biosphere reserves are sites established by countries and recognized by the UNESCO's Man and Biosphere (MaB) – Programme to promote sustainable development based on local community efforts and sound science. Biosphere reserves conserve nature and support sustainable development. They integrate cultural and biological diversity and combine these tasks by an intelligent zoning concept. Biosphere reserves should work on an integrated approach in addressing biodiversity and climate change challenges. The role of biosphere reserves is essential to rapidly seek and test solutions to the challenges of climate change as well as to monitor the changes as part of a global network (UNESCO 2008). For this theme, they should rely on interdisciplinary mechanisms combining science, culture and education.

In Berchtesgaden, an integrated approach was established by the project "Ecosystem research Berchtesgaden" between 1981 and 1991, which focussed on the impact of human activities on ecosystems. This was the main contribution of Germany to the "Man and Biosphere (MaB)" – Programme.

The instruments of this project were used to subsequently implement a management plan for the core and buffer zone of the former Biosphere Reserve, which is Berchtesgaden National Park. The plan was put into force by the Bavarian Ministry of Environment in 2001 (StMLU 2001).

This plan defined the investigation of climate impact to alpine ecosystems as main tasks of National Park scientific research. This is performed by long term monitoring programmes as well as by specific research projects in climate, land use change, cryosphere, snow cover, water balance modelling, biodiversity. Socio-economic research like regional economic effects of protected areas has been carried out. On this well founded scientific basis, the impacts on human societies, cultural and biological diversity and ecosystem services can be evaluated better for the welfare of local inhabitants (DUK 2011).

1. Introduction

a. UNESCO Biosphere Reserves

The conference “For life, for the future” discussed the role of the UNESCO biosphere reserves in implementing and advancing climate change policies. In the “Dresden declaration”, the participants called for closer links between climate change effects on human society and conservation of biological diversity. The world network of 560 biosphere reserves in more than 100 countries store experience for sustainable use and management and biodiversity conservation for over 40 years. Biosphere reserve can serve as models for adaptation to the impacts of this change. At policy level in the Member States, among others, problem – oriented, interdisciplinary and applied research, monitoring and evaluation in relation to climate change should be supported. Management plans should be adapted to changing climate, based on a vulnerability analysis, taking in account biological diversity and local population (DUK 2011).

b. The National Park of Berchtesgaden and the Biosphere Reserve Berchtesgadener Land

The National Park of Berchtesgaden was established in 1978 by a regulation of the Bavarian Parliament. It is situated in the southeast of Germany in Bavaria at the border to Austria. The size is about 208 km^2. The landed property is owned by the Free State of Bavaria and comprises four mountain chains and three valleys. The elevation ranges from 600 m up to 2700 m above sea level. The National Park is divided into a core zone (66 % of the area) and a buffer zone (34 %). The periphery of the national park was up to 2010 the transition zone of the Biosphere Reserve of Berchtesgaden, which was designated in 1990. The Biosphere Reserve was extended in 2010 the entire district (Landkreis) of Berchtesgadener Land with 15 communities and was renamed to Berchtesgadener Land Biosphere Reserve. About 103,000 inhabitants are living in the extended transition area.

As the National Park Berchtesgaden covers the core and main part of the buffer zone of the Biosphere Reserve, land use in this area primarily depends on environmental protection policies and is only marginally driven by economic forces (e.g. pressures resulting from alpine sport and tourism activities). The contrary is the case for the transition zone which is rather dominated by economic interests and agricultural granting policies. Due to complexity of the subject and the number of players involved we will focus in the following on the national park rather than on the whole biosphere reserve.

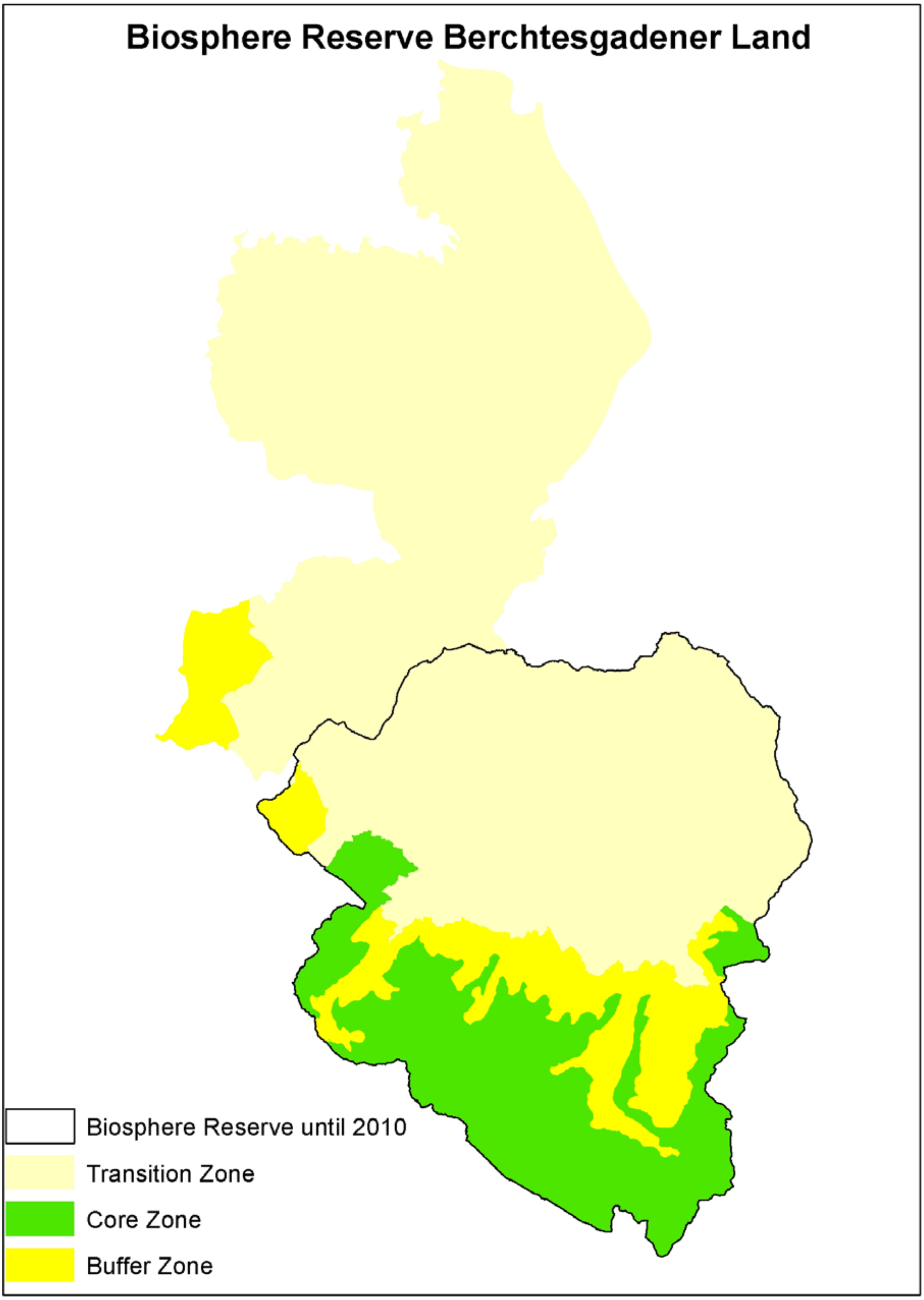


Figure 1: Zones of the Biosphere Reserve Berchtesgadener Land since 2010. The western, southern and eastern part of the core zone borders on Austria, mainly on protected areas.

One fundamental management principle of the national park is to let nature evolve itself without human disturbance. However natural dynamics (e.g. erosion and deposition, avalanches and reforestation) are often restricted to the core zone whereas the buffer zone is characterized by certain types of human use or interaction. Traditional alpine pasture areas which were still in use when the park was founded are maintained against natural woodland succession in order to preserve the aspect of cultural landscape heritage and the biodiversity related to these structures. Furthermore spruce monoculture resulting from historic use as firewood for the local salt industry cover huge areas of the buffer zone. Although no longer exploited in the economic sense these forests are subject to active human measures (e.g. selective cutting, planting, game controlling) in order to accelerate their evolution into natural mountain forests of mixed species composition.

National park managers have thus at the same time to minimize the effects of human influence as well as to guide specific activities according to the management plan. Consequently spatial planning and success control of management measures requires accurate and surface covering data on the landscape including rather natural land cover as well as man marked land use types and their evolution in the course of time.

c. Principles of Research in Berchtesgaden

In the year 1981, the interdisciplinary research project „Human impact on high mountain ecosystems“ – later renamed in „Applied ecosystem research Berchtesgaden“ - within the scope of the UNESCO programme „Man and Biosphere, task force 6, high mountain ecosystems (MaB 6)“ was prepared. It was the main German contribution to the MaB – Programme in this time. It analyzed and evaluated in reality ecosystem complexes or landscape systems with the main question: „How do human activities have an effect in the high mountain region on the natural resources like groundwater, surface water, soils, strata, local climate, plants and animals? And what is the retroactive effect of these effects?” The test area was considered to be a network system with the parts nature, exploitation and society. Analysis of the gradient of human impact on ecosystems was worked out by the interpretation of Colour-Infrared Aerial (CIR) photos and the classification of the interpreted units for human impact (cf. Chap. 3). The results of this project, which ended in 1991 (cf. HABER 2002, HABER at al 1990, KERNER et al 1991), form the basis of an applied and practically orientated method for ecosystem research in the National Park and Biosphere Reserve until today. The results and the project data are basis for the management plan of the national park, which became effective in 2001 (StMLU 2001). Beyond that, the research and the geographic database of the national park were continued on the basis of this project. All projects and responsibilities include more ecological and less social analysis and evaluation. Logically, the area of the national park and its periphery was designated as a Biosphere Reserve by UNESCO in 1990. After some years of critical discussion, it was accepted by local inhabitants and last year even expanded to the whole district Berchtesgadener Land.

Research focuses mainly on the local effects of global climate change, especially on the alpine vegetation, spatially concentrated in the core and buffer zone of the biosphere reserve. All projects base on the ecosystem approach of the MaB 6 – Project from 1981 – 1991. Economic sectors which can be found in the area include agriculture, forestry, salt mining, small-scale industry and crafts, retail trade, health services, tourism and resorts. They have principally been reflected by the MaB 6 - Project, but have not been pursued intensively by the National Park Administration

d. Maps and ecosystem types

The following ecosystem types exist within the national park (the core and main buffer zone of the Biosphere Reserve):

– 44,1 % Forest types

– 21,0 % (lean) grass covered communities,

– 19,3 % rock and rubble fields,

– 12,4 % mountain pine - and green alder shrubs,

– 3,2 % lakes and glaciers (StMLU 2001)

The data and evaluations in the following Chap. will focus on the former Biosphere reserve of Berchtesgaden, because the data base of the Geographical Information System of the National Park is not jet extended to the current Biosphere Reserve Berchtesgadener Land.

2. Climate

Berchtesgaden has temperate climate and is located in a transition zone between maritime and continental climatic influences. Due to the large difference in altitude, core and buffer zone of the Biosphere reserve are dominated by a typical climate of high mountains. It is documented by 15 automatic weather stations owned by the National Park Berchtesgaden and the Headquarter of the Bavarian Avalanche Security Service (Fig 3) and 7 gauge stations at the Section Hydrographic Service of the Bavarian Environment Agency (Fig. 2). Presently these stations are complemented by 12 mechanical weather station in low and medium altitude. The data of the automatic weather stations are sent every 10 minutes to the central database of the National Park Administration. The data of the mechanical weather stations are available for every hour as hourly values except precipitation, which is determined per day The German Weather Service and the National Park Service take care for this network..

a. Network of Water Level Gauges and Meteorological Stations

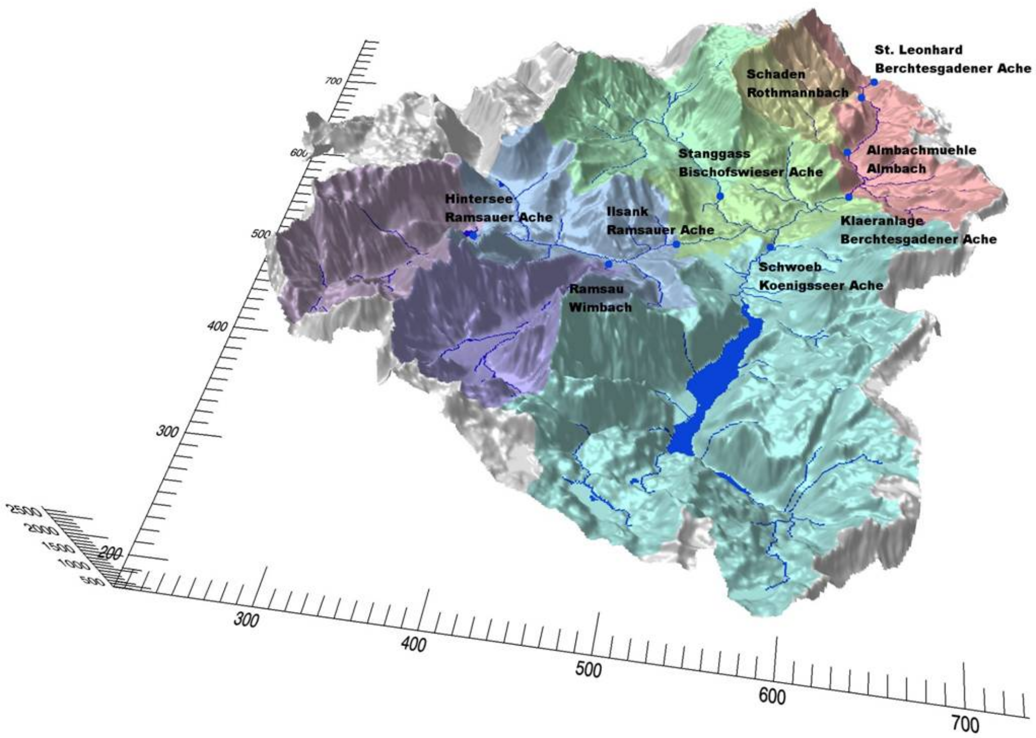


Figure 2: Gauge stations and watershed areas in the former Biosphere reserve (cf. Chap. 4 and 5)

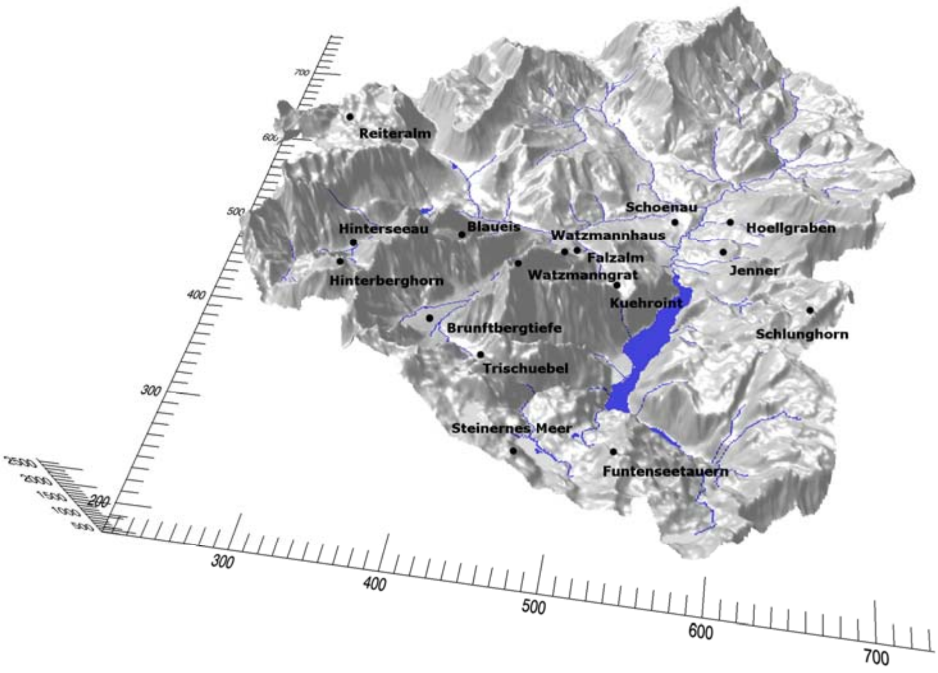


Figure 3: Automatic weather stations in the former Biosphere Reserve Berchtesgaden

b. Temperature

Air temperature decreases with increasing altitude. Based on the mechanical weather stations established between 1993 and the automatic weather stations established between 2005 and 2009 in the core and buffer zone of the biosphere reserve. KONNERT (2011) analyzed the daily variation per year, summarized for all measured day averages, presented in Fig. 4:

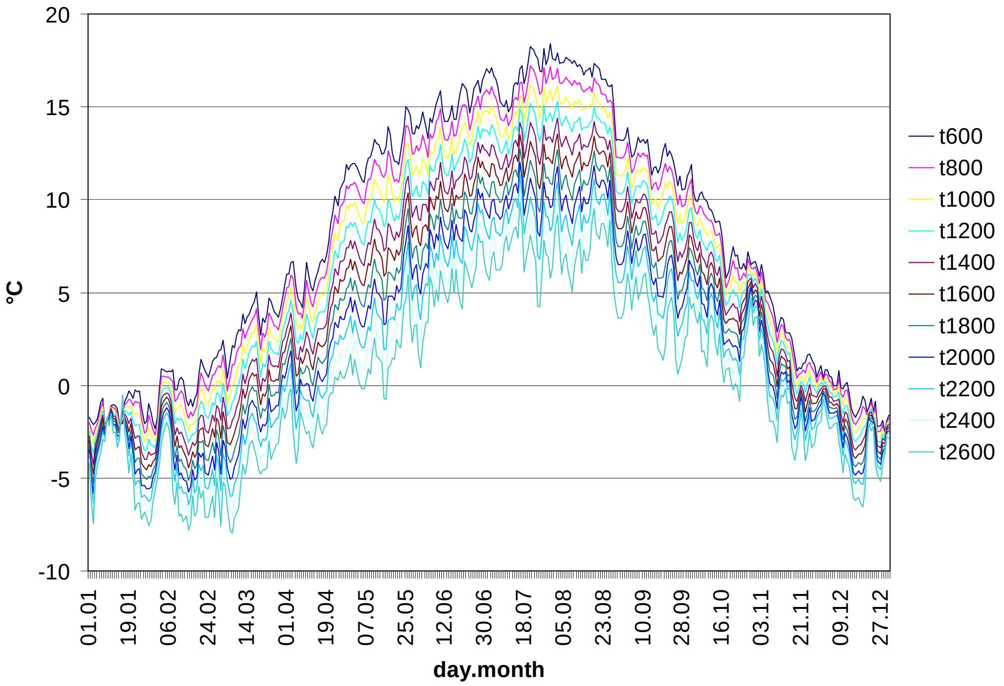


Figure 4: Daily variation per year, summarized for all measured day averages in Berchtesgaden (cf. KONNERT 2004, KONNERT 2011)

The difference of decreasing temperature gradient per 100 m altitude for every day is presented in the Fig. 5:

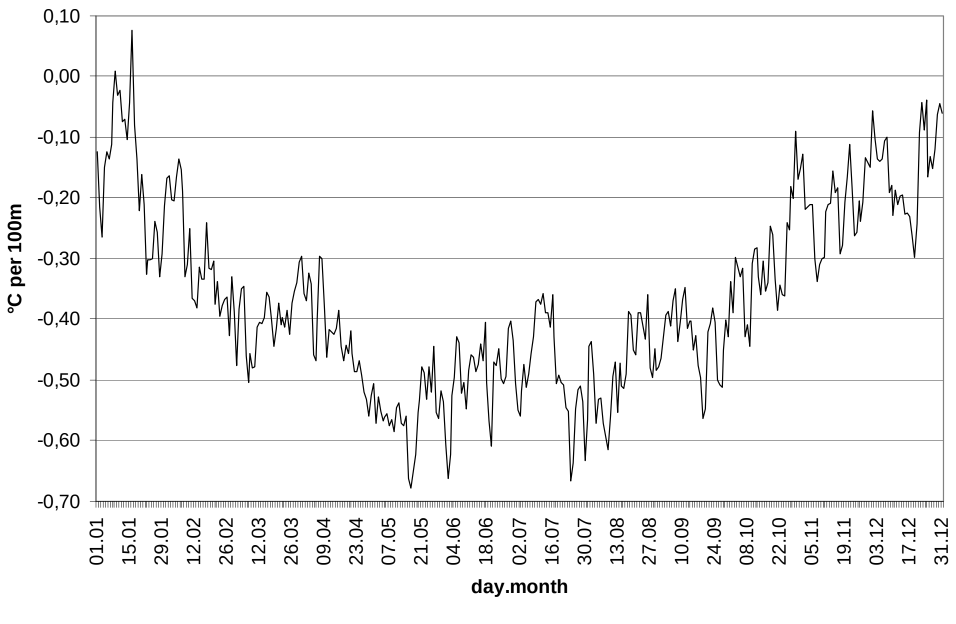


Figure 5.: Altitudinal gradient of temperature per 100 m and day, summarized for all weather stations in the National Park of Berchtesgaden. The weather stations cover the altitude from 600 to 2600 m above sea level. The short variations can be explained by the short measurements of the automatic stations in high altitude. In 20 years, these variations should be disappeared (KONNERT 2011).

The altitudinal gradient of temperature is in winter nearly 0, in spring and autumn between -0.3 and -0.5 and in summer mostly -0.6, sometimes -0.7 ^{o}C. Temperature inversions occur very often in winter und often in spring and autumn. This phenomenon can explain the results of Fig. 5.

The online weather station data are presented live by a web application developed by the Salzburger Research Studio iSpace (ISPACE 2011), which is presently under construction.

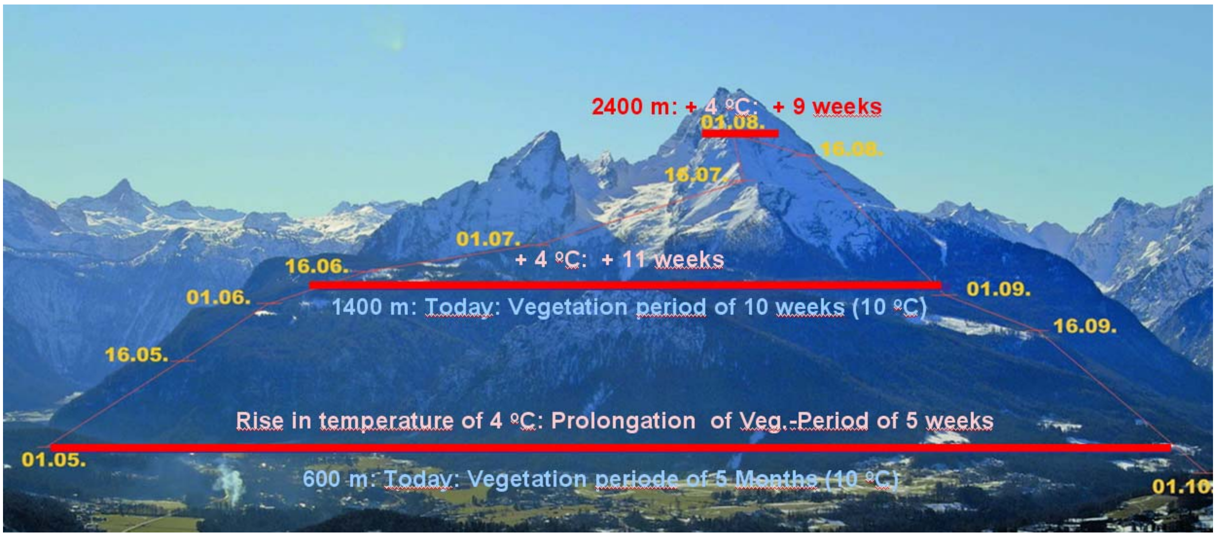


Figure 6: Prolongation of vegetation periods, based on Fig. 4 (10 ^{o}C average degree at different days in the year) and the assumption, that temperature will rise 4 ^{o} C in next 100 years (cf. IPCC Scenarios). Area decreases for temperature climbing the hill. But we do not know, how precipitation, moisture, solar radiation behalf, what will happen to snow cover, and if the development of soil formation will differ from increasing temperatures in the same altitudes, which is very important for predicted uphill migration of plant species.

c. Parameters

1. Water

Water balance will be changed by climate change. But the scenarios for precipitation, water flow and gauging water station data are more complicated than for temperature. A water balance model including snow cover is established in the area of the former Biosphere Reserve Berchtesgaden (cf. Chap. 4 and 5).

2. Wind parameters

Wind direction and wind speed are important parameters for hazards, that enforce with ongoing climate change. It will effect the disturbance of forests and the appearance of bark beetles, which is not a problem for core zone, but for the private forests neighbouring the buffer zone of Biosphere Reserve (cf. Chap. 7e).

3. Other parameters

Radiation is a driving force for the functioning of ecosystems. It is measured by the automatic weather station network and used by the water balance model (cf. Chap. 5).

Snow depths and snow temperatures are measured in an altitudinal profile from 600 up to 2200 m and used in the snow cover part of the water balance model (cf. Chap. 4b + c).

3. Land Use Change

The surface covering cartography of locally occurring land cover and land use types represents a fundamental basis of the environmental management in Berchtesgaden National Park. This database is built upon colour infrared (CIR) aerial images and their professional stereoscopic interpretation.

Changes in the land cover are caused by manifold factors having single (e.g. tree cutting), interacting (e.g. storm damage and bark beetle) or superimposed effects (e.g. type of use and climate). The assessment of changes needs comparable time slices of land cover inventories for retrospective comparisons.

A powerful data base on land cover has to document not only the present stages but also has to archive the growing number of past data layers and even give an insight into future scenarios. Therefore Berchtesgaden National Park has assigned an essential importance to its land cover data base which offers multiple benefits as inventory, analysis fundament, source of derived parameters, input factor for ecological modelling and decision support tool for planning and assessing a number of spatially or thematically focused monitoring and research programmes.

a. Quantifying and Monitoring Land Use

Beginning in 1980 the national park administration enabled regular CIR aerial image flight campaigns and the stereoscopic interpretation of these images (cf. Chap. 1c). Within about 30 years 5 generations of image flights and 4 professional interpretation layers have been created for the extent of the former biosphere reserve. Fig. 7 shows the most recent land cover inventory for the former biosphere reserve area as derived from the 2003 image generation.

The majority of important changes (i.e. changes in habitat type or degree of cover) that were detected between the interpretation layers of 1980-1990 and 1990-1997 occurs in the forested areas (Fig. 8). This can be explained on one hand by the impact of human measures (cutting and planting trees) and on the other by natural hazards (damages by storms, avalanches and insects) which are in general easily visible on aerial images. Some detailed view examples are given below (Fig. 9).

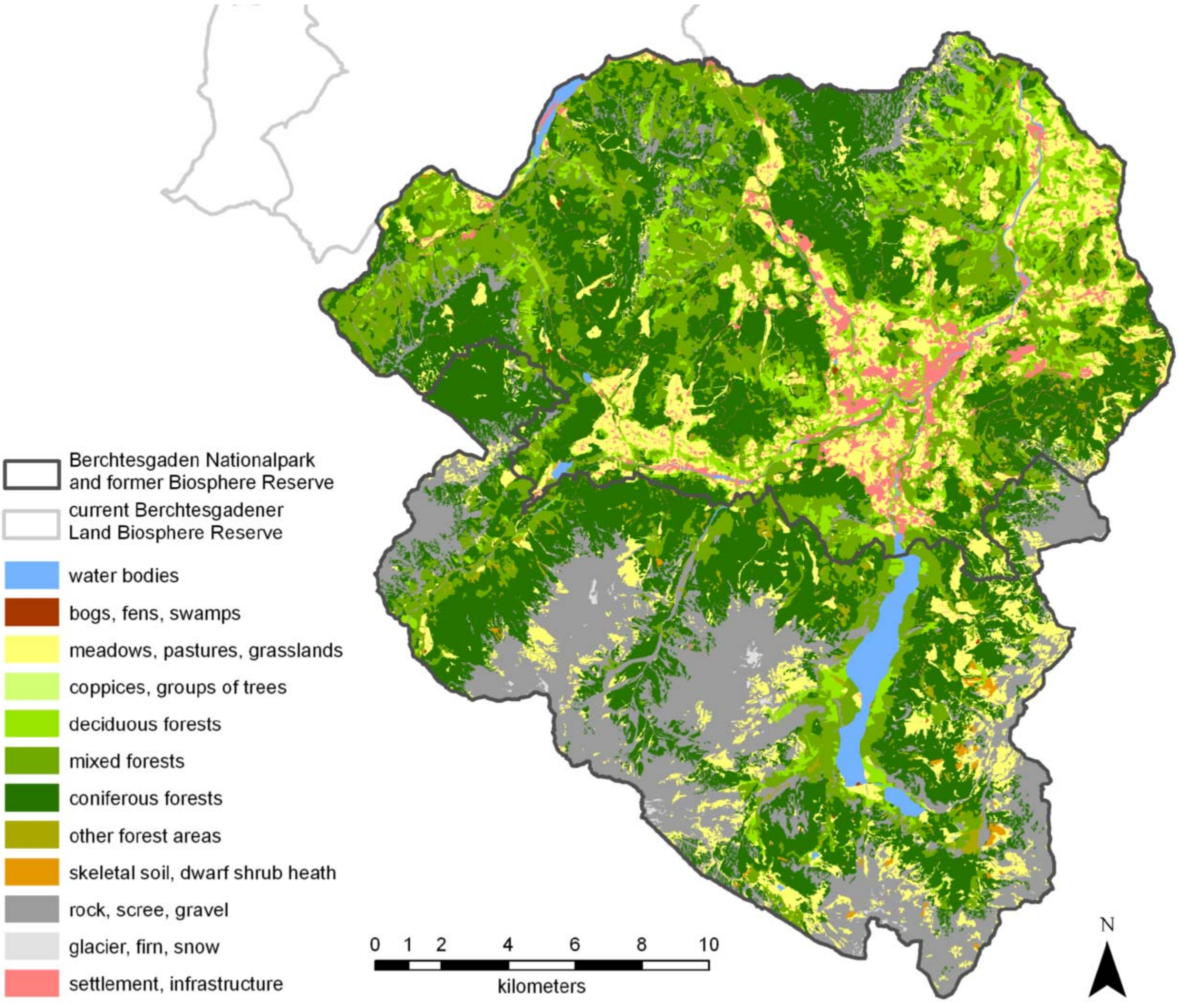


Figure 7: Aggregated land cover types of former Biosphere Reserve Berchtesgaden based on 2003 aerial images.

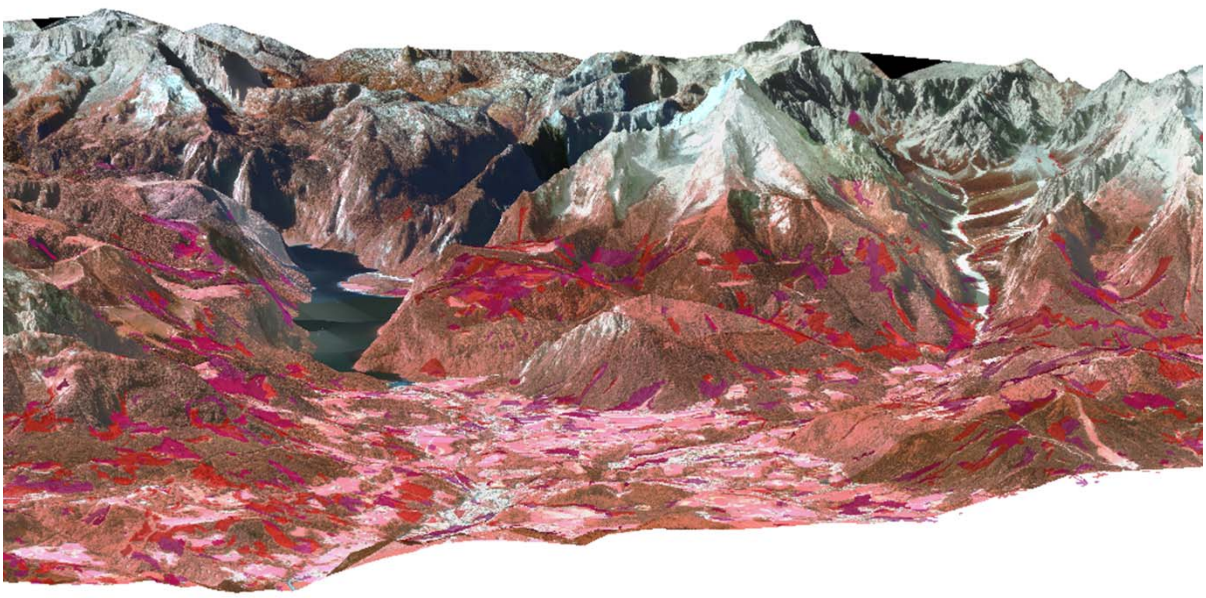


Figure. 8: Land cover changes between interpretations 1980-1990 (violet) and 1990-1997 (red).

Changes are not as obvious in non-forested areas of the national park and would deserve a more detailed analysis as it is often the creeping effects occurring within smaller spatial extents that are of particular management interest (mass movement, humidity regime, species composition). One detailed view example concerning mass movements is given in Fig. 9.

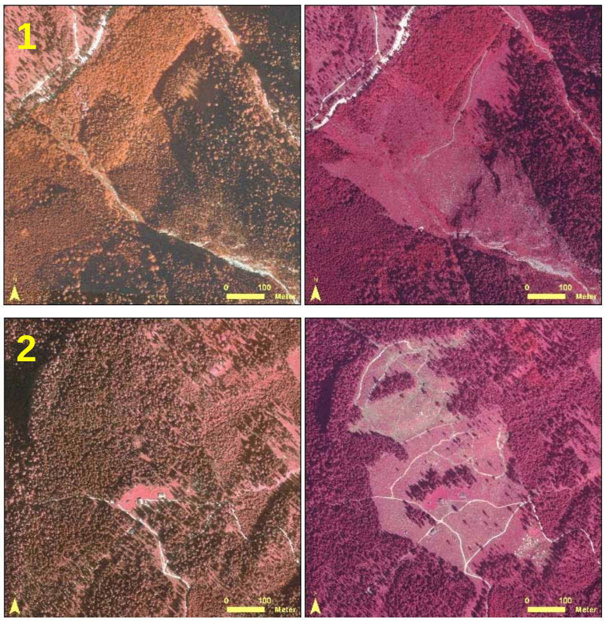
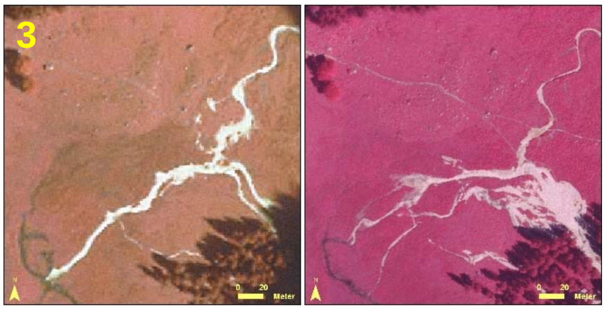


Figure 9: The visual comparison of 1997 and 2003 aerial images shows an area of forest devastation caused by an avalanche (1), a forest cutting area aimed at the clearing of forest pasture areas (2) and mass



movements caused by a torrent (3).

Major changes are also due to infrastructure construction activities that are of course of greater importance beyond than within the national park boundaries. The comparison with aerial images dating before the park foundation shows increasing woodland as a result of abandoned pastures. These changes can be observed in the whole region but are more pronounced outside the national park as economic factors have greater influence and the lower elevation is more favourable for woodland (Fig. 10).

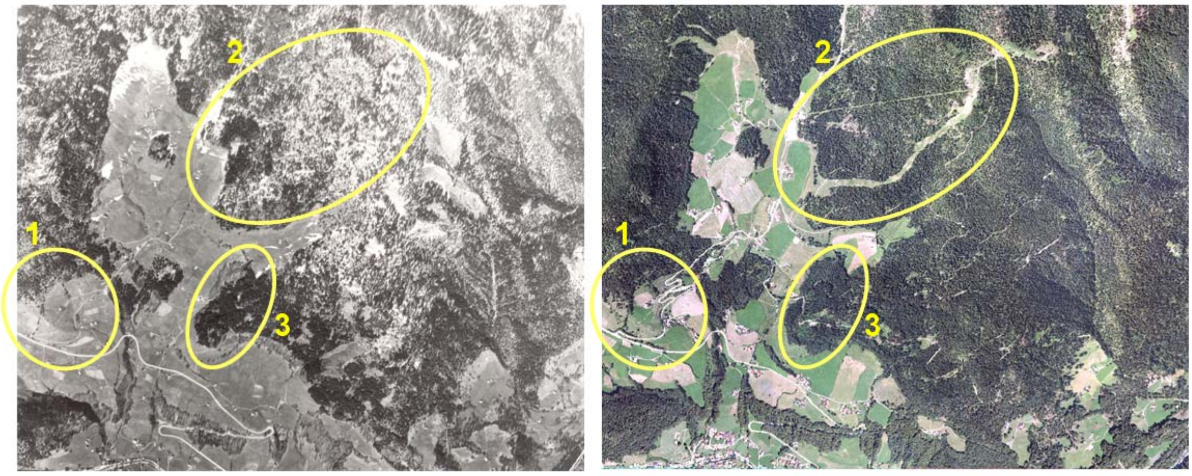


Figure 10: Comparison of 1945 and 2009 aerial images showing road construction (1), ski run and lift corridor (2), increasing forest cover (3) situated in close vicinity to the national park (transition zone of the Biosphere Reserve).

b. Understanding the Origins and Impacts of Land Use Change

The assessment of changes requires three distinct steps: (1) mapping of land cover stages (2) mapping of detected changes (3) explanation of underlying processes.

In this context it is of crucial importance that the change typology is adapted to the questions that should be answered. Based on a suitable classification of changes a spatially accurate cartography of the actually visible changes can be realized. This data layer represents a different type of information compared to a land cover stage given at a certain time and can now be used to understand the reasons and effects of land cover dynamics.

Berchtesgaden National Park has made several attempts to classify changes and the implicit types of processes. The most recent results are based on the still running cc (change check) HABITALP cooperation formed by four alpine national parks (Swiss National Park, National Parks Hohe Tauern and Gesäuse in Austria and Berchtesgaden National Park in Germany). This activity emerged as follow-up from the HABITALP project (LOTZ 2006) which was realized in the years 2002-2006 in the frame of the INTERREG IIIB Alpine Space Co-Funding Programme of the EU.

For a restricted test area of Berchtesgaden National Park the types of land cover changes that are critical for local management decisions were identified and examined in a detailed comparison. Although the time span between the two image generations compared was only 6 years, a couple of interesting observations was made (see Fig. 11 and 12).

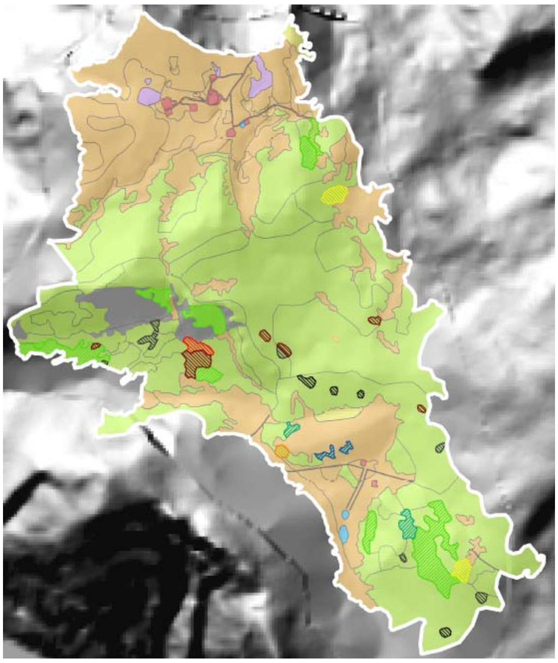


Figure 11: Changes between 2003 and 2009 concerning degree of tree canopy cover (HAUENSTEIN 2010)

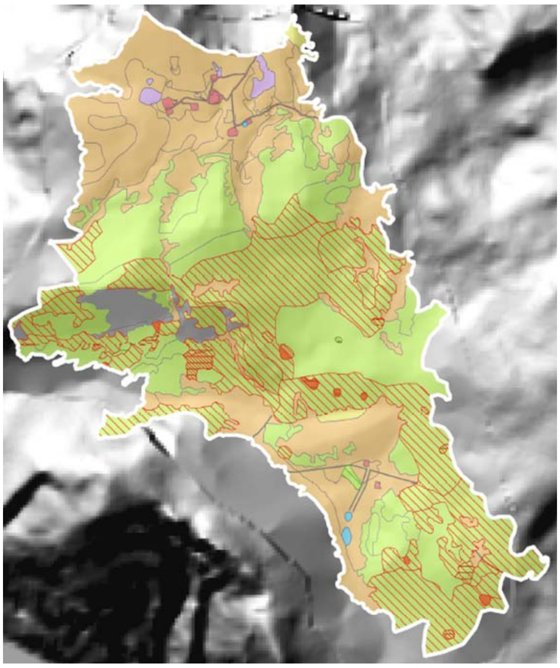


Figure 12: Changes between 2003 and 2009 concerning percentage of dead wood (HAUENSTEIN 2010)

The mapping of changes in dead wood and tree canopy cover for example gives important hints on the processes taking place in the observation area. A decrease in the degree of cover combined with an increase of standing dead tree trunks is an indicator for bark beetle activity if no other change is observed. If the decrease of cover comes along with a simultaneous increase of standing and collapsed dead wood this might reflect storm damages eventually combined with bark beetle attacks. A decreasing number of standing dead wood and increasing number of collapsed dead wood indicates the natural decay of standing trunks. If only the number of collapsed trunks decreases this indicates the succession of young plants overgrowing the height of the trunks. Areas with a stable percentage of dead wood within the observed time span indicate former storm or beetle damages but no recent activity. Areas with an increase in the degree of tree cover can be explained by forest succession if occurring within forested parts or by overgrowing of pasture areas in formerly non-forested parts below the tree line.

Even these few explanations show clearly that the mere mapping of changes cannot directly explain their causes as a number of circumstances has to be taken into account (interaction of factors, stage before the occurrence of change, surroundings etc.). It also becomes obvious that a very detailed and accurate spatial delimitation is required if such types of changes should be quantified and monitored.

But these first results are very promising. According to the national park zones spatially differentiated effects of realized management measures (buffer zone) or deliberately omitted measures (core zone) can be assessed. Effects of natural dynamics can be better distinguished from man made dynamics and help to separate climate impacts from land use impacts and adjust management decisions.

c. Challenges of long term Land Use Monitoring

Ever since the foundation of Berchtesgaden National Park in 1978 the survey of natural land cover and man marked land use types was of major interest. From the very beginning a geographic information system (GIS) and a relational database management system (RDBMS) were used to handle the data. At this time digital spatial data was still an exception and Berchtesgaden National Park was one of the pioneers in this field. Even today the outstanding data base is attracting a number of researchers.

In the course of the last decades technical improvements, facilitated data accessibility as well as the growing number of reporting obligations and environmental awareness have been raising the demand for temporal comparisons and monitoring data. In Berchtesgaden National Park a considerable time series of land cover data has become available due to the regular repetition of aerial images and their interpretations.

Temporal and spatial comparability of image material and derived interpretation data has been a permanent concern of the national park. However in the course of the last 30 years it has become obvious that it is not at all trivial to keep pace with technical progress and ensure comparable data at the same time.

As image quality (visibility) and spatial precision (positioning) are continuously increasing the so-called interpretation key (coded list of land cover types) needs to be refined regularly and the resulting polygon delimitations require spatial corrections.

Although the principals of the method remained unchanged over the years, it is particularly demanding to distinguish genuine land cover changes from those due to methodological adaptations.

Accurate temporal analysis requires the adaptation of former land cover data to the current technical state. An enormous potential is hidden in the technical valorisation of former image generations. Digitized and geo-referenced by the aid of powerful modern means ancient images could considerably enhance the data base and allow for better retrospective interpretation and analysis.

In contrast to mono-temporal data multi-temporal land cover polygons do not only document one stable stage but must allow for monitoring the quantitative and qualitative changes that occur within a given delimitation. In order to ensure consistent temporal analysis across all time slices, data base solutions are required that can cope with increasing data quantity and complexity.

Nowadays many sites dispose of aerial images but only few have tackled so far the challenges of multi-temporal data management and spatial analysis of time series. Berchtesgaden National Park urgently needs a performing and practical solution that meets the increasing demands of data consistency and comparability. First attempts seem to be beyond financing possibilities.

Methodological standardization has always been a question in Berchtesgaden National Park and is discussed on different scales i.e. for different interpretations of the same area, on national level and on international alpine level.

Whereas the first image interpretation of 1980 was still based on a self-made land cover typology due to missing common standards (SPANDAU & SIUDA 1984), the second interpretation of 1990 was already based on a just published German interpretation key (BFN 1995). In order to guarantee comparability of the two time stamps both typologies where assigned simultaneously which demanded of course more resources than one simple codification.

In the following the German key was enlarged to fit local alpine needs and then transferred to the Hohe Tauern National Park in Austria and the Swiss National Park (both protected areas of more continental ecological character) (KIAS et al. 2001).

In the years 2002-2006 Berchtesgaden National Park made an enormous financial and personal effort as lead partner of the HABITALP project which was co-funded by the INTERREG III B Alpine Space Programme of the European Union (LOTZ 2006). The intention was to create an internationally standardized interpretation method for protected areas of the Alpine Convention in order to ensure comparability of land cover changes within the alpine chain - especially with regard to global changes. The interpretation key initially developed in Berchtesgaden was enlarged to serve 10 other protected areas which included not only commonly agreed contents but also translations into four languages. These steps were essential to ensure wide spread acceptance and applicability among the project community as well as transferability to further alpine regions. On the local Berchtesgaden level however the project required once more a double coded interpretation to ensure comparability of old and new datasets.

Presently Berchtesgaden National Park is affected by financing problems. Although the flight campaigns are meanwhile financed on the federal Bavarian level (in contrast to the time before 2009), the means for the image interpretation are missing. For this reason the aerial images of 2009 are not yet interpreted whereas the next flight campaign is scheduled for 2012. The development of a powerful data base solution for the comparability of ALL time slices and the adaptation of former data sets for this purpose are essential conditions of competent forward looking management and research in the national park. Additional means for integrative methodological guidance on alpine biogeographical level would be appreciated in order to minimize un-coordinated modifications and the loss of standards.

4. The Cryosphere

Only a few frozen areas in the core zone and main buffer zone of the Biosphere Reserve Berchtesgadener Land are existing, because the temperature at the highest elevations is not sufficient to maintain glaciers and permafrost areas. The average temperature for the weather station Funtenseetauern at 2520 m above sea level has been 1.5 ^{o} C since 2005, for the weather station Hinterberghorn at 2490 m has been 0.7 ^{o} C since 2009.

a. Glacier Extent and Mass Balance

Two tiny glaciers exist jet in the core zone of the biosphere reserve: Watzmanngletscher and Blaueis. The following data are based on the project ‘Bavarian glaciers’ (cf. HAGG 2008).

The Watzmanngletscher occurs at an altitude between 1950 and 2200 m a.s.l.. It nearly disappeared 60 years ago. Its maximal extent was 30 ha in 1820, 1856 and 1888. Since this time, the ice disappeared, but grow from 1965 – 1980. At the moment, the ice is melting away. In 2009, surface was 5.9 ha. It may disappear in the next 20 or 30 years, if the mean temperatures grow due to climate change.

The Blaueis is the most northern glacier in the alps with the lowest altitude between 1900 and 2300 m above sea level. Due to its exposition and surrounding steep rock faces the glacier is still present at this untypical elevation. The glacier volume and mass balance is investigated since 1889 by the project As it is observed generally in the Alps, glacier retreat took place. Within the last 200 years, the maximal surface extend was 25 ha in 1820, above 20 ha in 1924 and 16.4 ha in 1980. The minimal extend was 2009 with 7.9 ha. The minimal thickness of the ice sheet in 2007 was 3 m, the maximal thickness was 13 m. The ice volume was 0.4 million m3 at this time (HAGG 2008).

Glacier observation will be investigated in the future. Long term time-series will record changes of volume and extent.

b. Snow Cover

The dynamics of the snow cover and the respective water fluxes highly affect the hydrology of alpine regions. Snow cover development in mountainous regions is characterized by extreme heterogeneity in space and time. High altitudinal gradients and small scale orographic effects cause a large temporal and spatial variability of meteorological variables that force the development of the snow pack. A main driver of snow accumulation and ablation processes in complex terrain is the lateral redistribution of snow caused by wind and gravitation. These processes lead to a highly variable distribution of snow on different spatial scales. The integration of a new snow module into an existing hydrological land surface model is supposed to improve the modelling of water fluxes influenced by snow accumulation and ablation, and to analyze its impacts on the local and regional hydrology. We complement the deterministic hydrological model WaSiM-ETH (SCHULLA & JASPER 2000) with principles of the high alpine specific snow model AMUNDSEN (STRASSER 2008, 2011). The new approach is based on the calculation of energy fluxes at the snow cover considering terrain-dependent radiation fluxes and lateral snow transport processes. Model results are validated via the available measurements of snow water equivalent (SWE) and snow height. The spatial distribution of the snow cover is compared to satellite-based remote sensing data. Fig.13 and 14 show results simulated with the new model system. Snow cover duration represents an integrated result of all snow accumulation, ablation, and redistribution processes throughout a winter season. Snow cover duration shows a maximum at high elevated, northern-oriented, shaded, and sheltered areas at the foot of steep faces, where the accumulation input is large due to high snowfall rates and incoming mass from snow slides and the incoming energy input for ablation by solar radiation and air temperature is limited. To assess future changes in snow cover dynamics, the model system will be forced with climate change scenario data. We will use ECHAM5 data dynamically downscaled with the Regional Climate Model WRF (Weather Research and Forecasting Model). We will focus on a comparison between the periods 1970 – 2000 and 2020 -2050.

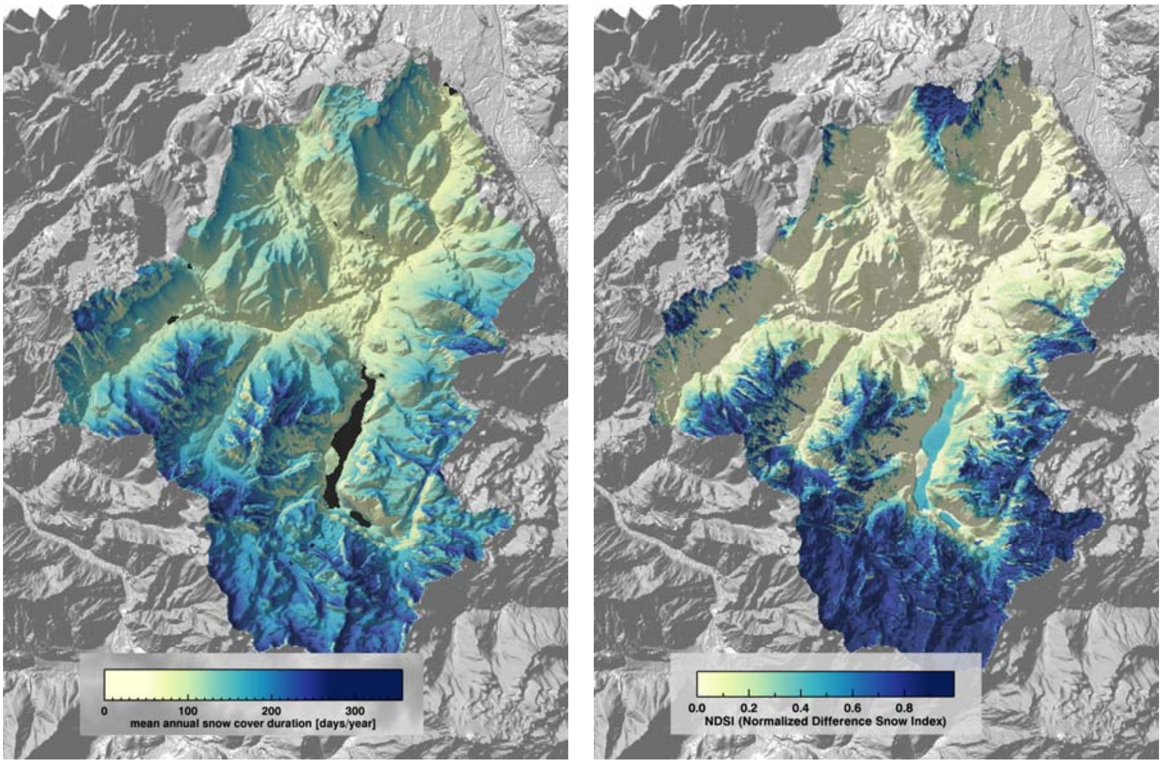


Figure 13: Modelled mean snow cover duration 2001 – 2010 (left), NDSI (not showing negative values), extracted from a Landsat-ETM+ scene on May 01, 2005 (right).

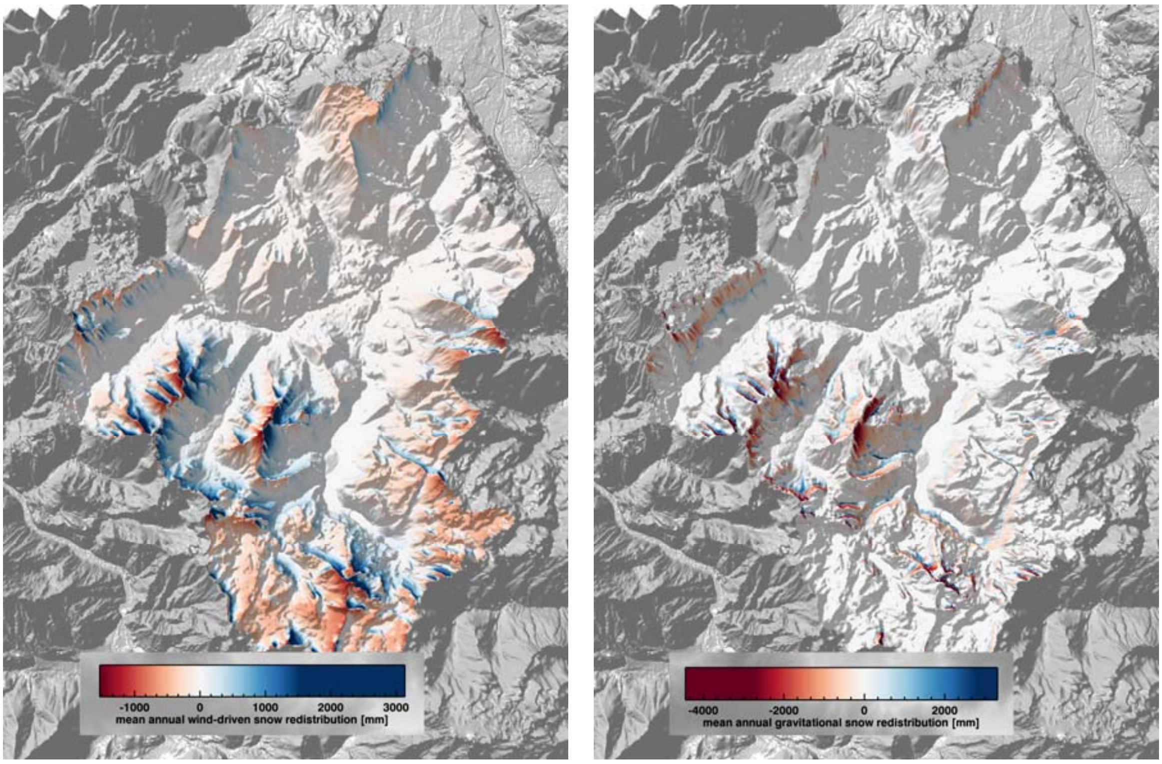


Figure 14: Simulated mean annual lateral snow transport 2001 - 2010 by wind-driven snow redistribution (left) and gravitational snow slides (right).

c. Snow Melt

Runoff generation in Alpine regions is typically affected by snow processes and snow cover development. Snow accumulation, storage, redistribution, and ablation control the availability of water. Melt water release is a main source of water in spring. Determining these dynamics as well as melting and discharge generation by hydrological models is subject to high uncertainties. Generally, the full complexity of the water balance in alpine regions is far from being understood. High altitudinal gradients and a strong variability of meteorological variables in time and space result in heterogeneous snow cover dynamics, melting and discharge generation. To determine these dynamics in the complex terrain of the Berchtesgaden National Park, we combined the high-alpine specific snow model AMUNDSEN with the distributed hydrological WaSiM-ETH (see Chap. 5a and 5b) . The development of the snow cover in space and time controls water storage and release. Modeling the snow cover dynamics is described in the previous chapter. These simulations allow for a precise prediction of snowmelt timing for each location in the terrain. Fig. 15 shows modeled and measured snow water equivalent at the station Kühroint during two winters. A decrease in SWE indicates sublimation or melt water release. The fast ablation of snow in spring leads to large increases in the runoff rates during that period. Fig. 16 shows measured and modeled runoff during the melting period 2006 at the gauge Hintersee. Mean monthly snow melt sums for each subbasin are shown in Fig. 17.

The assessment of future changes in snow cover dynamics using ECHAM5 data dynamically downscaled with the Regional Climate Model WRF (Weather Research and Forecasting Model) will allow for a projection of future snow melt and runoff behaviour in the catchment.

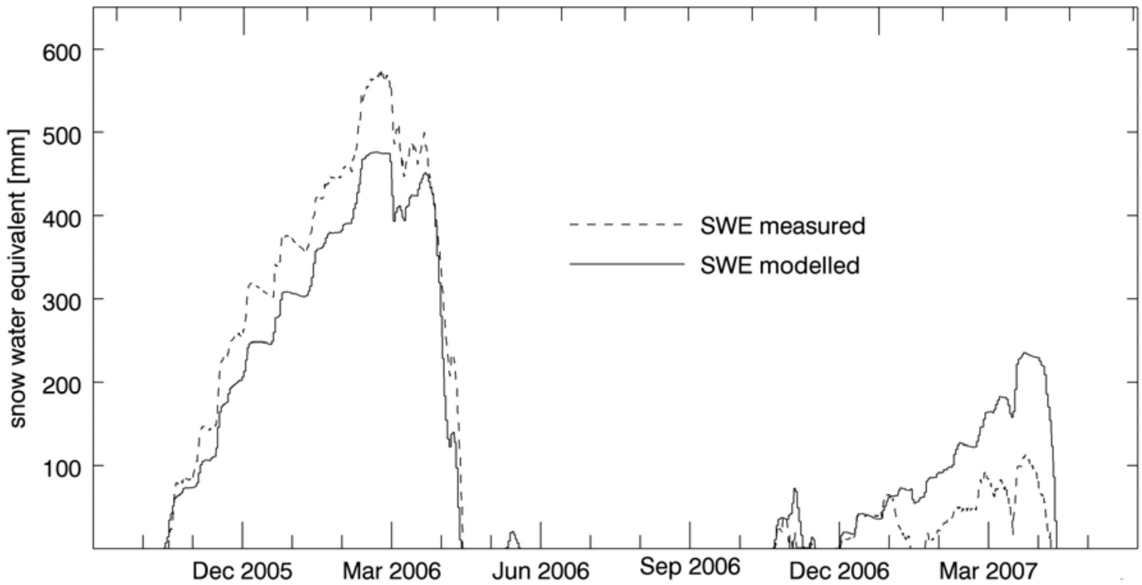


Figure 15: Snow cover evolution at the Kühroint station site (1407 m MSL) as modelled and recorded with a snow pillow.

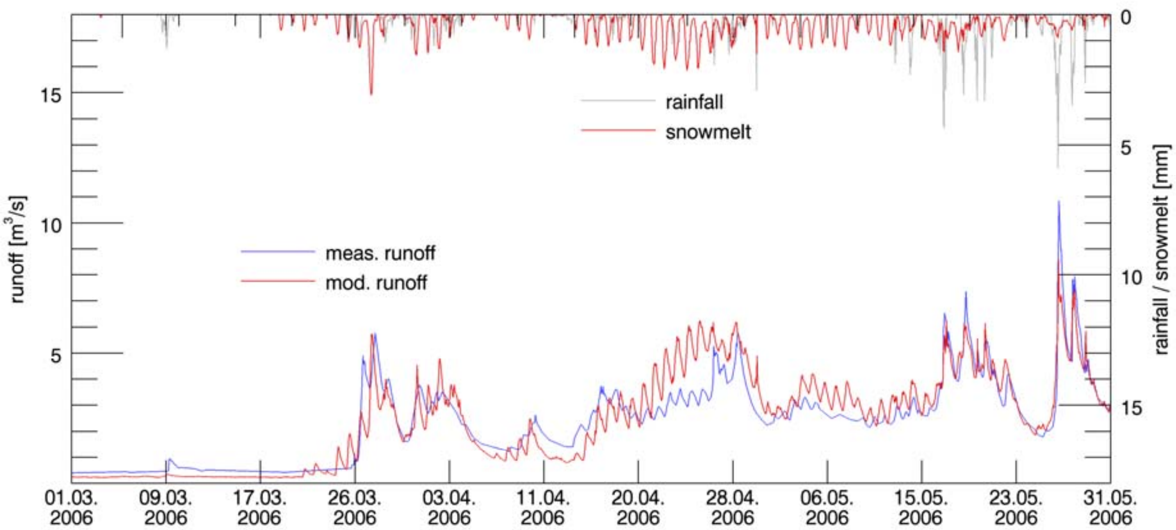


Figure 16: Modelled and measured runoff at gauge Hintersee during melting period 2006.

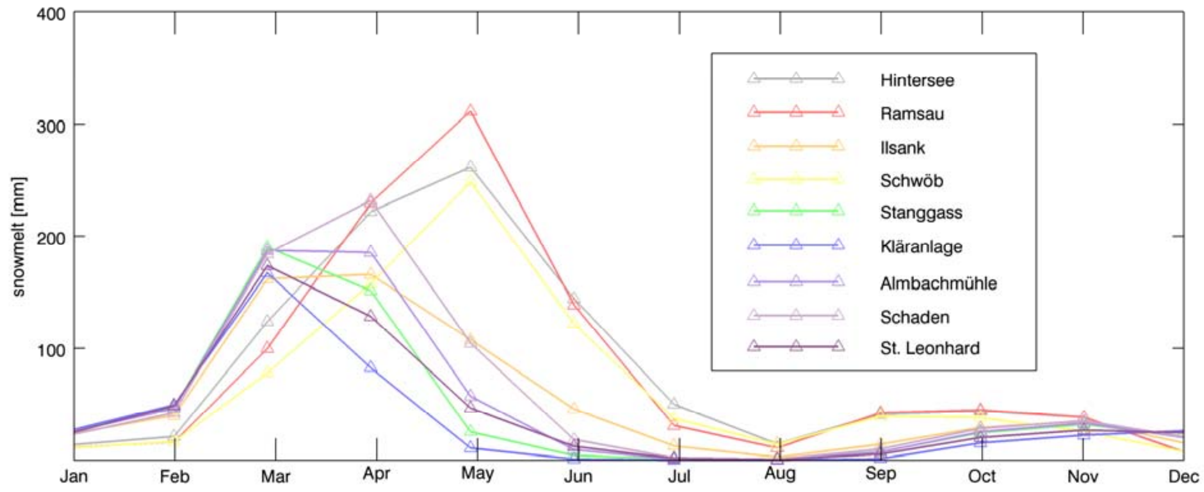


Figure 17: Mean monthly snowmelt sums (2002 - 2010).

d. Permafrost

Permafrost is defined as constantly frozen ground like soil, rubble and rock for at least two years. True permafrost is not visible, because the surface defrosts in summer.

In the framework of the EU Interreg Project PermaNET the Glaciology, Geomorphodynamics and Geochronology Institute of the University of Zürich was mandated by the Geological Survey in the Bavarian Environment Agency to determine the Permafrost areas in the Bavarian Alps. One of the main research targets was the core zone of the Biosphere Reserve Berchtesgadener Land. The underground temperatures were measured with help of data loggers in seven places of the Hochkalter peak at about 2600 m. Other measurements were installed in a gradient form the peak of Hochkalter to the weather station Blaueis at 1800 m. These measurements validated the energy balance models, which determined the probability of occurrence of permafrost in the area (BÖCKLI et. al. 2011).

In the core zone, permafrost can be found mostly in northern slopes above 2500 m. Due to the tiny area and thickness and climate change, permafrost will disappear possibly in the next 50 years and almost certainly in the next 100 years (BÖCKLI et. al. 2011, cf. Fig. 18). Fortunately, no infrastructure areas will be influenced by this process.

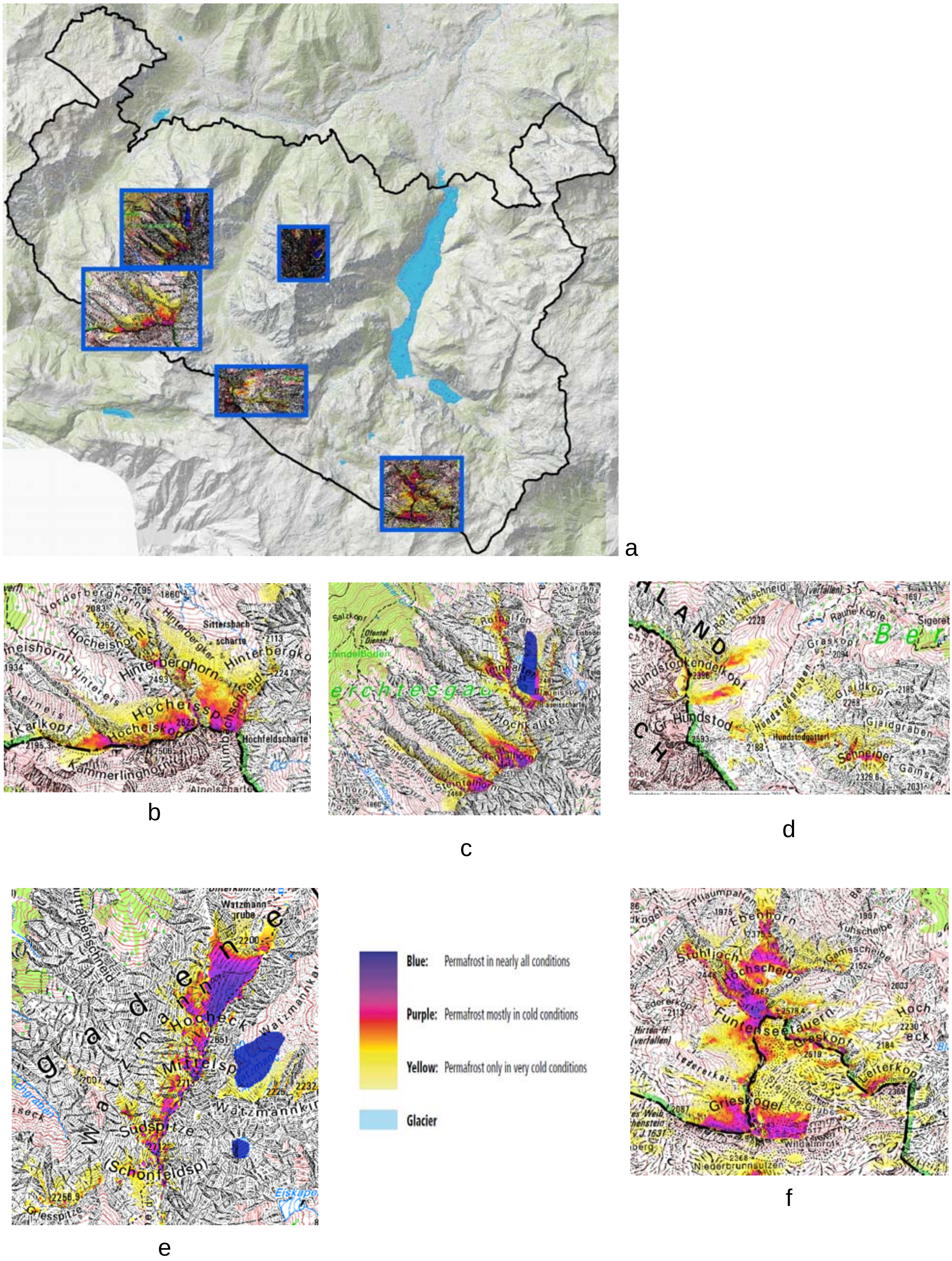


Figure 18a - f : Potential occurrence of permafrost in the core and buffer zone of the National Park and Biosphere Reserve (BÖCKLI et. al. 2011) a. Overview b. Hochkalter c. Hocheiskopf d. Schneiber e. Watzmann/Hocheck f. Funtenseetauern

5. Water Systems

a. Water Quantity

The water balance in high alpine regions is often affected by a significant variation of meteorological variables in space and time, a complex hydrogeological situation and a heterogeneous snow cover dynamics. However, mountain regions are an important water source for human consumption and economic use within mountain regions and in downstream lowlands. The Berchtesgaden National Park and its surroundings are characterized by extreme topography with mountain ranges covering an altitude from 607 to 2713 m a.s.l.. About one quarter of the investigated catchment is steeper than 35°. The mountain ranges in the region consist of soluble limestone with a high number of subsurface pathways (karst), highly affecting both the soil and groundwater storage. In a preliminary study, KRALLER et al (2011) summarized recent karst water research results for the area and synthesized a subsurface water flow in north direction and groundwater redistribution throughout surface water divides. We apply a physically based distributed hydrological model (WaSiM-ETH (SCHULLA & JASPER 2000)) within the watershed of the river Berchtesgadener Ache with a time step of 1 h and a spatial resolution of 50 m. Due to good data availability for the National Park Area, the model setup is based on meteorological data by a spatially dense network of meteorological stations at different elevations (cf. Chap. 2) and furthermore extensive land use and soil data. Discharge data from nine gauges within the area allow us to separate the area into nine subcatchments. The model is able to account for all processes affecting the water balance. Our research goal is to determine and predict water balance and its components, particularly runoff and water yield of mountain catchments (including wetlands and glaciers) under different global change scenarios. By applying the distribute model, we are able to determine the relationship between precipitation, evapotranspiration, snow cover dynamics and snowmelt, soil moisture and runoff within the subbasins and the overall catchment in different time scales

b. Water Quality and Sediment Production

The Berchtesgaden Nationalpark is located in the northern limestone alps, which are exposed to karstification processes since alpine lift. The result of this process are rock strata, composed of matrix, fractures, fissures and conduits where infiltrating water is underlying different flow characteristics. Groundwater is emerging at hundreds of spring locations, which are not only ecologically important habitats for highly adapted and sometimes endemic species but also crucial as water supply for alpine cottages and settlements in the valleys.

Since more than 10 years the Berchtesgaden Nationalpark is operating a spring monitoring programme, where field parameters and also nutrients and bacterial contamination of the spring water are investigated at a defined interval (cf. Fig. 20). The time series are analyzed in different perspectives. On the one hand, hydrological dynamics are observed and the underlying aquifer system characterized, on the other hand the possible climate impact on spring habitats is recorded.

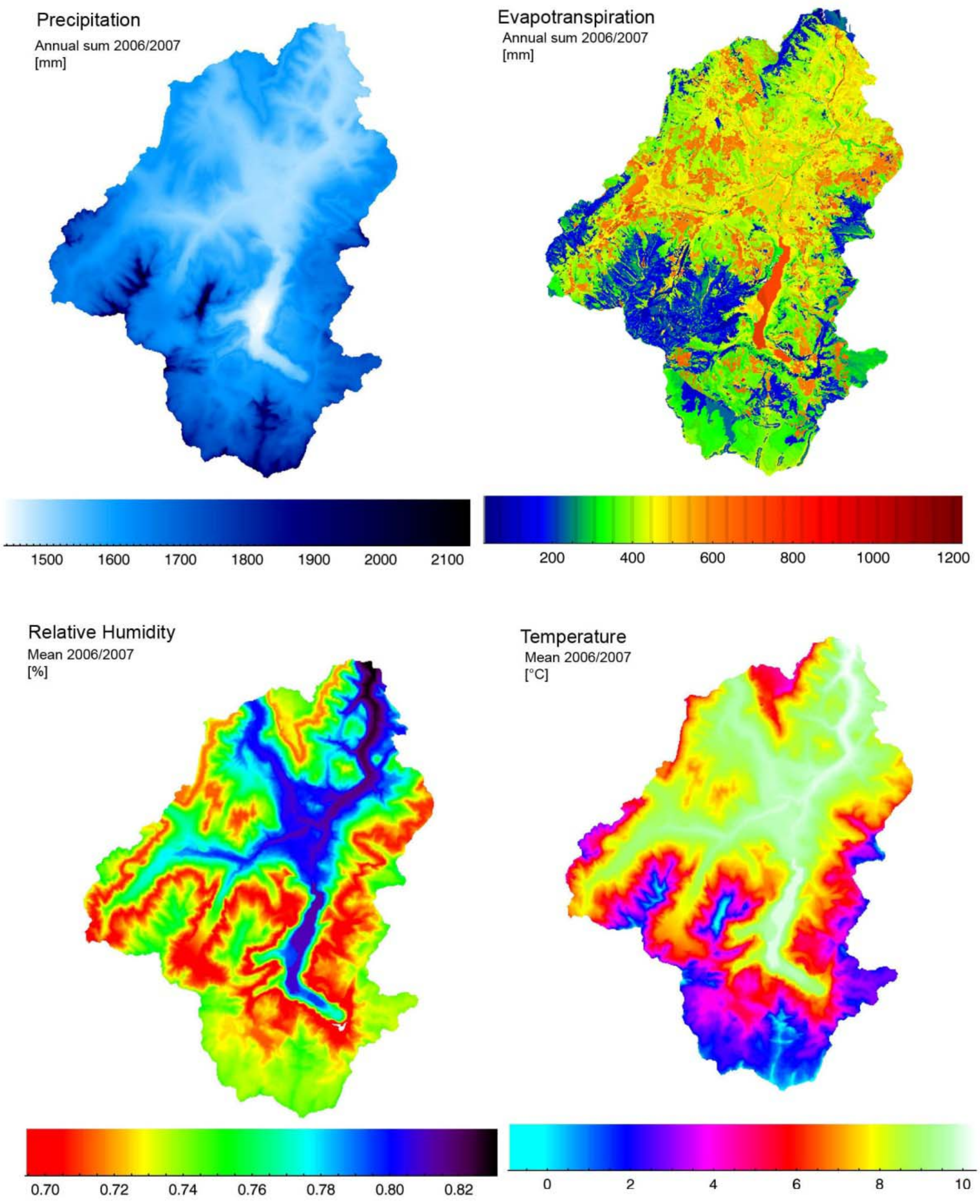


Figure 19: Important parameters of the Berchtesgaden Water Balance modell

c. Aquatic Community Structure

About 1980, an intensive limnological project investigated the lake Königssee (SIEBECK 1982). Based on this study, fish species and their potential food were investigated in detail (KLEIN et. al 1991; TRAUNSPURGER 1991, GERSTMEIER 1991). The lake Königssee is monitored by the local Water authority (Wasserwirtschaftsamt Traunstein) every six years.

A simple monitoring programme should be started to monitor water parameter of the Lake Königssee with regard to climate change.

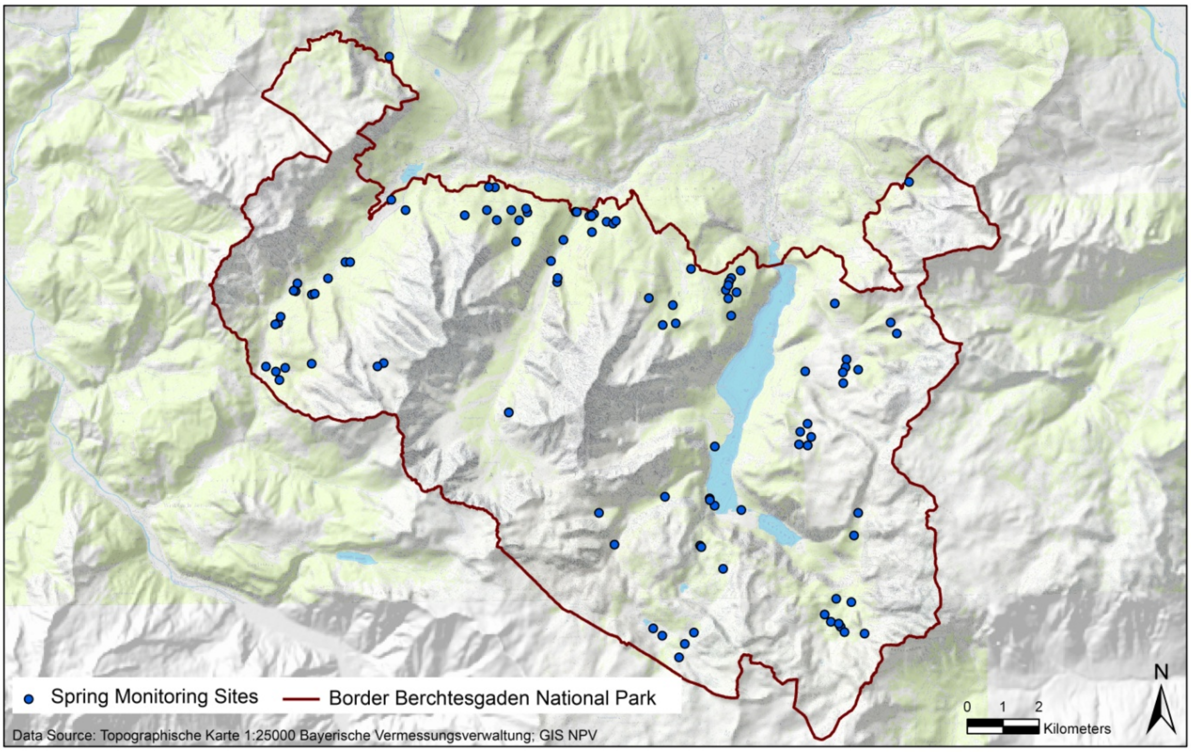


Figure 20: Water spring monitoring sites

Focusing to the effects of climate change on the aquatic community structure of spring habitats, the macrozoobenthos species in the National Park have been documented in much detail (cf. Chap. 7a, Fig. 20). At present, a focus of our research is given to species distribution patterns along an altitudinal transect and their potential change (BÜCKLE & GERECKE 2011).

6. Ecosystem Functions and Services

In Berchtesgaden region, only less knowledge exists about N and C Cycles.

a. Role in Alpine Areas in N, C and P Cycle

The Nitrogen input on the weather station of the Bavarian Agency of Forestry in 1500 m altitude is one of the lowest N – Inputs in the 24 Bavarian forest weather stations. In Fig. 21 is shown, that the annual input of N is between 5 and 10 kg / ha * year. This input may not influence the alpine vegetation communities as much as climate change (cf. KUDERNATSCH 2006). The uncertainty should be clarified by a project, which determines the empirical critical load of input in an altitudinal gradient for try and wet Nitrogen input for sensitive alpine ecosystems.

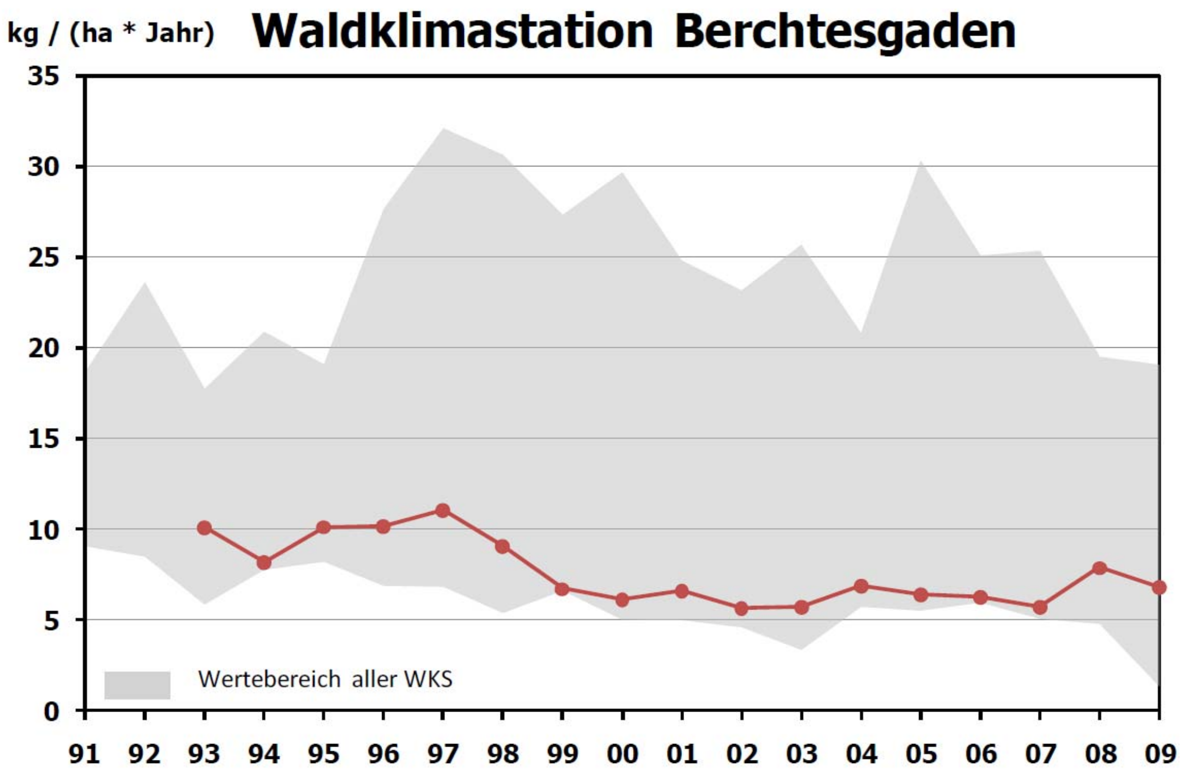


Figure 21: Annual Input of N at the Berchtesgaden Waldklimastation (Forest weather station) of the Bayerische Landesanstalt für Wald und Forstwirtschaft (Bavarian Agency of Forestry) (LWF 2011). This weather station is located in the core zone of the Biosphere Reserve and is with an altitude of 1500 m a.s.l. the highest forest weather station in Bavarian. The grey area represents the range of N input for all Bavarian forest weather stations.

We do not know very much about C Cycle. The forest biomass could be derived from the known structure of forests (cf. Chap. 7e).

Water quality is monitored by the local water agency (Wasserwirtschaftsamt Traunstein). Physical, chemical including Nitrogen and Phosphate measurement and biological samples are assembled to quality measurement for running waters and lakes. These data can be used for an integrated approach concerning N and P cycle. The water balance model (cf. Chap. 4 and 5) could be widened to mass transport model using these data.

b. Role of Grazing Lands in C, N and Water Cycles and Slope Stability

In the core und main buffer zone of the Biosphere Reserve exist 35 alps. In the beginning of the first half of the 19th century we had 91 alps in this area. The number was reduced mainly for economic reasons like low-yield soils, short vegetation time and increasing water shortage (StMLU 2001). The farmers nowadays keep running a traditional, indigenous and local knowledge. They contribute strongly to the biodiversity in the buffer zone.

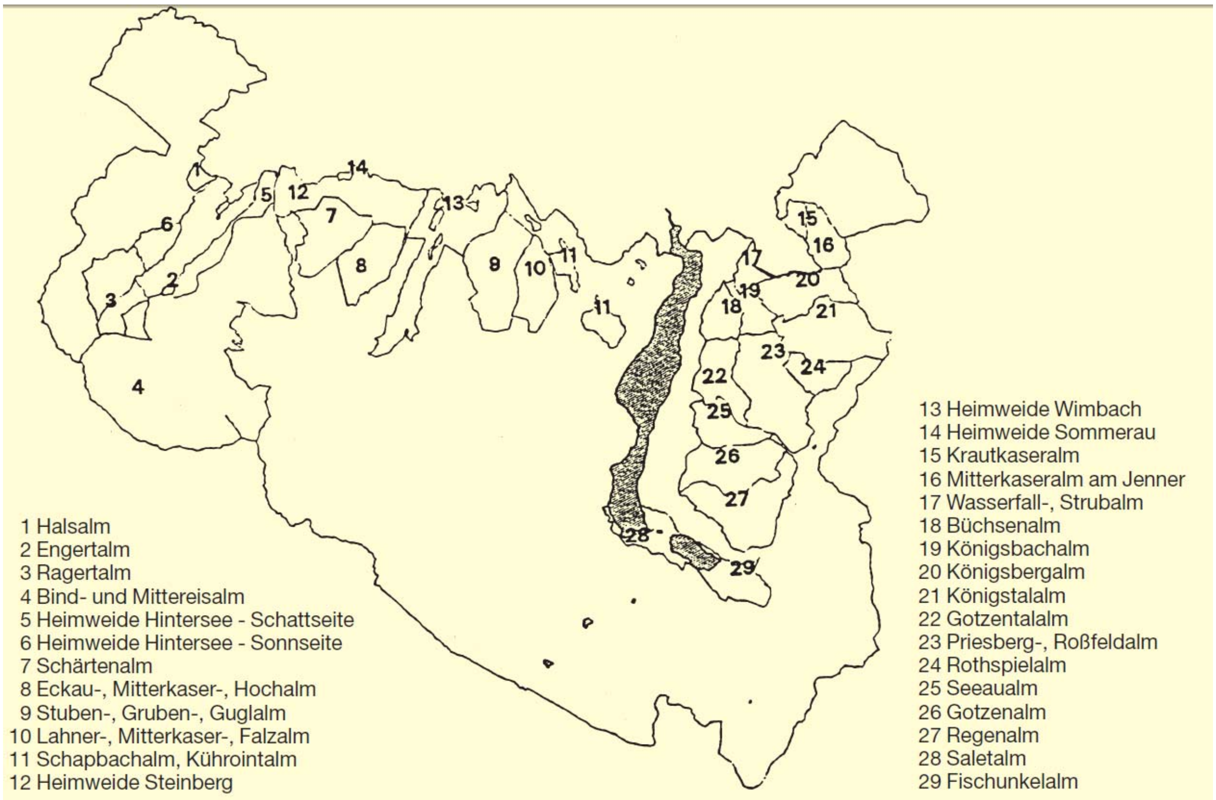


Figure 22: Alps in the main buffer zone of the Biosphere Reserve (StMLU 2001)

The legal title for the 32 alp farmers is several hundred years old. They are not only allowed to have grazing cattle in meadows, but also grazing cattle in forest.

The different land use and biotope types are derived from aerial photos (cf. Chap. 3). On this basis, on the basis of the water balance model (cf. Chap. 4 b, c and 5) and of potential occurrence of plant species (cf. Chap. 8) we could evaluate the future role of grazing lands to predict the future structure and function of mountain grazing lands along with the likely impacts on material cycles and geomorphic processes. Household incomes could be worked out adding an economic model to all this models.

c. Soil Systems

Soil types and soil thickness build a mosaic divided into small sections. On slopes, the thickness is between 30 and 60 cm. In the valley, we can find sometimes soil thickness of until four meters. Geological layers are chalky. For this reason, rendzina soils, slope colluviums soil and brown calcareous soils are the main soil types in the area. The soil types are documented in the National Park Plan as Map 3 (Soil types) and Map 4 (Organic soil plating).

KÜFMANN (2008) detected, that the soil genesis in our area recently is highly influenced by air dust from neighboured regions, especially from the central alps. Since the end of ice time probably 9 – 13 cm of silicate dust was brought in by wind. This would not correspondent to the impact of climate change for an altitude zone.

Little is know about impact of climate change on soil types and soil thickness. With help of the above mentioned models, we could try to get an idea about this problem.

d. Pollution f. Plant Pests and Diseases

Toxic pollution is not known for the area.

Invasive plant species are not yet a problem for the Biosphere reserve.

Bark beetle invasions

Due to historical forest cultivation, the dominant tree species in today's Berchtesgaden National Park management zone is spruce. Spruce monocultures, in particular if harmed by storm events, facilitate bark beetle invasions. Measures to re-establish natural mixed mountain forests have been taken ever since the park was first established. Due to its ecological demands, the bark beetle will profit from the effects of climate change: extreme weather events increase the risk for bark beetle damages in forest ecosystems, especially spruce monocultures. The bark beetle may appear earlier after the winter and the number of bark beetle generations will increase in warm years. Warmer late summers promote maturation grub and therefore decrease winter mortality of the population. Forest ecosystems under drought stress are more difficult to locate than storm-damaged timber and thus present a greater management challenge (KRALLER et. al 2010).

Since 1985, the development dynamics is monitored by pheromone traps for this species.

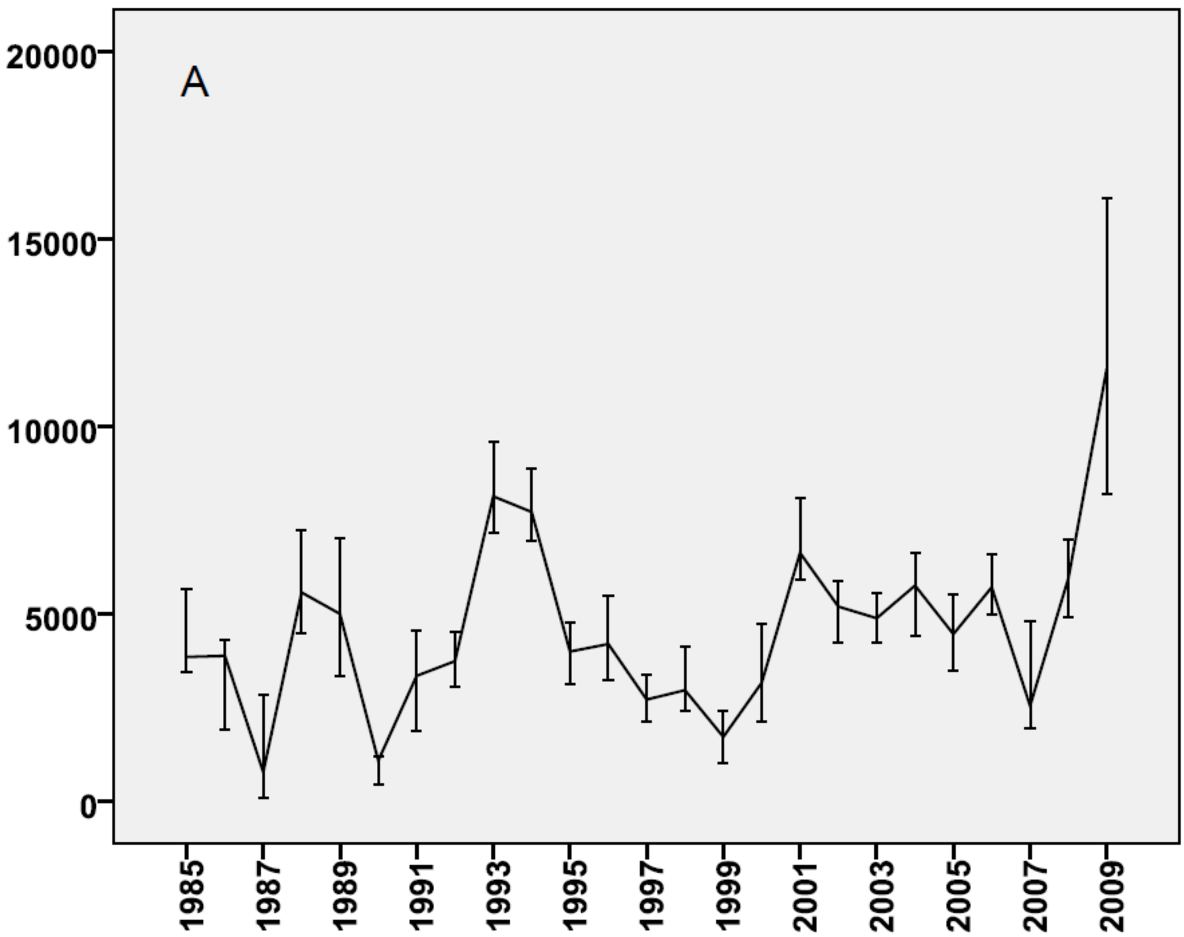


Figure 23: Medium total fly of bark beetles in the trap network of the about 30 pair of traps in 4 transects in the National Park of Berchtesgaden from 1995 – 200 in number per trap. The error bar shows 95 % confidential interval (KAUTZ et al. 2011).

The violent storms Vivian and Wiebke in 1990, Lothar in 1999 and Kyrill in 2007 are represented in Fig. 23. Three to four years after Vivian/Wiebke the traps caught about 7000 – 8000 individuals. Within the same time delay, the number of bark beetles doubled after Kyrill in 2007 compared to 1990. The assumption, that climate change will intensify violent storms, will heavily affect spruce monocultures.

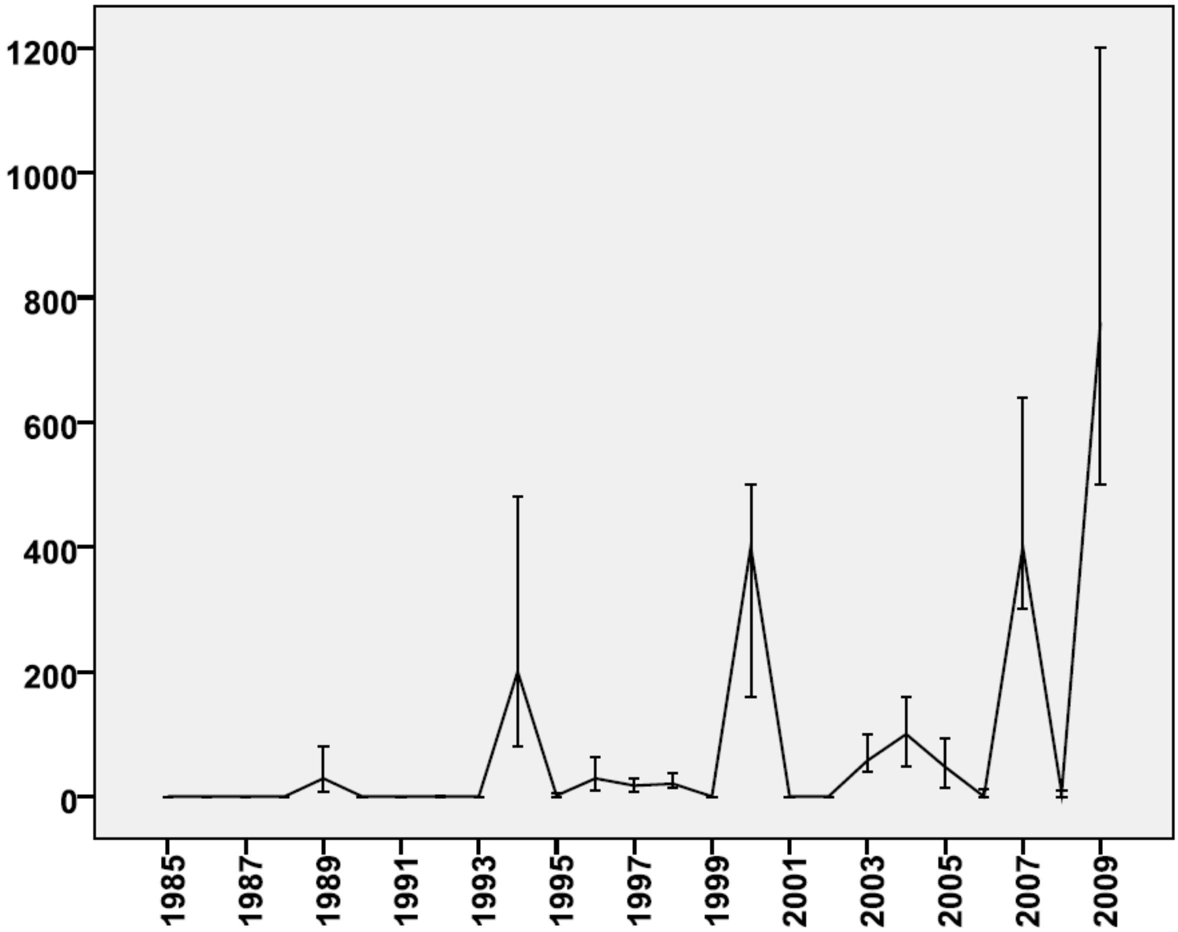


Figure 24: Trapping of bark beetle in April in National Park: Median values of individuals of bark beetle per trap and the 95% confidence intervals (KAUTZ et al. 2011).

In the first years of trapping, bark beetles did not reach the traps (cf. Fig. 24). This changed significantly since 1994. This may be a signal of climate change.

7. Biodiversity

a. Assessment and Monitoring

Landscape biodiversity

The advantage of assessing and monitoring biodiversity on the level of species is the accuracy of the results that can be obtained. However, sometimes there is the need of getting a general idea of the potential biodiversity in a specific area. Then landscape diversity analyzes can be the method of choice - e.g. because examinations concerning species or genetics are not affordable. Within HABITALP (Alpine Habitat Diversity), a project based on the INTERREG IIB Alpine Space Programme, it was - among other things - the aim to develop a tool for the assessment of diversity (LOTZ 2006). Beyond that, the results should serve as a decisive factor for defining prior management areas. This was accomplished by choosing the diversity of the relief on the one hand and the habitats on the other hand, which were based on an interpretation of colour infrared aerial photographs. Fig. 25 shows the results of modelling diversity for the former Berchtesgaden Biosphere Reserve (National Park and periphery) by combining relief and habitat diversity using a Geographic Information System.

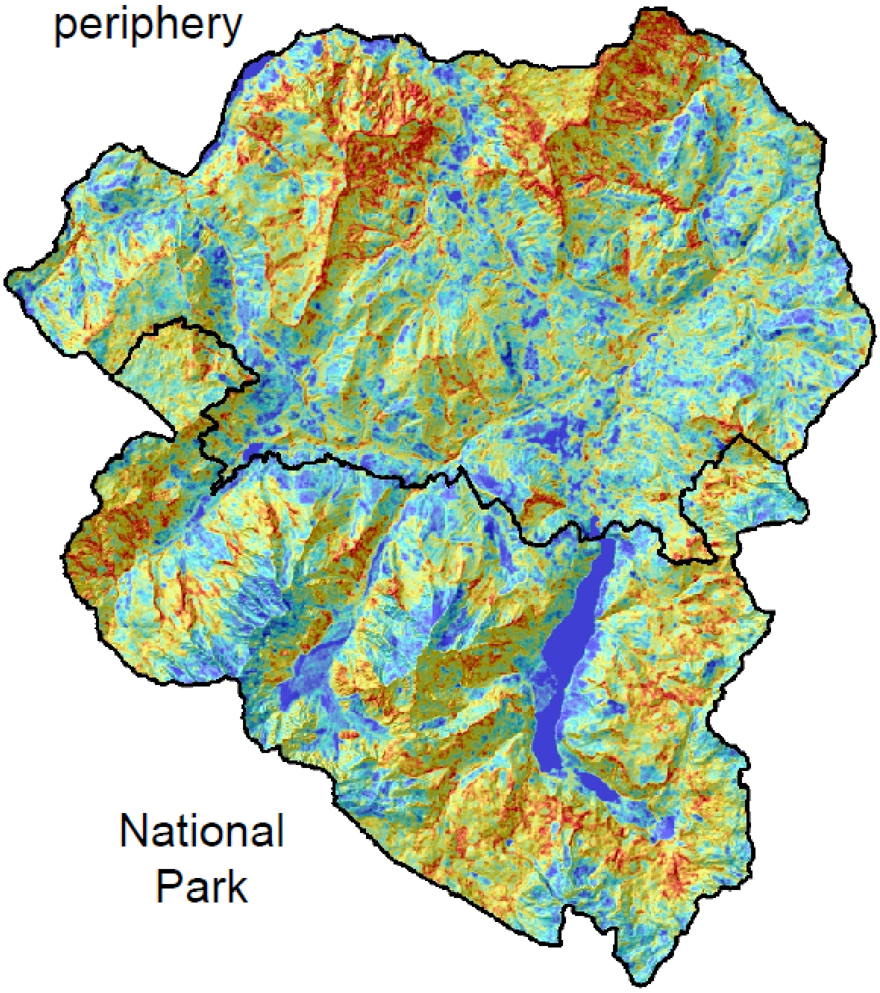


Figure 25: Landscape diversity model for former Berchtesgaden Biosphere Reserve (GRAB 2006).

Areas in red indicate a mosaic of ridges and canyons with varying aspects and steep ascents in combination with a frequent change in habitat types whereas the blue colour stands for large uniform zones.

For the interpretation and implementation of the resulting maps it is very important not to divide in “good” or “precious” and “bad” or “worthless”. In fact, this assessment has to be carried out by considering the needs of the specific species or group of species the research is focused on. To this effect a highly diverse landscape can offer advantages for species requiring food, shelter and an overview in immediate vicinity.

Large coherent areas can be just as precious by serving as potential habitats for large mammals or as corridors for migrating species.

Vascular plants

First scientific investigations on flora in the Berchtesgaden Alps have taken place since 1785. At present, more than 1100 ferns and vascular plant species are known (LIPPERT et. al, 1997).

First phytosociological mappings with the method from BRAUN-BLANQUET (1964) were carried out at the beginning of 1960er years. Until now, more than 4000 vegetation mappings with about 189.000 date records are known from all altitudinal vegetations zones of the former Biosphere reserve from 600 to 2700 m a.s.l. (cf. Fig. 26). They are documented in the information system FLORIS including coordinates. The areas from the last 10 years are established as monitoring places. On this base, an area-wide vegetation map for the national park was worked out (StMLU 2001).

Beyond that, the floristic information system contains more than single 40.000 locations of vascular plants from the former Biosphere Reserve Berchtesgaden.

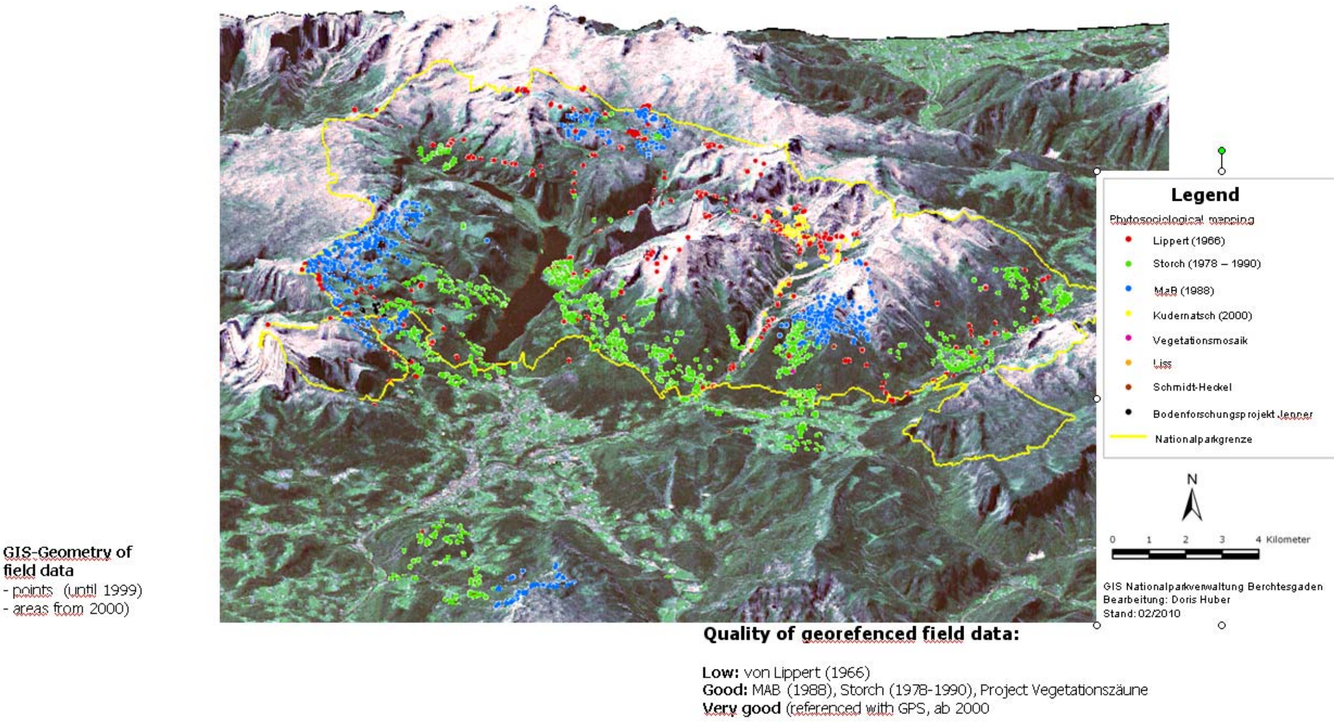


Figure 26: Phytosociological mapping in Berchtesgaden

These data were overlaid with the topographic and climatic data from the Geographic Information system like results of the interpretation of CIR photos, digital elevation model, slope, aspect, temperature, snow high and so on (cf. Fig. 28).

These data were combined by logistic regression. For 300 of the about 1100 species habitat suitability models were worked out (HECHT & HUBER 2002, cf. Fig. 27 for one species).

With help of these data, the biodiversity for vascular plants could be determined for the core and main buffer zone of the Biosphere Reserve. If the database would be widened to the now existing biosphere reserve, the model results could be transferred to the new areas.

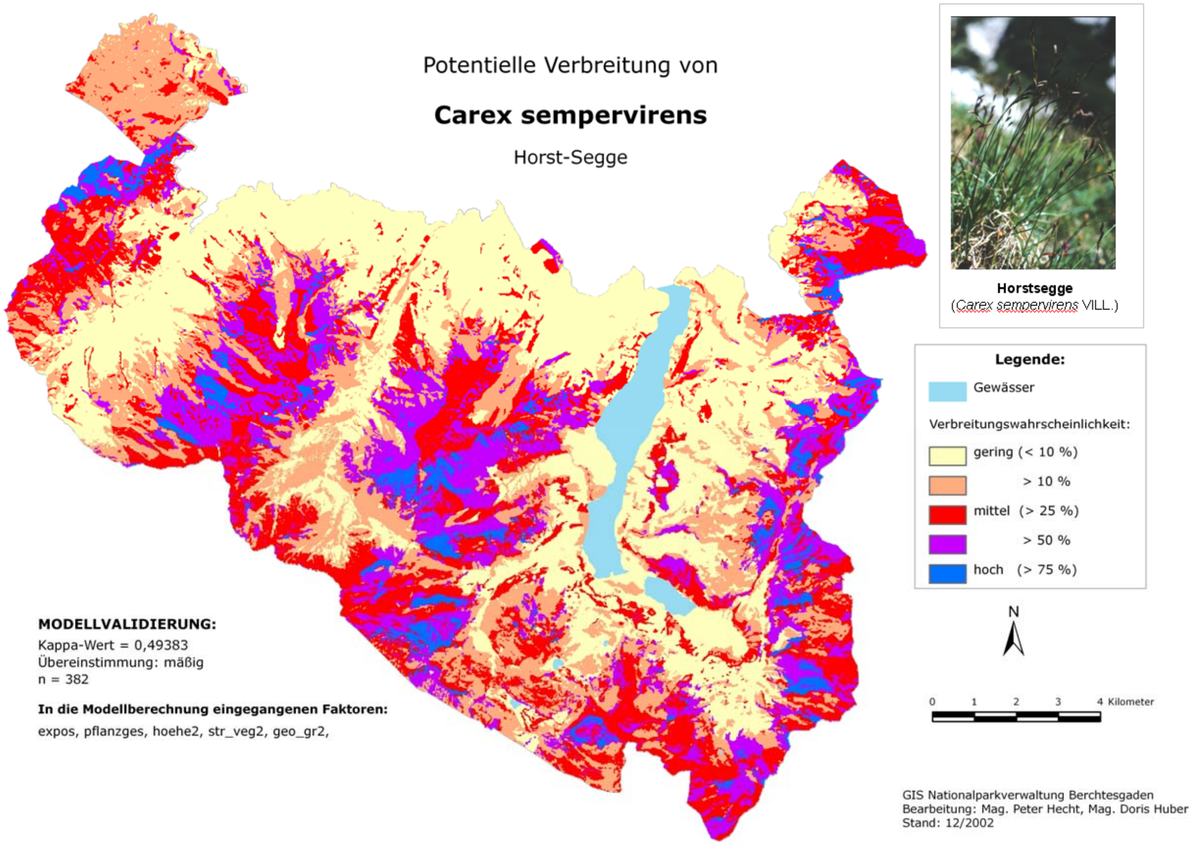


Figure 27: Habitat suitability model for Carex sempervirens

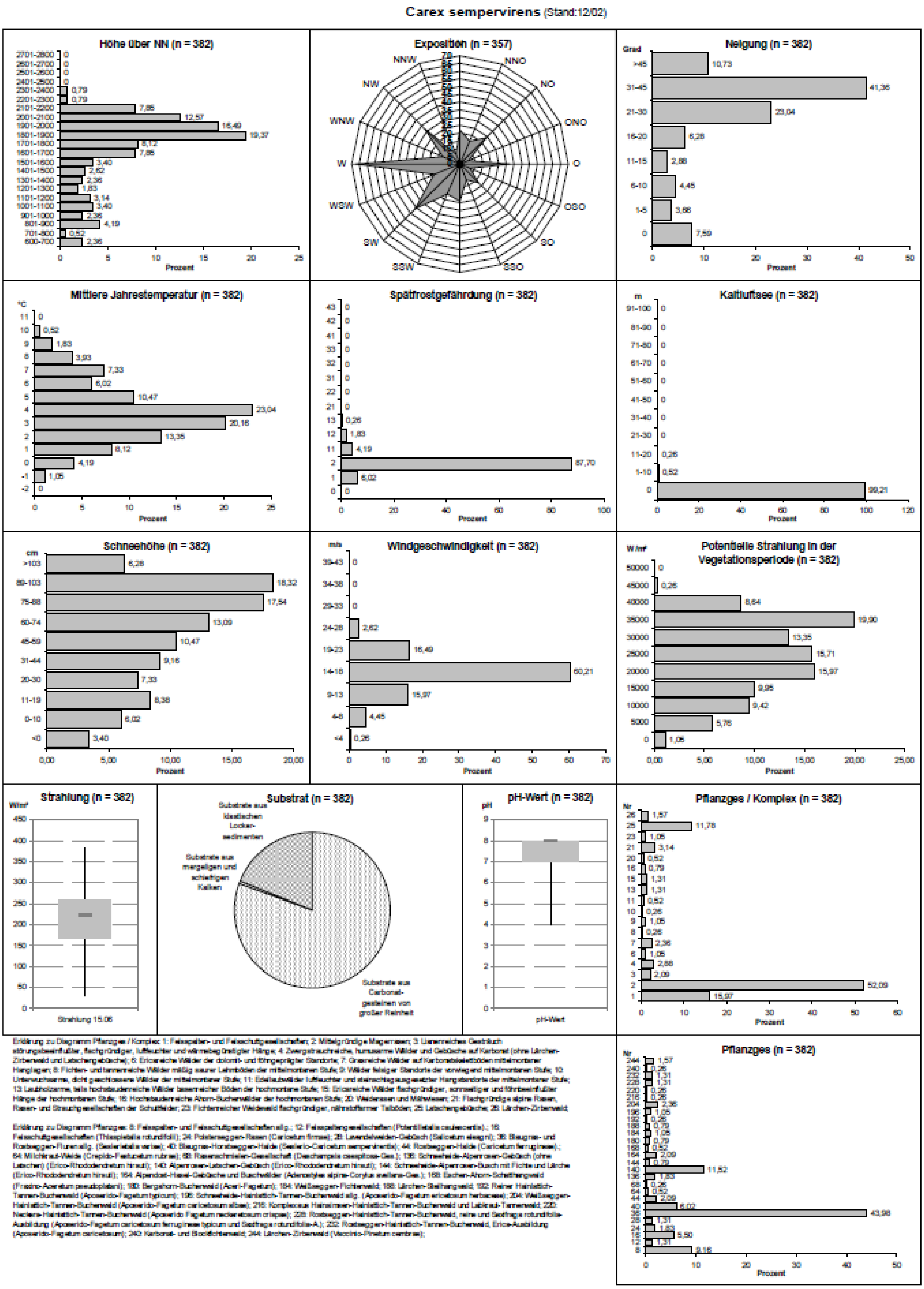


Figure 28: Topographic and climatic characteristics for Carex sempervirens, derived from the information systems of the National Park as a base for the Habitat suitability model

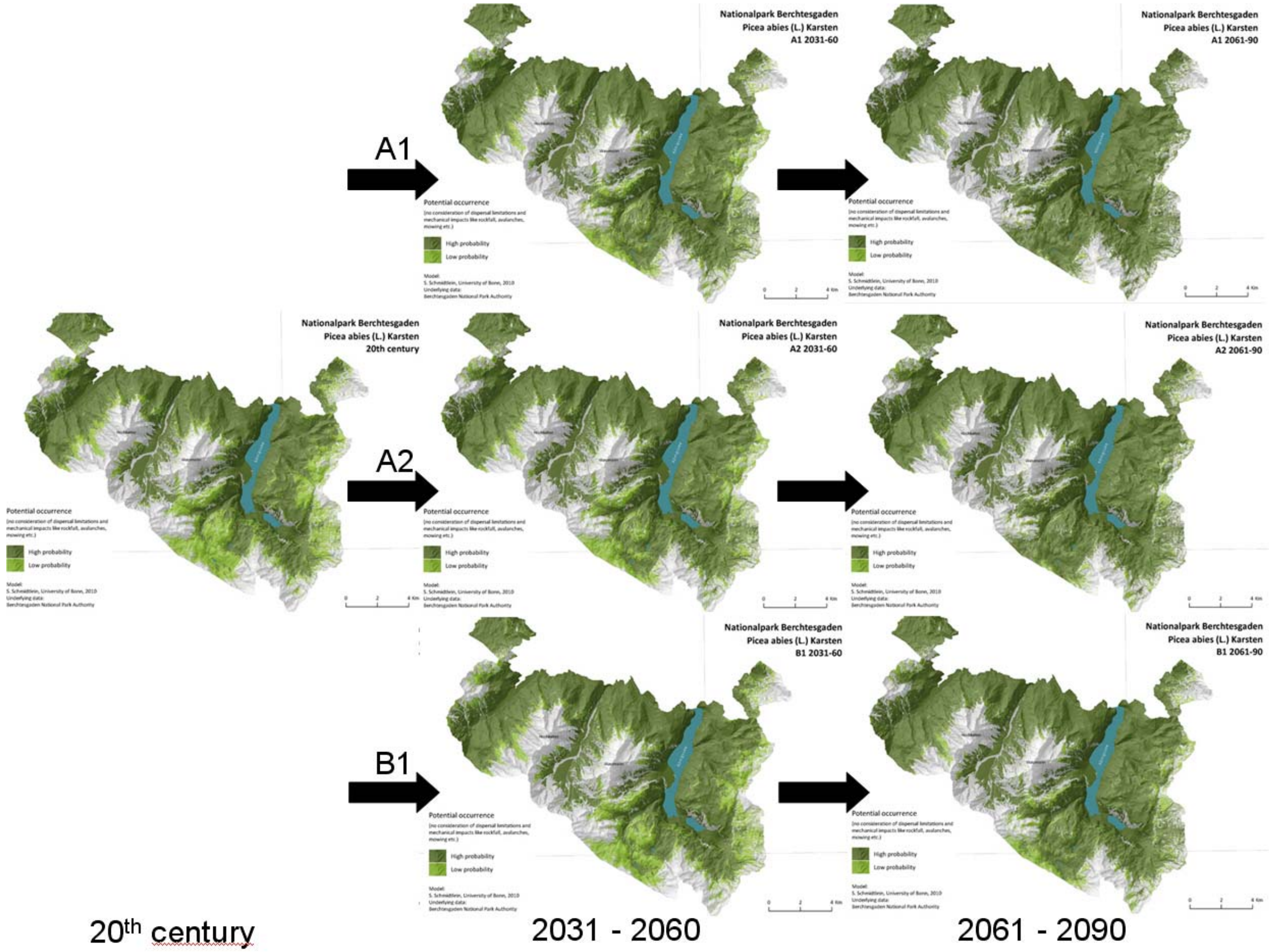


Figure 29: The vegetation geography group at the University of Bonn is working on climate change scenarios for the potential distribution of 158 vascular plant species with frequent occurrences in the Berchtesgaden National Park (SCHMIDTLEIN et al. 2010). The examples given in the figure show maximum entropy models for Norway spruce. They are based on information on substrate availability, slope and climatic information. Future climate conditions correspond to IPCC – Scenarios A1, A2 and B1 for the periods 2031-2060 and in 2061-2090, respectively.

Gloria sites

The Global Observation Research Initiative in Alpine Environments (GLORIA) network wants to proof the impact of climate change on summit vegetation. It includes 36 target regions with 135 summits at the moment (GLORIA 2011). The National Park of Berchtesgaden is at present involved with 3 summit, which were monitored between 2003 and 2005 for the first time (cf. Fig. 30).

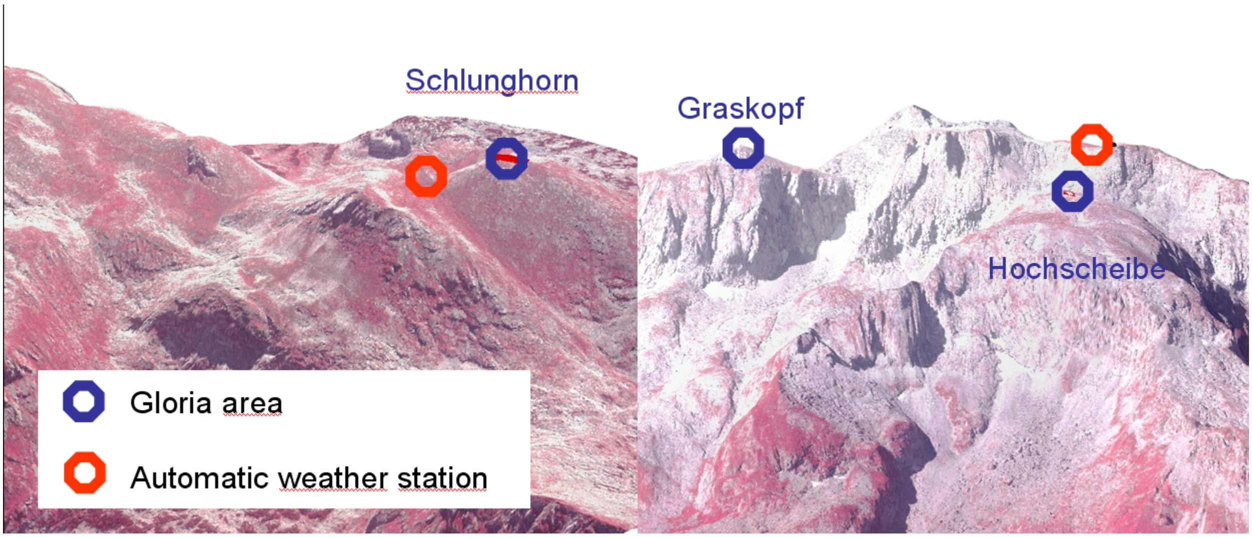


Figure 30: Gloria areas Schlunghorn, Graskopf and Hochscheibe and automatic weather Stations (cf. Chap. 2) in the test site Berchtesgaden. Light red: vegetation covers only a part of the area. Dark red: vegetation covers the whole area

Schlunghorn peak is 2200 m a.s.l. and was populated in 2003 by 120 vascular plant species. Hochscheibe peak at 2460 m had 60 vascular plant species, Graskopf at 2520 m had 40 species. During the next years, we will resurvey these peaks.

Water springs

Springs are locations of groundwater exfiltration and represent unique ecosystems. They mostly have very tiny temperature amplitudes in day and year. To examine these habitats and to determine possible climate impacts, a long-term monitoring project was implemented seventeen years ago. Investigation parameters are location, altitude, discharge rates and dynamics, chemical, physical and structural parameters as well as flora and fauna. About 750 animal species were found in more than 60 springs in the National Park (GERECKE & FRANZ 2006). More than fifteen endemic species new to science have been discovered and described.

In a special project, diatoms were investigated in 9 springs located mainly at sites 1 (Schapbach/Kühroint) and 3 (Funtensee, cf. Fig. 31). Overall 104 taxa belonging to 39 genera were found. Almost 54% of the 104 species where classified as rare or threatened, 4 species as endangered for the Red List of central Europe

(CANTONATI & LANGE-BERTALOT 2010). Two species new to science were discovered and described.

Roughly assuming that the area of one spring is about 100 m^2, these species are living in a very-specific ecosystem type on less than 0,03 per mille of the area of the national park.

However, historical reference data are not available. Emerging spring species might be more able to adapt to changing conditions, thus non-emerging species are potentially more changed by climate change. In the first five years, only the site Kühroint / Schapbach was monitored by zoological and physical-chemical investigation. After five years, 6 monitoring sites were defined. The investigations take place every 6 years. At present, we assume, that the climate change signal at sites 1 (Kühroint) and 2 (Koppenwand) is superimposed by the forest development stage and at site 5 (Priesberg) by traditional alpine pasture activities (cf. Fig. 31).

At present, we do not detect a change of spring communities by impact of climate change. But we expect, that the animal species in the lower part of running waters will migrate with increasing temperature to the peak of the running waters, which are the water springs. We establish a monitoring transect for the site nr 4 (Röthbach) running water from an altitude of 600 m to 1400 m a.s.l to get a first idea, which species would migrate to the springs (BÜCKLE & GERECKE 2011) as they probably did since the last ice age. However, historical reference data are not available.

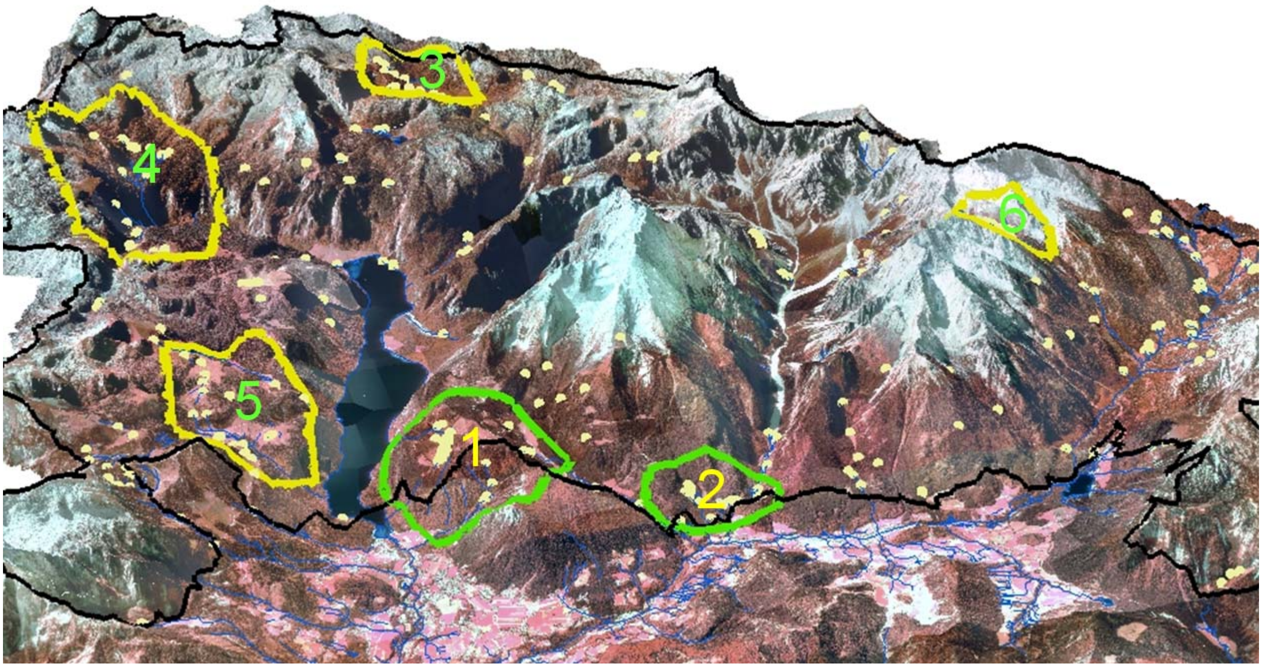


Figure 31: Monitoring sites of the spring monitoring Programme. 1 Kühroint/Schapbach 2 Koppenwand 3 Funtensee 4 Röth 5 Priesberg 6 Sittersbach. Yellow points are water springs in the National Park

Other groups

Following plant and animal species numbers are known in the National Park of Berchtesgaden:

Plant or Animal Group	**Number of species**	**Status of Year**
Diatoms	104	2010
Ferns and flowering plants	1000	1997
Mosses	493	1996
Lichens	718	1999
Fungi	1940	1988
Mammals	55	2003
Breeding birds	80	2003
Reptils	7	2000
Amphibians	8	2000
Mayflies	18	2006
Stone flies	35	2006
Saltatoria	28	1996
Beetles	95 + 9	2001+ 2006
Carabids	94	1996
Aculeata	250	1987
Formicidae	32	2005
Trichoptera	44	2006
Lepidoptera Butterflies	85	1984 - 86
Lepidoptera Moths	427	2003
Spiders	111	2003
Opiliones	30	1986
Molluscs	109	2006
Macrozoobentos in springs	735	2006
Hymenoptera	24	1987

Table 1: Number of plant and animal species in the National Park of Berchtesgaden.

A lot of species especially from the invertebrate groups are not known in Berchtesgaden. For this reason it is not possible to have an idea, whether they are important for biodiversity functioning and if they are affected by climate change. Likewise, it is not possible to decide, if there may be key fauna and flora species.

b. Biodiversity Functioning

With the "Bavarian Climate Programme 2020" the Bavarian Ministry of Science, Research and Art (StMWFK) in cooperation with Bavarian universities and technical authorities elaborated a package of measures especially aligned for Bavarian conditions. One of these measures is FORKAST, the Research Cooperation on „Impact of climate change on ecosystems and climatic adaptation strategies", incorporating 16 projects and one coordination module. Besides the interlinked cooperation of the subprojects in the research cooperation FORKAST interdisciplinary working groups with specific thematic foci were set up. One of the three plots, where interdisciplinary collaboration is carried out, is the National Park of Berchtesgaden (FORKAST 2011). Following projects take place in this framework in the National Park of Berchtesgaden:

Ecological impacts of climate-induced phenological changes on the Bavarian vegetation

Phenology regulates ecological services like competition, growth, biodiversity and pollination. Historical data indicate earlier vegetation periods and longer flowering seasons. Their analysis, together with manipulative experiments, will show how extreme weather events and climate change influence plant phenology and dependent interactions between organisms. The different reactions of species (e.g. to late frost or pest insects) should allow for species-directed management strategies. In Berchtesgaden National Park, phenological records date back to 1994 and they are used as supportive data source. In addition, two vertical transects were observed in 2009 and again in 2010 regarding date and duration of the flowering period, its micro-stages and the changes under manipulated conditions (cf. Chap. 7d).

Endangerment of plant-pollinator networks by climate change and extreme weather events

Interactions between flowering plants and pollinators are extremely important both from an economist's and an ecologist's point of view. Plant-pollinator networks (PPN) may be particularly threatened by climate change since they consist of mutually dependent species that differ in their responses to projected climatic changes. Of particular concern is the danger of desynchronization of plant flowering and insect activity periods. A deeper understanding of PPNs will allow for strategies to prevent species loss and to preserve the essential ecosystem functions provided by PPNs. A combination of data sources (field data collected along an alpine elevation gradient in

Berchtesgaden NP, statistical analysis of existing datasets, related FORKAST projects) will be used to parameterize prognostic models that will help to estimate the consequences of climatic trends and extreme events for PPN stability and to identify threatened species. The theoretical background of these research efforts is documented in BENADI et al. (2011).

Effects of climate change on the timberline and the vegetation of the alpine belt

This project focuses on the analysis of mechanisms behind the present distribution of alpine species along an altitudinal gradient and the current and future climate-related shifts in the calcareous grassland vegetation of the subalpine and alpine levels. This is done by functional and historical analysis of vegetation dynamics. Historical analysis includes the history of land use, past climate changes, glaciations and changes in the timberline. Functional analysis examines traits of plants related to the environment e.g. reproduction rate, generation time and dispersal potential. The vulnerability of species of the alpine grassland communities may be predicted using simple models and a risk assessment implemented. In the study area, 32 plots are spread over an altitudinal gradient from 630 to 2245 m a.s.l..

Combined effects of climate change, extreme events and habitat fragmentation on diurnal butterflies and trophic interactions

The long-term survival of animal populations and their adaptability to changing climate conditions highly depends on trophic interactions and genetic diversity. Focusing on diurnal butterflies, this project analyzes the combined effects of climate change, habitat fragmentation and extreme events. Differently fragmented grassland habitats along a climate gradient serve as study sites in Berchtesgaden National Park. The analysis will also cover the risk of extinction, the impact on population dynamics and trophic plant-herbivore-antagonist interactions, the adaptability of animal populations with different genetic diversity as well as the temporal variance in biodiversity, dispersal and genetic diversity of diurnal butterfly populations. Based on the findings, the project intends to develop adaptation and protection strategies.

c. Biodiversity Management

Dendroecological investigations

Tree-ring variations are ecological indicators for tree growth and vitality. In a recent research project tree ring widths were used to analyze whether and how climate change influences the mountain ecosystems. Key questions are: Has temperature increased since the 1990ies reflected by tree growth? Are the effects species-dependent? What is the influence of site factors and altitude? How will extreme events affect mountain forests? Which adaptations are necessary?

Spruce, fir and beech, the main tree species in mixed mountain forests in the Berchtesgaden area were investigated along four altitudinal zones between 700 and 1700 m a.s.l.. In total about 800 individual trees were sampled at 18 sites. Tree-rings were measured, dated and analyzed with regard to growth trends and climate-growth-relationships. According to the length of the tree ring series and available climatic data we considered the last 100 – 200 years (DITTMAR et al. 2011).

Among the investigated species spruce had the strongest correlation between tree ring width and climate. Below 1000m a.s.l. growth was reduced in dry and warm years while above 1300 m growth increased during such years. The influence of temperature and precipitation on radial growth of fir was very small indicating very favourable growth conditions for this tree species in the Berchtesgaden region between 700 and 1300m a.s.l. Beech growth was limited by cold temperatures and late frost events above 1000m. Tree-ring width of larch was positively correlated with temperature and duration of sunshine duration especially in high altitudes indicating a dominating effect of radiation for this highly light demanding species. The increase of average annual temperature of about 1.5 °C since 1990 had no influence on tree ring growth for any species.

The results indicate that mountain forests in the Berchtesgaden area were very vital in the investigated period. The predicted climate change with warmer and dryer years with more sunshine is supposed to have a positive effect on vitality and stability of the mountain forest ecosystems. Long term effects strongly depend on velocity and intensity of climate change and our current knowledge does not allow exact predictions. Concerning practical management the results indicate that below 1000m a.s.l. the proportion of spruce should be reduced in favour of fir and beech while in higher altitudes spruce seems to be vital also under changing climate conditions. This confirms our efforts to convert non-natural spruce monocultures to more near-natural mixed forests with spruce, beech, fir, and sycamore maple as main tree species in the lower altitudes of the Berchtesgaden National Park.

d. Alpine Community Change

Phenological observations

Since 1995 park rangers have observed 22 sites along an altitudinal gradient from nearly 700 to about 1400 m NN in the Schapbach valley. During springtime 21 plant species are observed phenologically. The development stage of flowers and leaves is documented using a key provided by ELLENBERG (1974). These data were analyzed by CORNELIUS et al (2011). First results will be published within the next months.

Impact of climate change on alpine plant societies

The impact of climate change on alpine vegetation units was investigated by KUDERNATSCH (2006). He worked out the effect of temperature rise on alpine calcareous grassland. Species compositions of 48 reference sites were compared with 1988 census data. of the phytosociological mapping (cf. Chap. 7 a).

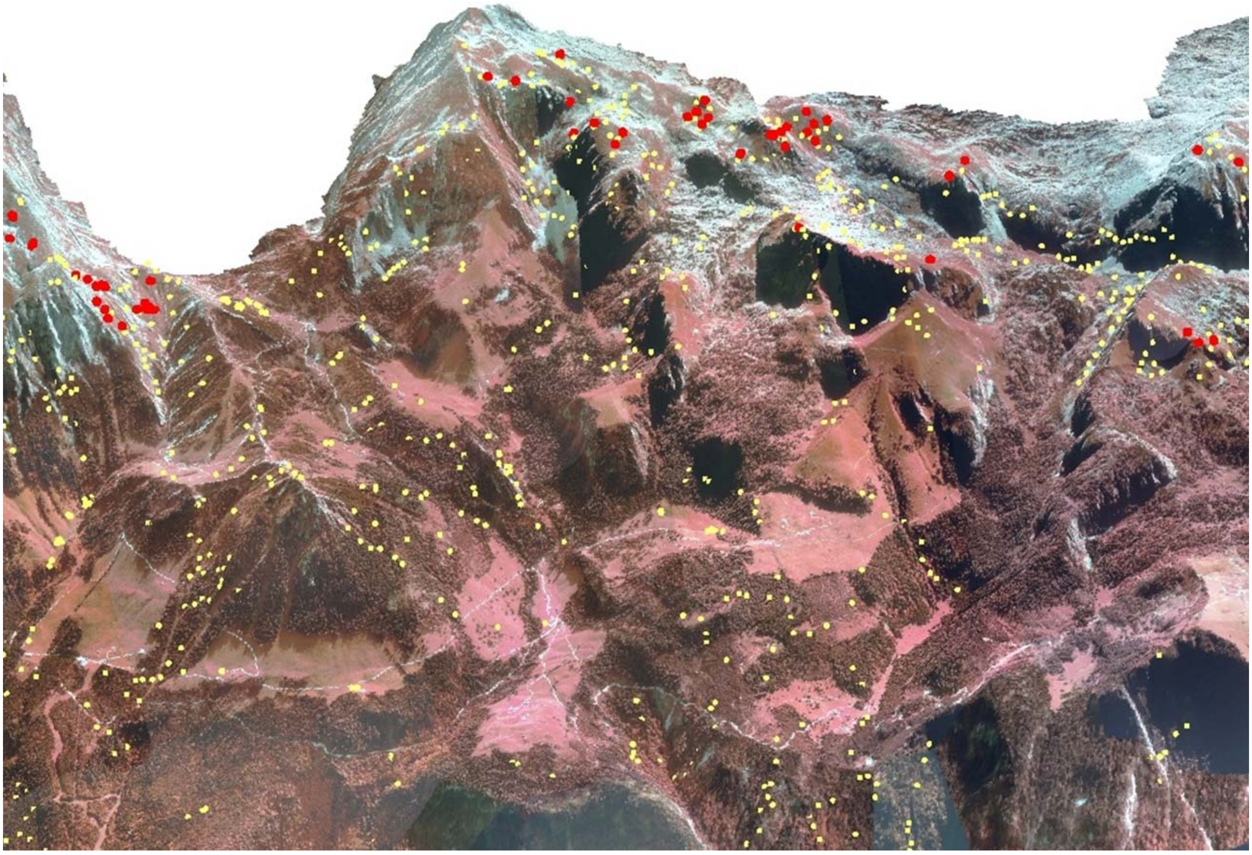


Figure 32: Yellow points represent the phytosociological inventory sites (cf. Chap. 7a). Red points represent the 48 compared study areas.

In addition, 32 open-top chambers causing an artificial temperature increase were installed. Species composition of manipulated sites was compared with reference sites. The approach shows that plant individuals experience more fitness due to temperature rise, leading to population growth and higher species numbers. These plant population shifts are observable in Berchtesgaden NP as well as in other alpine regions.

e. Forest Structure

The forests of the core and main buffer zone of the biosphere reserve exist from the submontainous area at an altitude of about 500 m up to the alpine zone of about 2000 m above sea level. Naturally we can find beech or mixed beech forest communities with sycamore, ash and partly Norway maple, whych-elm and summer lime. In mountainous locations between 700 and 1400 m dominates mountainous mixed forest with common beech, silver fir, spruce and sycamore. The percentage of spruce increases with altitude.

Clearing, use of wood, preserving of wildlife and grazing in the wood resulted in artificial spruce monocultures for these zones. In the northern slopes of Nationalpark leaf trees are lacking nearly completely.

In the subalpine zone from 1400 to 2000 m a.s.l. we can find spruce dominated and larix communities. In some areas Swiss stone pine is growing. In the upper subalpine zone these forest communities are infiltrated with mountain pine, which dominates the alpine zone.

Clear-cutting, use of wood, preserving of wildlife and grazing in the wood resulted in spruce monocultures for these zones too and caused a sinking of the tree line (StMLU 2001).

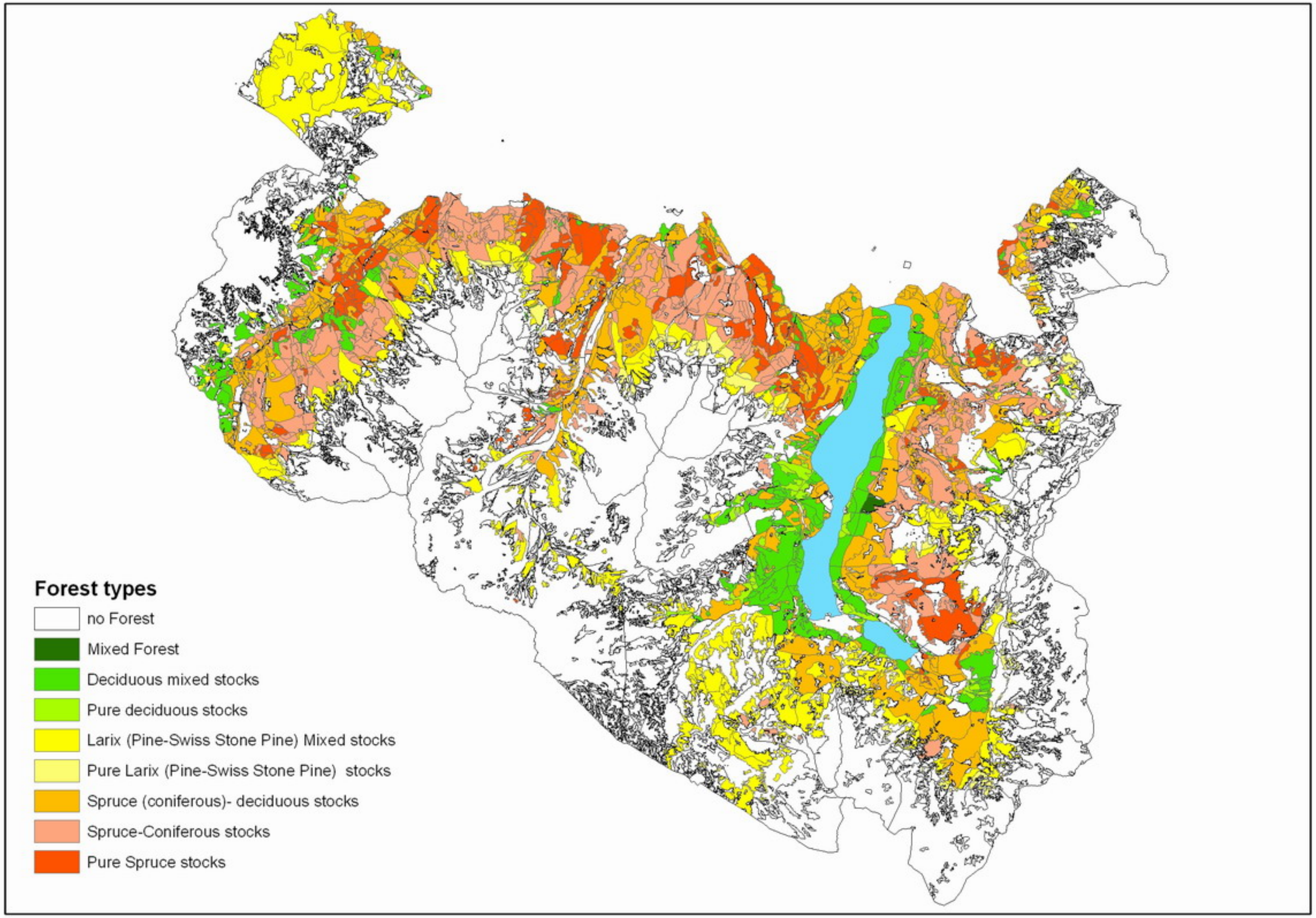


Figure 33: Forest types or stand of tree types of the core and main buffer zone in the Biosphere Reserve. The last forest inventory of the National Park of Berchtesgaden in 1995 – 1997 detected 125 different tree types (KONNERT 2000). In this map, they are aggregated into 8 type groups

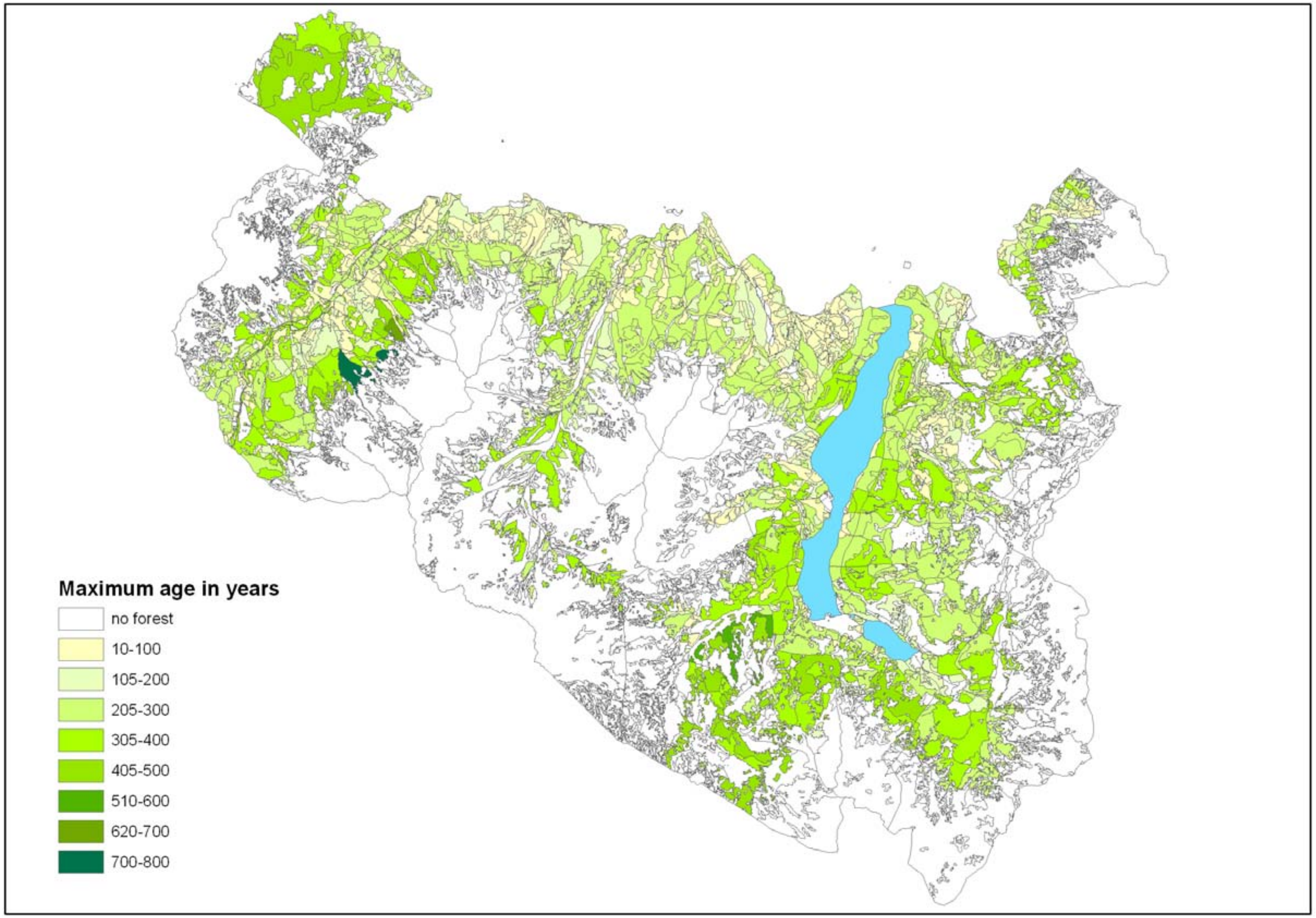


Figure 34: Maximum age of the forest types. The age of the forest stands is derived from "Revier" book, which depends from forest inventory (KONNERT 2011).

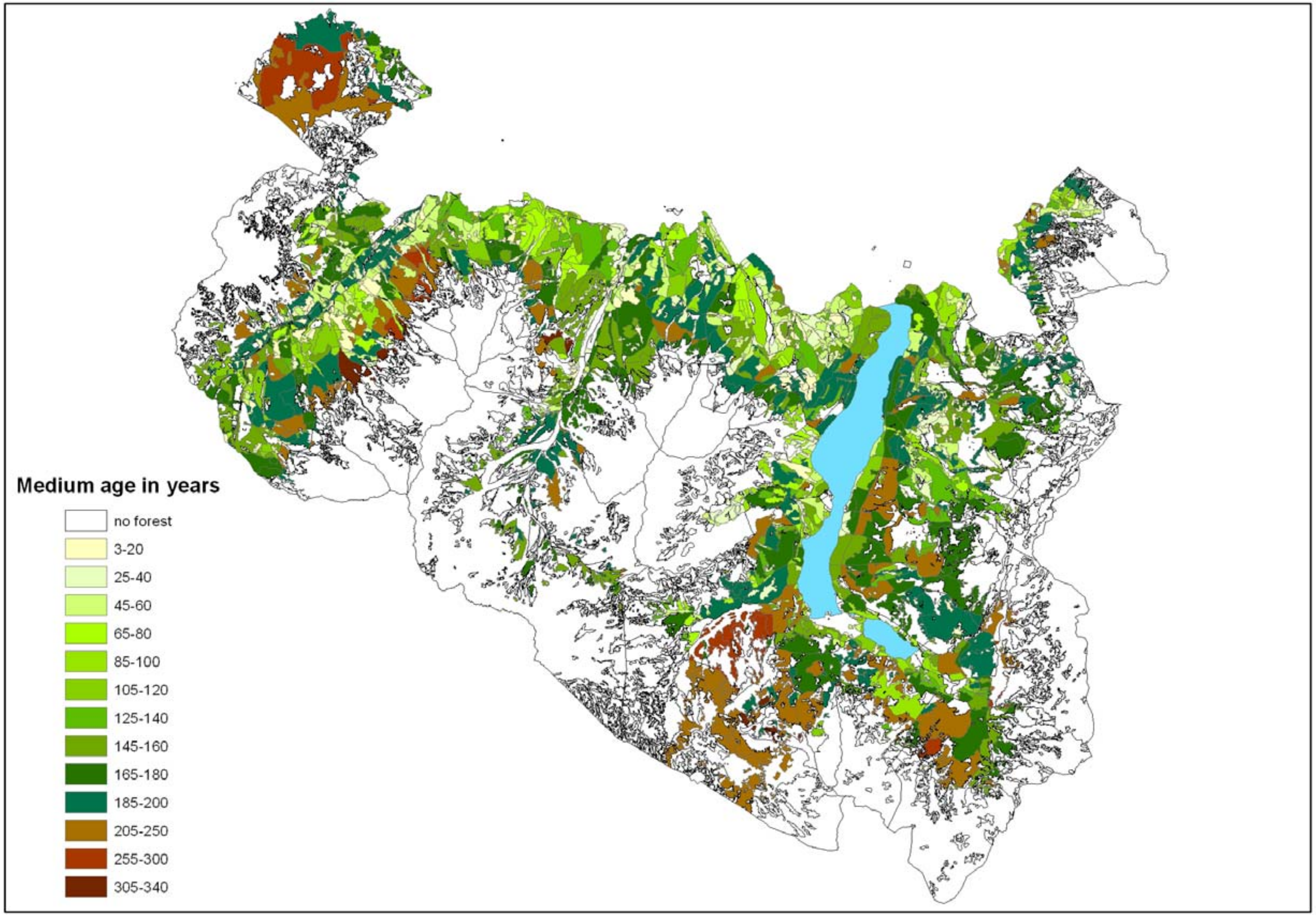


Figure 35: Medium age of the forest types in the core and main buffer zone. The age of the forest stands is derived from "Revier" book, which depend from forest inventory (KONNERT 2011).

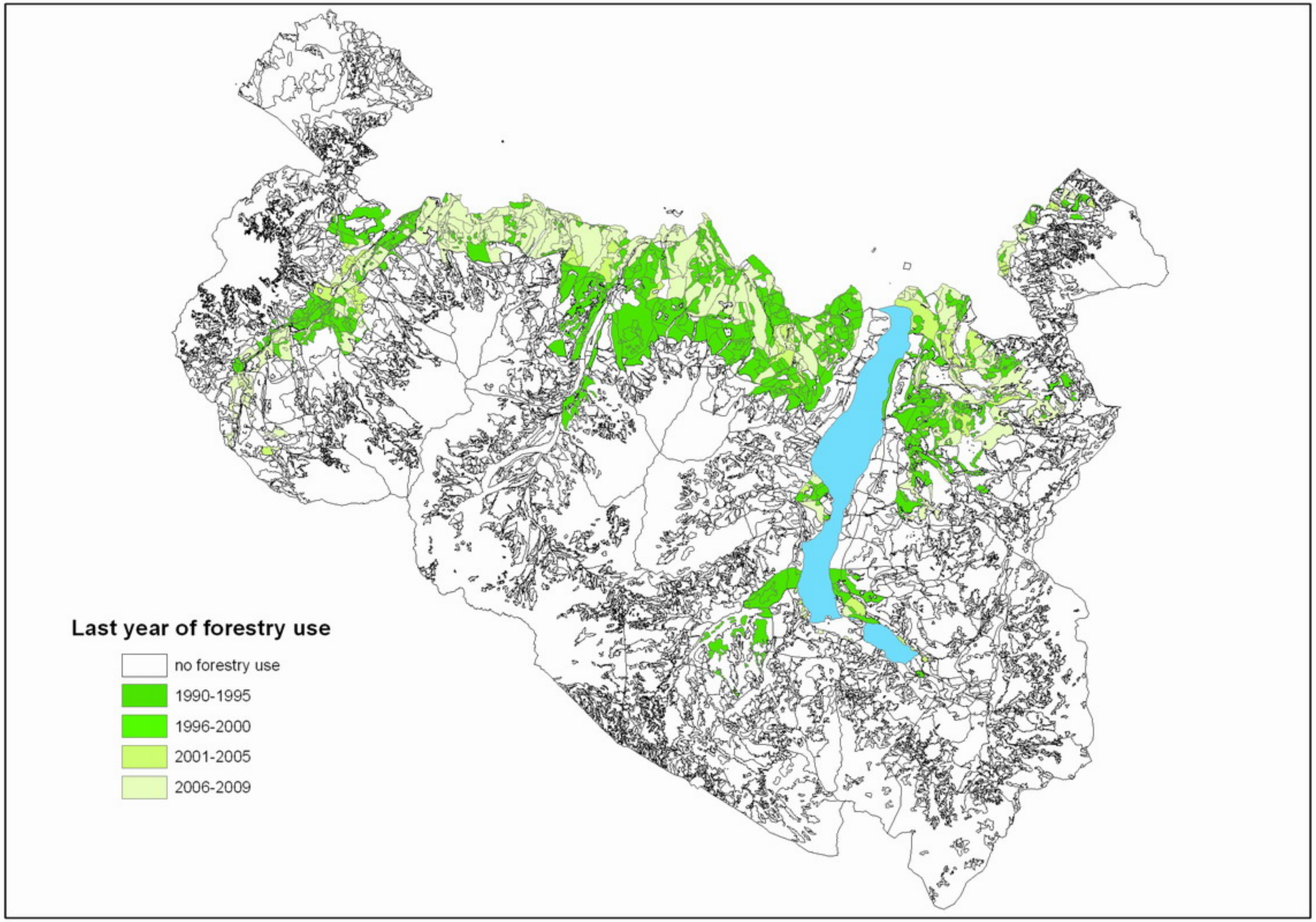


Figure 36: Last year of forestry use. The last year of forestry use is derived from the forest chronicle recording of the National Park. The last year of forestry use was determined for the period of time 1987 – 2009

Berchtesgaden National Park is presently carrying out its third forest inventory. For the first inventory dating back to 1983/84 more than 5400 inventory points were created for the forests in the national park. They are regularly distributed within a mesh of one point per 2 ha. The inventory was repeated in 1995/97. The results for the comparison between the first and the second inventory are documented in KONNERT (2000).

Important results of the forest inventory are: in the core zone there are rather natural or semi-natural forests, whereas strongly human marked forest types are typical for the buffer zone. The occurrence of tree species in the second inventory was: spruce 50 %, larch 28 %, beech 8 %, sycamore 4 %, Swiss stone pine 4 % and other tree species 6 %. In lower altitudinal vegetation zones spruce covered 73 % of the area. This is the result of former forest cultivation. Referring to the whole National Park area spruce monocultures decreased between the first and second forest inventory from 30,6 % to 28 % and spruce dominated forests interspersed by other tree species decreased from 44 % to 38 %. In the buffer zone this trend was more pronounced (decrease from 58 % to 47 %) due to the specific measures of the National Park administration to support more natural forest compositions.

If upcoming trees are more than 20 cm high and their diameter in about 1,30 m height is still inferior to 5 cm, this is defined as rejuvenation in the sense of the forest cover. The data of the second inventory shows that the forest development in Berchtesgaden National Park - as indicated by the rejuvenation - has a tendency to more natural forest types.

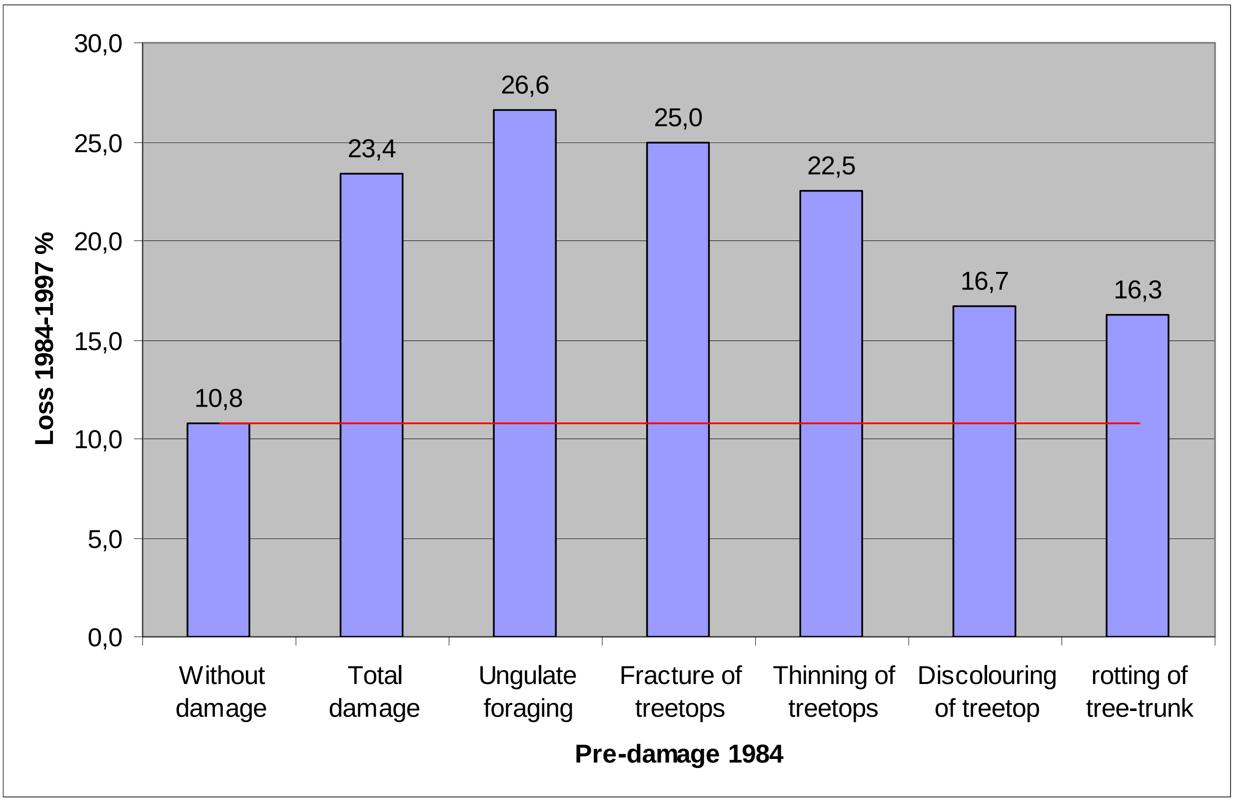


Figure 37: Loss of trees with and without damage between first and second forest inventory

Comparing the data and analysis of the two forest inventories in 1984 and 1997, we could get a certain idea about the loss of trees with pre-damage in comparison to trees without proven pre-damage. With these analyses we could point out some factors which destabilize forest sites (cf. Fig. 37).

The non-damaged trees of the year 1984 have a loss rate of 10,8 % whereas those with pre-damage have a total loss rate of 23,4 %.

If we differentiate by type of damage, we can prove, that the highest losses with 26,6 % occur in old trees affected by ungulate (red deer) foraging. Fracture of tree tops, mostly due to wind and snow break, and thinning of tree top branches by industrial emissions cause a loss of 25 % respectively 22,5 %. Losses caused by discolouring of treetops (16,7 %) and rotting of tree trunks (16,3 %) are lower (KONNERT 2000).

f. Culturally-Dependent Wild Species

Probably we have a lot of culturally-depended wild species especially in the buffer and transition zone of the biosphere reserve. But we have only few knowledge about these species. We need to gain basic knowledge about them.

g. Impact of Invasive Species

At the moment there are only a few invasive species in the environment of National Park and Biosphere Reserve. Caused by the impact of climate change, neighboured species may migrate to our region. We must not consider these species as invasive species in a lot of case, but as new indigenous species. We will review these cases for some species groups with our monitoring programmes (cf. Chap. 6d and 7).

8. Hazards

a. Floods and Wildland Fire

Floods are not important in the area of the former Biosphere reserve, because the potential flood plains in the former Biosphere reserve are not very large. Even if storms and downpowers will enforce with increasing climate change, only a few areas are affected by these events. If the local water balance model (cf. Chap. 4 + 5) is implemented in our information system as a monitoring system, we shall be able to predict heavy rainfall in short time. We can analyze these events using the documentation by our weather stations and gauge stations and the water balance model working with these data. And we could perform a probabilistic analysis of observed floods to estimate potential changes in the frequency and magnitude of extreme events.

Wildland fires do not be of great significance in the area of the former Biosphere reserve at the moment, because we have a wet climate (cf. Chap. 5a) with humid season all the year. But if precipitation shall diminish in summer and autumn, as regional scenarios show, we will get problems with wildlife fires. We will get a deeper impression, if the local scenarios of our water balance models, widened with the potential fuel properties, will have worked out climate change and the potential fire occurrence for our region (cf. Chap. 4 and 5). If the local water balance model is implemented in our information system as a monitoring system, we will be able to identify dry areas and the possible areas that may be affected by wildland fires. If it gets more important, we would analyze due to our information systems, if it may be a hazard to economic, ecologic and social functioning, or if it would promote biodiversity. On this basis and with help of our water balance models and biodiversity database, we should be able to analyze feedback cycles between fire, ecosystem function and vegetation change. If such an event occurs, we will be able to identify the exact influenced area by our colour infrared aerial photo interpretation. We could use these results as an input for repeated analyzes by our models and could thus refine the results.

b. Mass Movements and Avalanches

In the core zone of Biosphere Reserve and National Park, mass movements and avalanches are considered to be natural processes. In the national park plan we documented landslides rock gliding and rockfall in maps, based on a combination of land cover types, derived from CIR – photos (cf. Chap. 3), digital elevation model and geological map (cf. Fig.38 and 39).

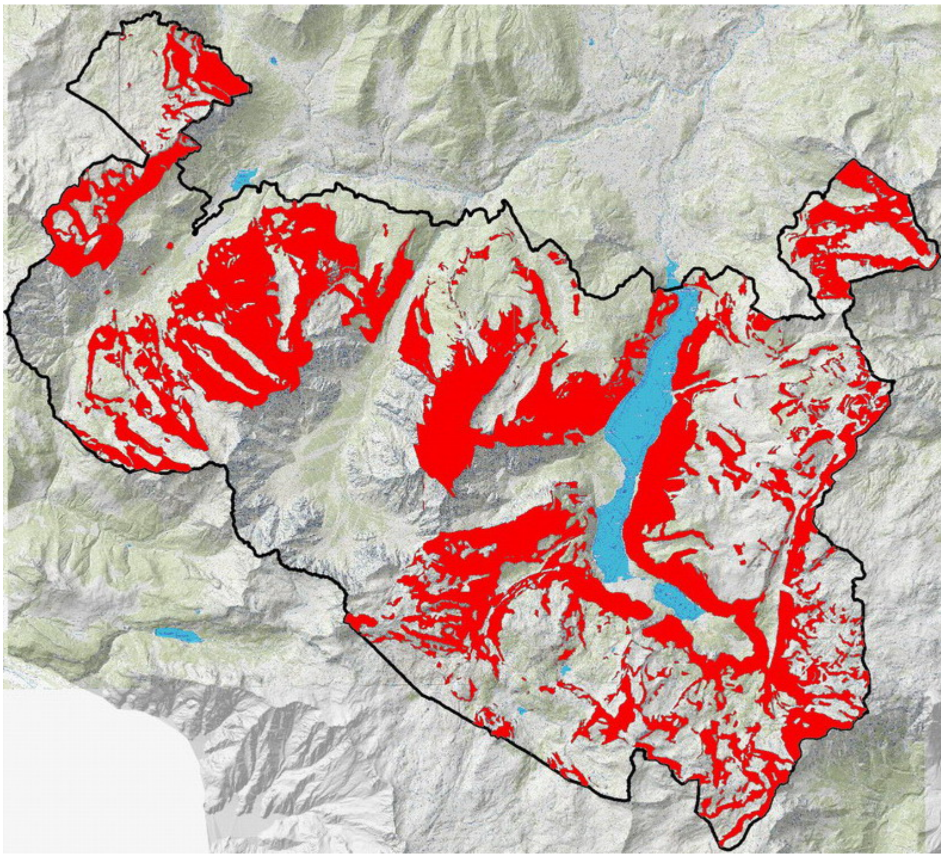


Figure 38: Potential areas of rock gliding (cf. StMLU 2001, Map 7)

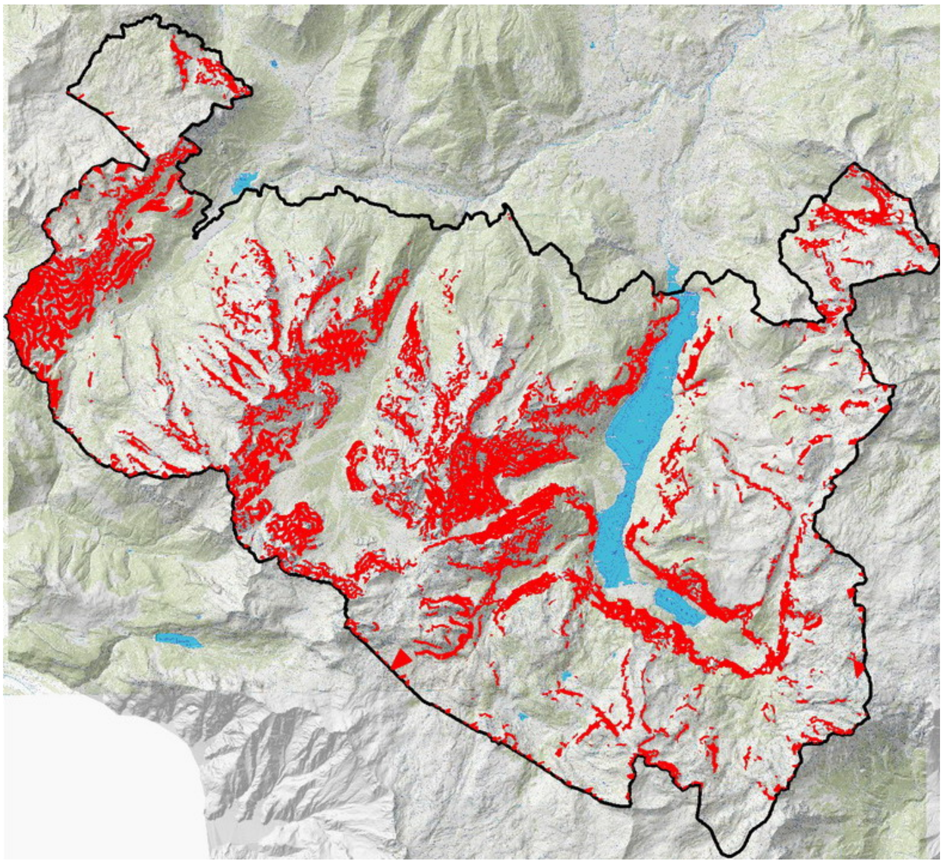


Figure 39: Potential areas of rockfall (cf.StMLU 2001, Map 8)

The ClimChAlp Interreg III B Alpine Space project, financed by European community, aimed at supporting the political decisions regarding protection and natural disasters prevention due to climate change in the Alps. In Workpackage 7 ‘Impacts of Climate Change on Spatial Development and Economy’ were analyze and worked out the interrelation of climate change on spatial development and economic key sectors for some example regions. One of these region was the county and new Biosphere Reserve Berchtesgadener Land (cf. CLIMCHALP 2008).

9. Health Determinants and Outcomes Afflicting Humans and Livestock

Insect may act as vectors for diseases, which are not yet in our region, but may be transferred by new insect species, which widen their coverage to north due to climate change. For this reason, the Friedrich Löffler Institut launched a project together with the. Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) in Müncheberg. This project will identify the Culicidae as vectors for viruses, which may cause new diseases in Germany. About 50 traps for biting mites are installed all over Germany. One of these traps is located in the National Park Berchtesgaden.

10. Mountain Economies

a. Employment and Income

The income of inhabitants in the former Biosphere Reserve depends mainly on tourism (JOB et al 2003). The income of inhabitants by agriculture and forestry is nearly 2 %. This is caused by the unfavourable topography. Tourism began in the end of the 19^{th} century. Nowadays, we can identify more than 2 million overnight stays with about 75 % in summer. Tourism generated by attraction of National Park, contributed ten yeas ago with about 4.6 Mio. € to touristic income. This is about 2.7 % of all touristic economy in the former Biosphere reserve or about 200 working spaces.

b. Forest Products, Mountain Pastures, Valuation of Ecosystems, Tourism and Recreation Economies

Forest products, mountain pastures, valuation, valuation of ecosystems and tourism and recreation economies focus on the transition zone. Principles and possible change has been reflected in the ClimCHAlp Project (CLIMCHALP 2008). Monitoring systems do not yet exists.

11. Society and Global Change

a. Governance Institutions

A transboundary alliance with the members „National Park Berchtesgaden“, „Biosphere Reserve Berchtesgadener Land“ and the Austrian „Nature Park Weißbach“ as well as transsectoral partners have been awarded by alpine convention as pilot region ‘Berchtesgaden – Salzburg’ promoting ecological connectivity. The protected areas are regarded as cornerstone of this alliance. This alliance realizes projects and develops and tests pilot projects and recommends procedures having regard to climate change, thus contributing to the conservation of alpine biodiversity (BELARDI et. al 2011, FÜREDER et. al 2011). By this way, National Park Berchtesgaden is more intensively integrated into the spatial – functional network of the surrounding area and institutions.

b. Rights and Access to Water Resources

Farmers proceed with transhumance since hundreds of year. They obtained a deep understanding of sustainable ecosystem services and thus contributed to high biodiversity within their pastures. However, in the last decade, especially in 2003 and 2006, there have been exceptionally dry summers and autumns in our region with some periods of water scarcity. After intensive discussions the National Park Authority ordered a hydrologic expertise, which should investigate the present water resources and possible future water resources influenced by climate change for one of the most beautiful alpine pastures, the Gotzenalm with six farmers and a mountain hut for visitors.

The expertise looked with scientific methods (cf. Chap. 4 + 5) for the status quo of the possibilities for water supply (cf. Fig. 40). In result, the present water supply is sufficient. But in future there may be a bottleneck in late summer and autumn. This depends on the kind of climate change scenario, that will come true. As we do not exactly know, what will happen, we must be flexible in the planning process to decide for the right measures (cf. Chap. 13 b.).

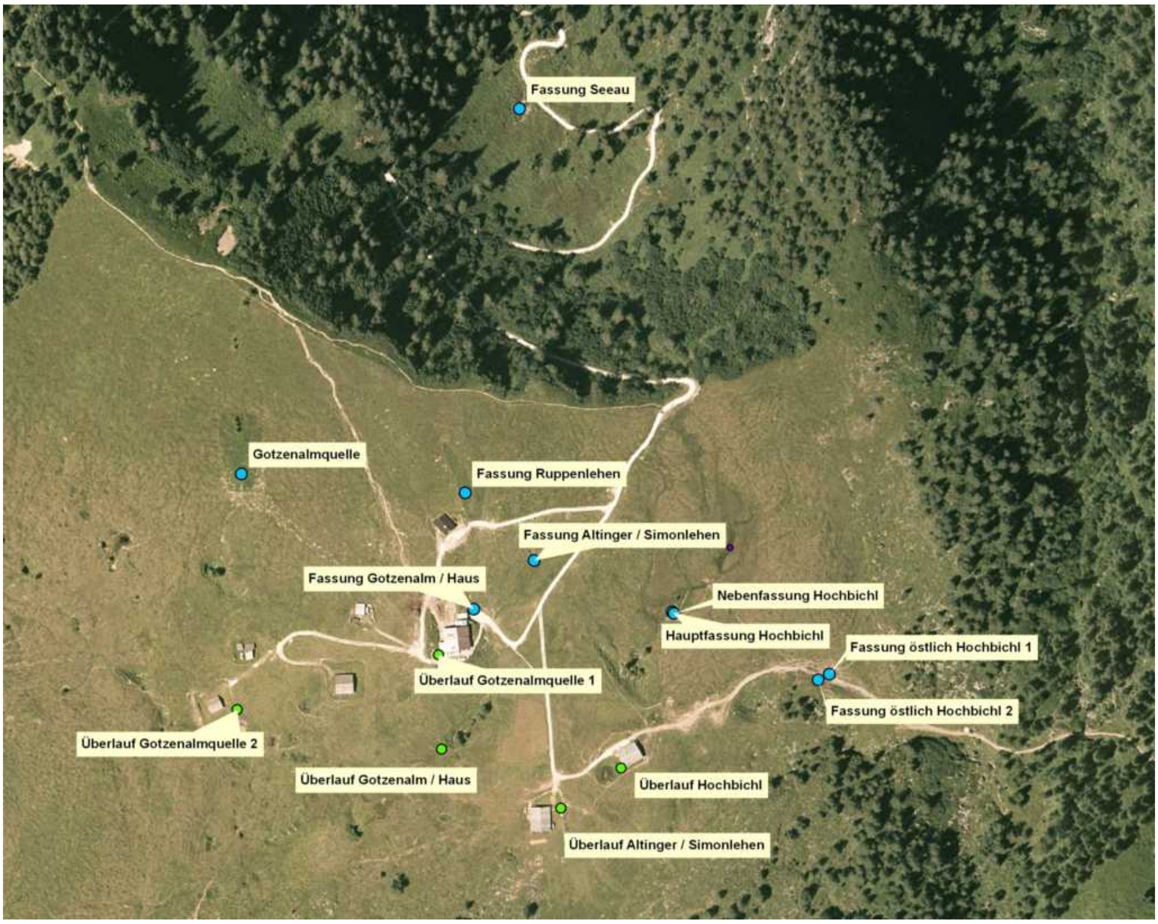


Figure 40: Springs and other possible water supply areas at the Gotzenalm

12 Documentation of Data, Methods and Measures in Information systems

Initiated and advanced by the MaB 6 Programme (see Chap. 1c) in the early 1980ies the geographic information system (GIS) has soon become the central instrument of spatial data management for the national park administration. Linked with a relational database the GIS has been serving since then as cross-sectoral source of information for multiple purposes in the field of research, monitoring and management. Results of project and administrative activities are permanently integrated into the database and in return made available to the users.

The long term maintenance implies certain challenges e.g. the adaptation of existing data models to changing demands or the transfer of existing applications to progressing software standards. However the integration of thematically highly diverse information systems into one common interdisciplinary data base means an essential valorisation of the data pool and is therefore of major concern.

Based on the expanding web technology data accessibility is possible for a growing circle of users. This means a spreading of information not only within national park staff but also within Bavarian Administrative Authorities and even among the general public.

13 Management plan and Climate change

a. History

The Berchtesgaden National Park was designated in 1978 by the Bavarian Ministry of Environment. This executive order demanded a framework plan, which should determine the regional objective for the development of the landscape. It should fix the borders of the periphery. A management plan was required for the area of the National Park. This task was realized on methods and data fundament created by the MaB 6 – project (cf. Chap. 1c) and put into force by the Bavarian Ministry for Environment (StMLU 2001). At this time, the borders of the transition zone of the former Biosphere Reserve Berchtesgadener Land were clearly defined.

The functions of the National Park were defined in this framework. Guiding principles and indicators were derived from these functions. Inventories of subjects of protection and nearly all human activities have been worked out on the basis of the Geographic Information System.

Human activities have been evaluated with regard to nature protection. On this basis, the zoning for the core and buffer zone of National Park and the transition zone of the Biosphere Reserve was determined. The concept for management measures was formulated on this base. The management plan shall be updated after ten years of work and evaluation.

b. Update of management plan

We could show in the Chap. 3 – 8 that climate change may have a strong impact on the dynamic of ecosystems and the change of biocoenosis. In most examples the status quo is known. But the future development of e.g. forest types, population dynamics and dispersion of bark beetle or the necessary measures for the buffer zone with regard to climate change are very uncertain.

We must take into account these long term impacts on natural balance and on human activities on the basis of today's state of the art. We must "draw up and implement management plans to adapt a changing climate based on a vulnerability analysis, taking into account the conservation and sustainable use of biological diversity and involving the local population (DUK 2011)". At least the instruments and data for this challenge are available for the former Biosphere Reserve and National Park Berchtesgaden.

c. Scenarios

The scenarios and the necessary efficiency control must be implemented into the management plan text. Future developments must be recognised in this connection. This may be linear developments as constant increase or decrease, this may be modifications in cyclic courses like course of the year or of the day, this may be alternatives in development, which branch off in different time schedules.

Spatial and temporal change is documented by applied National Park research.

Potentials and risks for the local and regional development and the included disturbance and stress potential are identified and evaluated by management sections.

Environmental education takes up this knowledge and passes it on to the relevant groups. “Intensify efforts to use biosphere reserves as learning sites for sustainable development, that communicate how biodiversity conservation sustains the flow of ecosystem services and supports the creation of economic opportunities. DUK 2011).” We have the chance to realize this part of the Dresden declaration.

14 Summary

In the Biosphere Reserve Berchtesgadener Land and National Park Berchtesgaden, ecosystem research and the underlying information systems were established 30 years ago in the framework of a MaB - Project. Later on, the management plan for the national park was built upon these results and data basis. In form of an open planning process with the stakeholders of the region, it was worked out and put into force in 2001. It formulated the duty to examine the impact of climate change on alpine biocoenosis. In the next decade, main emphasis was put on this question and the relevant biotic and abiotic conditions.

Monitoring land cover changes is the central instrument for identifying and distinguishing climate change and land use change effects. The climatic conditions were recorded by a network of weather and gauge stations. The cryosphere was interpreted by using an energy balance model. The analysis of the water balance especially combined with snow cover is not yet finished. We are looking forward to the results based on the IPCC – Scenarios for this important topic. The well known occurrence of vascular plants at specific sites was used to get an idea about generalizing habitat suitability models. Model results as well as the monitoring of bark beetle and springs deliver indications for possible climate change impacts. These methods should be widened to the extensive group of invertebrate species.

The income of local inhabitants depending on the existence of the national park, was estimated statistically. Ecological connectivity with the National Park as corner stone was analyzed in cooperation with adjacent partners.

On this well founded scientific basis, the impacts on human societies, cultural and biological diversity and ecosystem services can be better evaluated for the welfare and sustainable development of local population.

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