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Global Change “Climate Change Response of Sensitive Habitats and Landscapes in Austria”

Final Report

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1. Introduction

1.1. Climate change impacts on biodiversity: concepts and terms

Climate change was identified as major threat to biodiversity next to habitat change, invasive alien species, overexploitation and pollution (Millennium Ecosystem Assessment, 2005).

This concern among scientists is documented in a vast amount of literature on different aspects of climate change impacts on biodiversity. Here, only some examples are mentioned to show the broad range of studies: Evidence for changes in ecosystems related to climate have been documented for the high European Alps (Dullinger et al., 2004, Gottfried et al., 2011, Pauli et al., 2007), for the spreading of invasive species (Vogl et al., 2008), for threats on plant diversity in Europe (Pompe et al., 2008, Thuiller et al., 2005) or for important ecosystems services such as water availability and quality (Futter et al., 2009, Whitehead et al., 2009) and agricultural productivity (Olesen et al., 2007). A comprehensive review on ecological and evolutionary responses to recent climate change is given by Parmesan (2006).

At the same time as studies on effects of climate change accumulate, also reviews and critical comments on the use of the different methodological approaches became an important source for highlighting the strengths and the weaknesses of investigating this issue. Botkin et al. (2007) mentioned *“eight ways to improve biodiversity forecasting”* including definition problems, modeling approaches, questioning the current use of ecological principles and summarizes his recommendations by going for an integrated framework of species persistence models considering multiple causes of biodiversity change. At this point, we want to go into detail of a few of Botkin’s eight ways:

**“improve biodiversity forecasting”
(Botkin et al., 2007)**

- (i) “Select a specific definition of biodiversity”:

...“Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”...

(Secretariat of the Convention on Biological Diversity, 2006)

**Definition
Biodiversity**

This formal definition of the Convention’s text includes many different aspects of biodiversity also reflected in this broad range of studies mentioned before. Also Turnhout and Boonman-Berson (2011) stressed the point that referring to the totality of life on earth remains a blurry and broad definition not applicable as such to specific studies. This complex concept is becoming even more complex and quantitative as DNA analysis is added to the many organizational levels of biological diversity (Botkin et al., 2007).

- (ii) “Evaluate models before using them”:

biodiversity models

Many studies develop and implement statistical models for the evaluation of climate change impacts which is the most straightforward and best way. Still, the problems associated with such models are more and more an issue in the scientific debate and solutions for the weaknesses are topic of today's research (a.o. Bittner et al., 2011, Botkin et al., 2007, Ferrier and Guisan, 2006, Mokany and Ferrier, 2011). One of the issues addressed by Botkin et al. (2007) is the difficult validation of the models. These models address also different organizational levels of biodiversity.

In principle, there are two types of models used (Wiens et al., 2011):

- a) The species level: Species distribution models are used to project the future spatial distribution and range shifts of species under a certain scenario of climatic conditions.
- b) The community level: Addressing the rearrangement of habitats of given species or species groups is solved with habitat suitability models.

Niche theory

The general assumption of the models roots back to Hutchinson (1957) where he defined the theory of "ecological niche" – The set of specific biotic and abiotic conditions in which a species is able to persist and maintain stable populations. Thus this set of environmental conditions alone forecasts the distribution of a species or group of species.

Climate Space

Similarly, the combinations of acceptable climatic conditions where a species can occupy areas is called climate space, so spatial extent of particular climatic conditions will affect the geographic distribution of species occupying this niche space (Ohlemüller, 2011, Wiens et al., 2011). Ohlemüller (2011) also highlighted that climatic conditions change over time and these changes can be mapped. The shifts of the climate space needs to be traced in their spatial and temporal extent in order to help predicting biotic responses to such changes.

Bittner et al. (2011) emphasised two ways of modelling habitats by using niche-based assumptions: Either one can directly model the climate envelope of the habitat using the distribution data of the habitat itself, or indirectly by first modelling the habitat in terms of its plant species, and then model the climate envelope of these species in combination. Their main conclusion of the study was, that in principle the direct habitat approach resulted in better model performances.

All these models set the underlying assumption that species tend to retain their fundamental niche over time which is called niche conservatism (Wiens and Graham, 2005). They conclude that a new set of environmental conditions sets a barrier to dispersal and makes global climate change a danger to the world's biota.

species models

Guisan and Thuiller (2005) and Botkin et al. (2007) summarised a number of limitation to such niche-theory based models: (i) primarily correlative, these models use statistical relationships between the climatic conditions and the existence of species; and (ii) being in equilibrium with their environment, species become extinct

outside of the regions meeting their needs. On the other hand, there is evidence that species survived in small areas outside their geographic range which haven't met their apparent requirements. Also Ohlemüller (2011) stressed the point that adaptation and altered interactions between species will affect whether species remain limited to the conditions in which they currently occur or whether they can occupy new climate space. An organism may be able to exist in other climatic regimes, but its dispersal is limited or the current full range of climates may not encompass the full range of climates in which a taxon could potentially exist meaning we have a limited insight into the potential climatic significance of the taxon (Porch, 2011). Another aspect is the variety of ecological behaviour and plasticity in form and physiology because of environmental and local factors (Bunce et al., 2008) resulting in the fact that individual species will react differently to changes in their climatic conditions. Thus niche-theory models are likely to overestimate extinctions, even when they realistically suggest changes in ranges of many species.

Already Hutchinson (1957) made the important differentiation between the fundamental and the realised niche. The fundamental niche describes the abiotic conditions in which a species is able to persist, whereas the realised niche describes the conditions in which a species is preserved given the presence of other species (e.g., competitors and predators). So, even though the climate space would be adequate for a species, it cannot establish because of biotic interactions. If organisms react differently to changing climate conditions, also these interactions are likely to alter.

On the community level, the consequence will be eventually a transformed species composition and species turn-over (Bittner et al., 2011, Thuiller et al., 2005). Considering these aspects, Bittner et al. (2011) concluded that nevertheless a community-oriented approach is needed if one wants an answer to ecological and conservational questions.

habitat models

In this project, we follow this recommendation and choose an approach that works on the organisational level of habitats. As also Botkin et al. (2007) stressed, we seek for a specific definition to clarify from the beginning the level of biodiversity we were working with.

Mücher et al. (2009) stated that most of research done has been focusing on habitats as a whole are rarely considered. But the delineation of the habitat types in ecology is an own research topic as such and the term is used in rather different ways even though the definition from Article 1 of the Habitat Directive (92/43/EEC) launched by the Council of the European Community has become widely used in research:

**Definition
Habitat**

“natural habitats means terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural.”

The list of habitats, their definitions and their location is a grown construct within the European Community, often ambiguous and especially designed for valuable

habitats and the establishment of a network of conservation areas. Bunce et al. (2008, 2011) described in more detail the problems associated with the Annex I habitats concluding that for consistent monitoring of landscapes independently from the conservational value, another definition is needed.

Broader Habitat They introduced the so-called “Broader Habitats” where habitat is defined as: *“an element of the land surface that can be consistently defined spatially in the field in order to define the principal environments in which organisms live.”*

The aim of this strict definition is the elaboration of standard procedures to consistently monitor ecological changes in agricultural landscapes across Europe. The definition of standardised categories should enable the transfer of results among the studies and regions.

Plant life forms The basis of the categories was adopted from plant life forms as originally described by Raunkiaer (1934). Raunkiaer developed the idea that plant composition reflects climatic conditions and consequently could be used as a geographical instrument to describe plant adaptations to different climates. This adaptation concerns the location of the buds to survive the most unfavourable time of the year. Bloch-Peterson et al. (2006) described the principle in more detail:

...“plants can be divided into 30 life forms, gathered into five major life form groups ...; Phanerophytes (with surviving buds projecting freely into the air), Camaephytes (with surviving buds situated close to the ground), Hemicryptophytes (with surviving buds actually in the in the soil-surface), Cryptophytes (with surviving buds completely concealed in the ground or at the bottom of water) and Therophytes (completing their life-cycle within a season and remaining dormant as seed during the unfavourable time), the latter not having any wintering buds”...

The idea behind the broader habitats is now, that the changes in life form composition reveal the effects of climate changes and other environmental changes at very different scales, thus working as an indicator for global change, be it climate change or changes in land use. In addition, Bunce et al. (2011) work with the premise, that habitats are linked to species occurrence, thus giving a direct link between different biodiversity levels. This way, mapping and monitoring of life forms can register changes in plant conditions, but it will not register loss of single species or small changes in species composition. It has been demonstrated, that life-forms, functional plant types and other similar groupings of species are well-performing response units which detect any large-to medium scale ecological change (Morecroft et al., 2009).

The simplest way of relating thermal and moisture requirements for a large species assemblage is the derivation from the broad-scale relationships to environmental gradients (Porch, 2011). But acknowledging the fact, that the existence of most habitats in agricultural landscapes is also bound to human intervention than the climate (e.g., Botkin et al., 2011), we need an integrative measure of environmental

conditions on the local scale independently of the broad-scale climatic conditions to receive the local variation among the habitats.

The prevailing environmental conditions of habitats are commonly described using Ellenberg indicator values (Ellenberg et al., 2001). Ellenberg developed these values on the basis of field experience and ordered them on a scale of generally nine points. The idea behind is to provide a system which summarise complex environmental factors (e.g. groundwater level, soil moisture content, precipitation, humidity, etc.) into one formalised value. These figures are not intended to refer to conditions at a specific moment but should integrate the environmental settings over a period of time. Ellenberg stressed the point that the scale does not express the physiological preferences of the species but their ecological behaviour. With this widely-used Central European system it is possible to describe the ecological envelope according to Ellenberg's ecogram (Ellenberg, 1988) of broader habitats and conclude on their characteristics.

**Ellenberg
indicator values**

1.2. Climate change modelling

1.2.1. General characteristics of climate scenarios

Climate scenarios do not provide climate forecasts, according to the meaning of the word „scenario” standing for the description of potential situation in future. This has to be considered in particular for the interpretation and use of climate data from scenarios. Climate scenarios are influenced by assumptions and uncertainties.

The most relevant assumptions have to be made for future anthropogenic greenhouse gas emissions and land use changes. Societies are potentially free in the decision to reduce or increase greenhouse gas emissions and to set measures. However, the impacts of human activities on climate are dependent on real future emissions and not on declarations or intentions.

The IPCC provided in a special report different scenarios of anthropogenic greenhouse gas emissions and their impacts on average global temperatures (Nakicenovic et al., 2000). Storylines for four scenario families (A1, A2, B1, B2) with several individual scenarios were developed by the working group. All scenarios are based on different storylines considering population, economic and technological development, policies and social influences.

**Intergovernmen
tal Panel on
Climate Change
(IPCC)**

The lowest cumulative total carbon dioxide emissions are calculated for scenario B1 with an average of 983 GtC until the year 2100, the highest value is calculated for scenario A1F1 with an average of 2189 GtC. Until 2050 the differences of climate effects are not very large between all emission scenarios, due to the inertia of the climate system. However, after 2050 the differences are expected to increase significantly. Very often and also for this project the scenario A1B with a cumulated average of 1499 GtC is used as driver for climate models, simply because of pragmatic reasons to avoid extreme values.

**GtC: Giga-tons
carbon**

Climate simulations at two different scales are required to achieve regional climate scenarios.

**Global climate models (GCM)
Regional climate models (RCM)**

GCM provide climate scenarios on spatial resolutions of about 100 km – 300km horizontal grid spacing at mid-latitudes. Examples of GCM models are the HadCM3, developed at the Hadley Center in Exeter, or the ECHAM5, developed at the Max Planck Institute for Meteorology in Hamburg. Climate processes on smaller spatial scales cannot be resolved directly and have therefore to be transformed by parameterized RCM. All procedures are accompanied by uncertainties, for example natural uncertainties, model or downscaling uncertainties, increasing with the time horizon of the scenario (Heinrich and Gobiet, 2011). Hence, results of downscaled climate scenarios are also influenced by the characteristics of the models applied. The combination of the GCM HadCM3 together with the AIT-CCLM with a spatial resolution of 10 km grids - applied in this project - provides larger temperature change signals than other combinations for the time periods December – August. Precipitation is at the lower bound for the time periods June – August and at the upper bound for autumn (September – November). Differences between results of different model combinations were also identified in scenario comparisons (Groppelli et al., 2011).

Because climate scenarios are not weather predictions it is necessary to interpret data according to the uncertainties at different temporal or spatial scales, and the parameter properties. Temperature, a parameter with relatively low uncertainties, can for example be analyzed on seasonal changes or probabilities of high or low temperature periods. However, it is beyond the scope of the scenarios to ask for temperatures of a particular day or a small local site. Much more restricted are the possibilities for the identification of detailed precipitation data. The restrictions are partly caused by necessarily reduced representations of the complex hydrological processes in the models and partly by nonlinear interactions between regional terrestrial conditions and atmospheric processes. Consequently it is a big challenge to extract appropriate information from a bulk of data, provided by complex and skillful number crunching.

While the discussion about strength and weakness of climate scenario model increases the challenges for the interpretation of effects out of scenario data are not well considered. Following example will be used to discuss these aspects in the context of climate change and ecological effects.

The simulation of changes of the duration of vegetation periods between the time periods 1971/2000 and 2071/2100 provides a first impression about spatial differences of climate change effects (Figure 1). For this simulation the starting and end dates of the vegetation periods were selected by a moving window approach, searching for seven consecutive days with daily means above +5° C.

vegetation
period
1971/2000 and
2071/2100

Figure 1 : Simulated increases of the duration of vegetations periods between the climate periods 1971/2000 and 2071/2100 in days.

The overview over a large area provides an impetus for the consideration of uncertainties for transformations from simulation results to local effects, influenced by geomorphology. In areas with low geomorphic dynamic the simulation results can be used for the transformation within the square grids. Much more complicated is the situation in mountain areas with high geomorphic dynamic. Elevations can differ up to thousand meters within one grid cell; insolation is strongly dependent on the slope and exposition of the individual site. Useful interpretation of climate data have to consider in particular the impacts of snow cover on vegetation (Gottfried et al., 2011; Hantel and Maurer, 2011).

Hence, elongation of vegetation periods can have different means within one grid cell. Additional extensions of vegetation periods in flat lowland areas provide new opportunities for invasive species from southern regions. Such opportunities are in particular beneficial for short-day annual species able to grow during November and December. The dominant factor for vegetation change in mountain regions are temperature changes, under assumption of comparable precipitation conditions. Day length will be not a selective factor, due to relative actual vegetation periods and potential extensions of day length with increasing elevation. However,

heterogeneous topographic conditions will cause specific local pattern of climate change effects in the vegetation (Gottfried et al., 2011).

1.2.1. Climate scenarios for the selected landscapes

Data of the climate scenarios are based on the methodical developments within the joint project reclip:century (Loibl et al., 2011).

IPCC emission scenario A1B

The climate calculations are driven by the IPCC emission scenario A1B (Nakicenovic et al., 2000).

More details about the model characteristics can be found on http://cera-www.dkrz.de/IPC_DDC/IS92a/HadleyCM3/hadcm3.html.

Large scale climate scenarios were provided by the HadCM3, coupled atmosphere global climate model with a horizontal resolution of 2.5 degrees of latitude and 3.75 degrees of longitude with metric grid dimensions of about 250 km at 48 degrees of latitude. The radiative effects of greenhouse gases are explicitly represented; the aerosol background concentration is simply parameterized.

Downscaling to the 10 km grid was carried out with the Cosmo-Climate Local Model (CCLM) of the German Weather Service. It is a non-hydrostatic regional climate model with the multilayer soil model TERRA_LM (Schrodin and Heise, 2001).

Further details are available on <http://clm-community.eu>

Uncertainties of downscaling models were estimated by leave-one-out cross validation for the greater alpine region under consideration of sub regions (Heinrich and Gobiet, 2011). The relative bias in percent varies to some extent between individual months for 2-m air temperature and precipitation. However, the relative bias for precipitation with values between 10 to 32% is much larger for precipitation than for air temperature with values between 1 to 3.6%. The total variances are dominantly caused by the characteristics of the GCM, due to variance decompositions. The knowledge of the uncertainties is important for interpretation of scenario results, because it is not possible to eliminate uncertainties in model runs due to the unavailability of measured calibration data. Hence, temperature and precipitation values of scenario calculations were used without further modifications. Potential evapotranspiration was calculated with the Penman-Monteith formula (Allen et al., 1998) for estimation of water balances of the selected sites.

For further analyses it was necessary to match data from climate scenarios with survey data from local sites. Climate scenario data are provided for geo-referenced squares of 10 x 10 km; vegetation data for one point, defined by coordinates. Squares were referenced to site points if the coordinates were within the boundaries. This reference list provided the basis for further analyses of both data sets. In mountain areas the elevations of survey sites and of the reference level of climate scenario calculations were considered additionally for temperature analyses.

The temporal resolution of climate scenario calculations is 90 seconds, so it is possible to provide hourly data for analyses of extreme or average values. However,

it makes no sense to use this temporal resolution for analyses of potential effects of climate changes, due to the already mentioned uncertainties. Hence, time periods of ten years were used to calculate annual climate characteristics with a temporal resolution of one month. Moving temporal windows of particular length were used additionally for analyses for special analyses, e.g. frost or heat periods.

1.3. Review and metadata documentation of available databases containing consistent information about the interlinkages between landscapes, (local) ecosystems and habitats

During the last years, various projects conducted within the Dept. of Conservation Biology, Landscape Ecology and Vegetation Ecology were designed to gather consistent information on biodiversity aspects in agricultural landscapes of Austria.

Box 1 should give a short overview of selected projects and to which extent biodiversity issues were raised.

1.4. Aim of the present project

The outlined project presents an approach that couples modelled high-resolution climate data with expert knowledge about the sensitivity of semi-natural and cultivated habitats in representative Austrian agricultural landscapes. By doing so, it will be possible to assess the potential impact of changing temperature and precipitation patterns on regional biodiversity.

**Project's
objectives**

Five major objectives are addressed:

1. Selection of representative landscape samples mainly based on the results of SINUS and related projects;
2. Extraction of information on relevant “broader habitats” (Bunce et al., 2008) and consistent description of their ecological niches with special emphasis on sensitivity to climate change;
3. Climate change signal detection: extraction and comparison of local climate characteristics for the landscape samples (e.g., yearly variation and range of certain indicators out of climate model results of current climate and future climate (Loibl et al., 2007));
4. Establishing the relation of the ecological niches of broader habitats with the value ranges of current and future climate considering different yearly weather conditions;
5. Assessment of the impact of modelled climate change on broader habitats and evaluation of related risks to local and regional biodiversity

Box 1: Selected projects covering different aspects of biodiversity where results are useful for the present work.

Spatial Indices for LandUse Sustainability (SINUS) was implemented within the frame of the Austrian landscape research programme (KLF) and designed to develop reliable and operational indicators of practical use for long term monitoring and assessment of land use sustainability in Austrian cultural landscapes. Enabling objective measurements of the ecological performance of land use should result in practical guidelines for the future development of Austrian landscapes. The research project aimed at the identification and examination of the relationship between landscape structure and processes in the landscape. To achieve this result, 120 sample plots were mapped and attributes of landscape structure, the hemerobiotic state, trophic level, plant species richness, origin type and dynamic were recorded for every single landscape element. It could be clearly shown, that the structure of the landscape reflects its relative sustainability depending on the type of agricultural landscape. With increasing land use intensity, measured by the concept of hemerobiotic state, the landscape complexity decreases.

Bioindikatoren nachhaltiger Nutzung österreichischer Kulturlandschaften (BINKL) was also carried out in the frame of KLF. In selected agricultural landscape types, birds, mosses and vascular plants were recorded in 40 sample sites in order to extract character species on the one hand for the different landscape types and on the other hand for areas of different hemerobiotic state. In principle, the results reflected the European trend of intensification and loss of landscape elements.

The project „*Pilot study - Comparative biodiversity investigations in selected areas for the evaluation of the efficiency of measures according to ÖPUL 2000*“ aimed to analyse the measures within the Austrian agro-environmental program (ÖPUL) in respect to their effect on biodiversity and landscape. The objectives were twofold: to develop and test a methodology for analysing these effects, and apply those methods to evaluate the agro-environmental measures in selected areas. In 10 study sites, Vascular plants, birds and bryophytes were used as biodiversity indicators, parameters for landscape richness as indicators for the landscape and habitat level. The Austrian IACS-database could be employed to identify the agreements of the parcels in question. This allowed to detect landscape and species changes and to correlate these changes with the presence of certain agro-environmental measures. Measures with high potential of biodiversity enhancement cover much less area than measures more generally oriented towards environmentally friendly production with an only weak effect on biodiversity.

2. Material and Methods

2.1. Preparatory work

2.1.1. Selection of sample landscapes

data on habitat and vegetation

Data on habitat and vegetation were taken from databases for Austria, derived from ecological research projects during the years 1997 to 2004 (Peterseil et al., 2004). In principle, land use data were available for 167 squares (Figure 2), but vegetation relevés only partly obtainable. For the present study, 20 landscape samples with 1 km² area were selected in Upper-Austria, a province in the North of Austria and six samples in Vorarlberg, the westernmost province of Austria (Figure 3).

Figure 2: Location of 167 landsape samples as provided by former projects (Box 1).

regional environmental characteristics

In general, the region in Upper-Austria is dominated by continental climate with a mean total precipitation ranging between 800 to 1500 mm per year. Geologically, these samples are located in the Bohemian uplands (dominated by granite and gneiss) and the Molasse zone (loamy and gravel sediments), providing the bedrock for brown soils, pseudogleys and semipodsols. The geomorphological features are dominated by soft hills with an altitudinal range between 350 and 880m a.s.l. The selection of representative landscape samples was performed based on the map of Wrbka et al. (2002), where main cultural landscape types have been delineated for Austria. Low mountain ranges, dominated by either forests or grasslands, are prominent within the northern landscape samples whereas the southern ones comprise more differentiated agricultural uses such as grasslands, crop- and fodder-production.

Cultural landscapes types

- [102] Seminatural and natural grassland of alpine highlands
- ★ [103] Sub-alpine intensive pasture land
- + [201] Forested mountain slopes
- ◆ [205] forest dominated secondary mountain ranges
- [308] grassland dominated extra-alpine uplands
- ▲ [402] extra-alpine downlands; mixed agriculture, foddercrop production
- ◆ [404] extra-alpine basins and valley bottoms dominated by crop land

Figure 3: Landscape types (Wrbka et al., 2002) of 26 landscape samples located in the biogeographical regions of Upper-Austria and Vorarlberg. Forest and grassland use is dominating the northern landscape samples whereas crop- and fodder production are the main agricultural activities in the southern samples; alpine landscape types are prevalent in Vorarlberg, the westernmost landscape samples.

In Vorarlberg, the selected landscape samples belong to the cultural landscape types of natural grassland and extensive pastures of alpine and subalpine high altitude areas, intensive pastures of alpine and subalpine high altitude areas as well as to forest-dominated valley-slopes of the Alps. Central and Western Northern Alps together with Central Eastern Alps provide the geological frame of the samples. On about 130 days, a yearly precipitation of more than 2000 mm accumulates, thus being one the wettest region in Austria. The average temperatures of January range from -10°C to -5°C and -6°C to -2°C depending on the exact location of the individual samples. In July, average temperatures vary from 5°C to 10°C, 10°C to 15°C and 15°C to 17°C. This wide variety of geological and climatic conditions is also reflected in the soil types: brown soil top on moraine, sandstone or gravel, brown loam over marl, rendsina topping marl or limestone, gleyish brown soil, marl and slate.

2.1.2. Climate scenario data

Basically, climate data for the landscape samples were extracted from regional climate simulations carried out by the ‘reclip:more’ project for the entire Alpine area (Loibl et al., 2007, 2009). For conducting RCMs, input data from global climate models are essential.

reclip:more:
<http://foresight.ait.ac.at/SE/projects/reclip/>

For the reclip:more simulations, data from the GCM ECHAM5, a model simulating global climate down to 100 x 100 km grid spacing has been applied (c.f. Roeckner et al., 2003). Here the GCM HadCM3 results, based on the A1B greenhouse gas (GHG) concentration increase scenario were applied. The climate modelling literature proves that differences between GCM model results are mainly determined by

ECHAM5
<http://www.mpi-met.mpg.de/en/science/models/echam/echam5.html>

differences in GHG concentration in the atmosphere releasing temperature increase, surface temperature increase and various other impacts (c.f. IPCC, 2001a).

IPCC: A1B scenario
<http://www.ipcc.ch/>

The A1B scenario was one of the common GHG scenarios, referred as "business-as-usual" scenario, assuming a plausible course for global energy consumption related to certain activities, technologies, fuel compositions and finally greenhouse gas emissions into the atmosphere. Until recently, the A1B scenario had been in wide use by the climate modelling community and thus GCM results based on this GHG reference scenario were selected as RCM input to simulate climate with a higher spatial resolution, as the 250 x 250 grid spacing provides too coarse results for climate change impact analysis at regional scale.

CCLM
<http://www.comso-model.org>

The here applied RCM data were conducted with the Cosmo-Climate Local Model (CCLM) - a limited-area, non-hydrostatic, terrain-following model, designed to simulate atmospheric circulation for regional scale in a certain area, integrating the global climate simulations (Rockel et al., 2008). To integrate the GCM results into RCMs, these models copy the GCM's atmospheric conditions (in our case every 6 hours) along the boundary of the RCM' simulation domain and model the atmospheric processes and states within the defined domain for the smaller RCM grid-cells (in our case 10 x 10 km) in small time steps (in our case 90 seconds) to consider the atmospheric dynamics between the grid cells. Hourly data are stored as results to extract further indicators for longer time periods (e.g. monthly means) for various climate-related research questions.

**1981-1990
2041-2050**

Two time ranges had been simulated: the decade between 1981 and 1990 was selected as a climatically stable period to provide current climate reference data and the decade between 2041 and 2050 was selected to simulate the future climate. The simulation results which were used for the current habitat impact analysis are hourly temperature maxima, minima and averages as well as precipitation sums for the two decades, which were averaged to monthly means. Additional indicators for particular elevation ranges within the 10 x 10 km raster cells were further estimated using a 1 x 1 km digital elevation model and an elevation-related temperature gradient. The potential evapotranspiration was calculated for estimations of the water balances of the landscape samples applying the Penman-Monteith method (Allen et al., 1998).

Climate cluster

Based on mean total temperature and precipitation values per month, the landscape samples were clustered in SPSS 13.0 using the linkage between groups method (Backhaus et al., 2006). Clusters were calculated on data of the time period 1981-1990 to achieve groups of landscape samples for comparisons between prevailing climate conditions during landscape survey periods and Ellenberg values. A minimum rescaled Euclidian distance of 10 was used to achieve clusters comprising at least three sample sites. Cluster calculation over the whole year provided similar results as cluster calculations over the vegetation period. Additional cluster calculations with data from mountain areas with higher variability of climate conditions provided no sufficient results. The main reason for that effect was the spatial density of landscape samples. The spatial density of the landscape samples in

the data set provided climatic singularities in regions with high spatial climate variability. However, it was sufficient for investigations in areas with lower climate variability like in the selected region of Upper Austria.

2.1.3. Transformation and re-aggregation of vegetation data to the “broader habitat” level, according to the BioHab-method

Basically relying on life forms, the term General Habitat Category (GHC) was introduced by Bunce et al. (2008) also to include the non-life forms such as crops, categories on bare ground and sparsely vegetated land. In all there are about a 140 GHCs, comprising also combinations of maximum two life form/non-life form habitats.

Data on habitat and vegetation
GHC: General Habitat Category

In the FP7 project EBONE, a detailed manual was developed for consistent definitions, explanations on the surveillance of field data and monitoring procedures of the GHCs. The manual also explains how the core procedure of recording GHCs can be updated by different modules like qualifiers on management, abiotic conditions and plant species lists.

<http://www.ebone.wur.nl/UK/>

The manual describes the process of determining GHCs on p.27 (Box 1):

...“Determination of the GHC is based upon a sequence of five dichotomous divisions ... related to a set of six super-categories, (Urban, Cultivated, Sparsely Vegetated, Tree and Shrubs, Herbaceous wetland and other Herbaceous) which determine the series of LFs and NLFs and that are used to identify the appropriate GHC.

LF: life form
NLF: non-life form

The cover of the surface of a given habitat is estimated from a vertical perspective. It is therefore cover of the land surface of LFs and NLFs and combinations as seen from above, not that which is beneath a given canopy, except for forest canopies overlapping roads, tracks or rivers over 5 wide. ...

The GHCs are formed of individual LFs or NLFs and all possible combinations within each of the super category. No other combinations are possible i.e. there is a maximum number of 140 GHCs.”...

Within each super category, a further breakdown of habitats is performed. The complete list of GHCs is given in Annex A.

Box 2: Decision tree for super categories adapted from Bunce et al. (2011) as basis for the detail recording of General Habitat Categories; URB = urban, CUL = cultivated, SPV = sparsely vegetated, TRS = trees and shrubs, HER = herbaceous, HEL = helophytes, SHY = Submerged hydrophytes, EHY = Emergent hydrophytes.

Is the element urban or constructed?	> URB
Is the element a crop?	> CUL
Is the element over 70% natural bare surface (including water)?	> SPV
Is the element with more than 30% of the vegetation cover of trees and shrubs?	> TRS
Is the element with more than 30% of the vegetation cover of wetland herbaceous plants?	> HER-HEL > HER-SHY > HER-EHY
Is the element with over 70% of the vegetation cover of non-wetland herbaceous plants?	> other HER

The SINUS and BINKL projects, funded within the Austrian landscape research programme (KLF), yielded in consistent information on land use types, which was collected and stored in databases. As the objects of the existing SINUS and BINKL geodatabase are describing so-called landscape elements by means of landscape ecological attributes like land-use, disturbance, naturalness and the like, they do not fully fit into the profile of a broader habitat description. Therefore a re-aggregation of objects into broader habitat categories was necessary and achieved by straight forward databank management. Thus, each landscape element in the selected samples was assigned according to the GHCs of broader habitats by translating land use types into this system (Table 1). Figure 4 exemplifies one sample square in Upper-Austria “Extra-alpine basins and valley bottoms dominated by crop land”. On the one hand, the originally recorded land use types are visible showing a wide range of different crop types whereas on the other hand, the landscape sample is simplified in its diversity due to the aggregation of a few land use types into one GHC. As the refinement of the spatial resolution of the climate data is not feasible on the landscape element scale, this simplification seems not to hinder the analysis. This aggregation even has the advantage of pooling data and creating larger sample sizes.

Table 1: Nutztypen used in the national projects, their translation of the land use type categories into English and their assignment to GHCs.

Nutztyp	Land use type	GHC	
Acker Hackfrucht extensiv	root crop extensive	CUL/CRO	cultivated / crops
Acker Hackfrucht intensiv	root crop intensive	CUL/CRO	
Acker Hackfrucht mäßig int.	root crop medium intensive	CUL/CRO	
Acker mit Feldfutteranbau	forage crops	CUL/CRO	
Getreideacker extensiv	corn fields extensive	CUL/CRO	
Getreideacker intensiv	corn fields intensive	CUL/CRO	
Getreideacker mäßig intensiv	corn fields medium intensive	CUL/CRO	
Baumwiese alt	orchard old	CUL/WOC	cultivated / woody crops
Baumwiese jung	orchard young	CUL/WOC	
Gehölzplantagen	wood plantations	CUL/WOC	
Weingarten extensiv	vineyard extensive	CUL/WOC	
Weingarten intensiv	vineyard intensive	CUL/WOC	
Weingarten mäßig intensiv	vineyard medium intensive	CUL/WOC	
nicht beschriebener Wald	forest (in general)	FPH	forest phanero- phytes
Wald Forst alt	timber plantation old	FPH	
Wald Forst jung	timber plantation young	FPH	
Wald mäßig naturnah	seminatural forest	FPH	
Wald naturnah	natural forest	FPH	
Allee alt	avenue with old trees	FPH/DEC	forest phanero- phytes / deciduous
Allee jung	avenue with young trees	FPH/DEC	
Baumweiden alt	pasture with old trees	FPH/DEC	
Baumweiden jung	pasture with young trees	FPH/DEC	
Einzelbaum alt	old solitary tree	FPH/DEC	
Einzelbaum jung	young solitary tree	FPH/DEC	
Feldgehölz	small woodlot	FPH/DEC	
Hecke Baum	hedgerow of trees	FPH/DEC	herbaceous / caespitose hemicryp- tophytes
Hecke Strauch	hedgerow of shrubs	FPH/DEC	
Sonderbiotope natürlich	special biotope - natural	HER/CHE	
Weide extensiv	pasture extensive	HER/CHE	
Weide intensiv	pasture intensive	HER/CHE	
Weide mäßig intensiv	pasture medium intensive	HER/CHE	
Wiese extensiv	meadow extensive	HER/CHE	
Wiese intensiv	meadow intensive	HER/CHE	herbaceous / leafy hemicryp- tophytes
Wiese mäßig intensiv	meadow medium intensive	HER/CHE	
Brache jung	young fallow land	HER/LHE	
Brache mit Staudenflur	old fallow land with tall herbs	HER/LHE	
Feldraine	field margin	HER/LHE	
Fließgewässer mäßig naturnah	stream seminatural	SPV/AQU	
Fließgewässer naturnah	stream natural	SPV/AQU	sparsely vegetated / aquatic
Fließgewässer verbaut	stream artificial	SPV/AQU	
periodisches Fließgewässer natürlich	periodic stream natural	SPV/AQU	
periodisches Stillgew. natürlich	periodic lake natural	SPV/AQU	
Stillgewässer natürlich	lake natural	SPV/AQU	
Stillgewässer naturnah	lake seminatural	SPV/AQU	
Brache mit Gehölzflur	old fallow land with shrubs	TPH/DEC	tall phanero-

			phytes / deciduous urban / artificial
Blockrand- bzw. Zeilenverbauung aufgelockert	blocks and rows of houses loosened	URB/ART	
Blockrand- bzw. Zeilenverbauung verdichtet	blocks and rows of houses	URB/ART	
Dorfkern	village square	URB/ART	
Dorfkern aufgelockert	village square loosened	URB/ART	
Dorfkern verdichtet	village square compacted	URB/ART	
Dorfrand verdichtet	suburb compacted	URB/ART	
Einzelgehöfte und Kleinweiler verdichtet	detached houses paved	URB/ART	
Einzelhausbebauung	detached houses	URB/ART	
flächige Kleinarchitektur	built up element	URB/ART	
Industrie- und Gewerbegebiet aufgelockert	industrial sites loosened	URB/ART	
Industrie- und Gewerbegebiet verdichtet	industrial sites paved	URB/ART	
Lineare Kleinarchitektur	built up element (linear)	URB/ART	
Materialdeponieen	Deposition, land fill	URB/ART	
punktförm.Kleinarchitektur	built up element (point)	URB/ART	
Siedlung versiegelt	settlements paved	URB/ART	
Sonderbiotope künstlich	special biotop - artificial	URB/ART	
verdichtete Einzelhausbebauung	detached houses compacted	URB/ART	
versiegelte Sonderflächen	other paved areas	URB/ART	
Dorfrand	suburb	URB/GRA	urban /
Dorfrand aufgelockert	suburb loosened	URB/GRA	herbaceous
durchgrünte Einzelhausbebauung	detached houses loosened	URB/GRA	
Einzelgehöfte und Kleinweiler	estates and hamlets	URB/GRA	
Einzelgehöfte und Kleinweiler aufgelockert	estates and hamlets loosened	URB/GRA	
Siedlung grün	settlements (with gardens)	URB/GRA	
periodisches Fließgewässer künstlich	periodic stream artificial	URB/NON	urban /
periodisches Stillgew. künstlich	periodic lake artificial	URB/NON	non- vegetated
Stillgewässer künstlich	lake artificial	URB/NON	
Verkehrsweg versiegelt	paved roads	URB/NON	
Verkehrsweg wassergebunden	dirt roads	URB/NON	
Parks und Gärten	Gardens and parks	URB/VEG	urban /
Verkehrswege begrünt	roads vegetated	URB/VEG	vegetated

Vegetation relevés are randomly distributed among the landscape samples. But for nearly each broader habitat type, species data are available, all in all there were 683 species recorded (Annex B). The distribution of the sample sizes among the different GHCs showed a rather large variation (Annex C). Therefore we excluded sample sizes with $n < 5$ from further analysis. All data are stored in ArcGIS 9.2 Geodatabase (ESRI, Inc., Redlands, CA).

Figure 4: landscape sample in Upper-Austria; on top, the map shows the originally recorded categories of land use types; on the bottom, after the assignment of the GHCs. Abbreviations of the GHCs see Table 1.

2.2. Statistical analysis of climate driven transitions between broader habitat categories

2.2.1. Regression analysis

Spatial data exploration was performed with ArcGIS 9.2 (ESRI, Inc., Redlands, CA), statistical analysis was conducted with R 2.7.1 (R Development Core Team, 2008). The Ellenberg indicator values (Table 2) were taken from Ellenberg et al. (2001).

Indicator values are also provided for Austria; <http://statedv.boku.ac.at/zeigerwarte/> (in German)

Ellenberg conceived these values as ‘quasimetric’ in order to allow averaging. Means of Ellenberg’s T (temperature; ranging from 1 to 9) and W values (water availability; ranging from 1 to 12) were calculated per (1) landscape sample and (2) for GHC and landscape sample. Linear regression analysis was performed with all mean values versus climatic variables: T values versus “mean annual temperature” and “mean temperature April – September” as well as W values versus “annual water balance”, “water balance January – September”, “annual precipitation”, “precipitation January – September” and “precipitation April – September”.

Table 2: Ellenberg values ranges for temperature and water availability and their ecological meaning.

T	Temperature value	W	water availability value
1	very cold, only in very high altitudes	1	very dry
2	between 1 and 3	2	between 1 and 3
3	cold, mainly subalpine regions	3	dry
4	between 3 and 5 (mountainous regions)	4	between 3 and 5
5	temperate (low to mountainous regions)	5	mainly on medium moist soils
6	between 5 and 7	6	between 5 and 7
7	warm	7	mainly on moist but not wet soils
8	between 7 and 9	8	between 7 and 9
9	extremely warm	9	wet, often oxygen-poor soils
		10	periodically wet,
		11	hydrophytes on water surface
		12	submerged plants

2.3. Construction of “ecogrammes” for all relevant broader habitat categories

Based on the vegetation data, the species-associated Ellenberg values were taken to describe an ecological envelope – a so-called ecogram (Ellenberg, 1988). Ellenberg originally wanted to describe the main driving factors for the most important tree species covering Central Europe. He argued that soil is the main responsible within a climatically homogenous region. Therefore he applied a ‘coordinate system’ of soil reaction and soil humidity and marked the area where individual tree species can be found. In a further application, not only species but also plant associations can be visualised.

schematic visualisation of the original Ellenberg ecogramm

In our approach, we adapted the original concept to climate parameters in order to look for the occupied area of the broader habitat in view of temperature and humidity. For each habitat in each landscape cluster, ecological envelopes were therefore produced with the focus on Ellenberg values T and W. The percentage of each Ellenberg T and W value was calculated and displayed, giving indication for the

prevailing ecological factors of the individual habitats. Pooling of the habitat data from the landscape samples on climate cluster raised on the one hand sample sizes and enhanced on the other hand the robustness of the ecograms for the regressions.

2.4. Sensitivity

In order to assess how likely climate change is going to affect the ecological envelope of the broader habitats, we developed a sensitivity index inspired by the method of the saprobic index (e.g., Rolauffs et al., 2004).

Sensitivity: “is the degree to which a species is affected either adversely or beneficially, by climate change.” (IPCCb, 2001)

Reflecting the width of the ecological envelope, we counted the inverse number of Ellenberg T and W values per GHC and climate cluster, e. g. in a specific habitat, Ellenberg values ‘3’, ‘4’, ‘5’, ‘6’ are present, so the resulting value is $1/4 = 0.25$. Additionally, we calculated the ratio of number of present plants with Ellenberg values (1 to 9) and the number of plants without Ellenberg indication (0). Finally, adding these two ratios, we get an index for the sensitivity of a certain habitat in one cluster.

saprobic index: “Indication or measure of the level of organic pollution”. (ALLa); Terminology source: <http://www.eionet.europa.eu>

2.5. Plant life-history strategies according to Grime

The list of environmental factors which are responsible for the existence and occurrence is long and manifold containing aspects on disturbance, temperature, humidity, nutrient supply and many more. In this respect, it is important to notice if one of these factors gets into the extremes of its range, stress is put onto plant life. Then, organisms are forced to develop strategies in order to handle these stress factors.

Grime (2001) defined plant strategies as a

plant strategies

„...grouping of similar or analogous genetic characteristics, which recur widely among species or populations and cause them to exhibit similarities in ecology...”

These genetic similarities among species or populations also result in resemblances in their ecological behaviour. This leads further to the conclusion that species with comparable life strategies cluster at that scale on which ecological situation is uniform (Lavorel et al., 1997, Massant et al., 2009).

Grime’s triangular classification of plant life-history strategies (Grime 1977, 1979) is therefore based on the intensity of stress and also disturbance (Figure 3). He made a difference between a **competitive strategy (C)** with low disturbance and sufficient resources, **stress tolerant strategy (S)** when resources are rare and conditions extreme (be it minimum or maximum), and **ruderal strategy (R)** where disturbance is common, resources abundant and conditions not in the

triangle of primary plant strategies

extremes. Furthermore, there are intermediate strategies in all possible combinations.

Figure 5: triangle of primary strategies; C=competitive, S=stress-tolerant, R=ruderals and intermediate types with relative relevance of competition (I_c), stress (I_s) and disturbance (I_d) (adapted from Grime et al., 1988).

Competitors are in general long-living species, as well as the stress tolerators. The latter also show very low production and reproduction rates. Ruderals are ephemeral species with high growth rate and reproduction rate. These strategies will play an important role in the reaction of species to changing environmental conditions. Our interest within the present project also focuses on the distribution of the strategy types in the broader habitats.

<http://www2.ufz.de/biolflor/index.jsp>

For this, we assigned each plant species in our landscape samples to one specific strategy type using the database BIOLFLOR (Klotz et al., 2002). In this database, >3600 plant species with more than 60 traits are stored and is maintained by the Department of Community Ecology (UFZ – Centre of Environmental Research) and continuously updated. An extensive documentation on the traits is also available. In Box 3, a short description is given of the individual plant strategy types as defined by Klotz and Kühn (2002), which we used for our designation.

For some species, an attribution to an ecological strategy was not meaningful, as they have such a specialised life strategy that a classification into the strategy model was not appropriate. Examples are parasites or water plants.

Box 3: Definitions of the plant life-history strategies from Klotz and Kühn (2002); translated from German

Competitors (c): Trees, shrubs and herbaceous species with high competitive ability, due to investment of the main biomass in vegetative plant organs.

Stress tolerators (s): Small shrubs and herbs with low growth and adaptations to extreme environmental conditions like e.g. high salinity level, low temperatures, aridity, wetness.

Ruderals (r): mostly annual herbaceous plants, which are characterised by a low lifespan and high seed production and thus are able to colonise pioneer sites rapidly.

Competitor-ruderals (cr): intermediate type between c and r. These are either tall growing annual or short-living persistent species.

Competitor-stress tolerators (cs): intermediate type between c and s. Here, persistent and highly competitive species occur on sites with one environmental factor in its minimum or maximum. Examples are marsh plants, plants of dry sites or tall growing alpine plants.

Stress tolerators-ruderals (sr): intermediate type between s and r. These species are ephemeral on sites with at least one environmental factor in its minimum or maximum, e.g., annual species on dry or wet sites, low-saline soils or in cold climates.

Competitor-stress tolerators-ruderals (csr): intermediate type of all primary main strategies. These are in general rather small growing, ephemeral, persistent rosette plants.

2.5.1. Strategies in the Broader Habitats

In order to classify the strategies of the GHCs into the triangle, we needed firstly to give values to the individual C-, S-, R- strategies: C = (100, 0, 0), S = (0, 100, 0), R = (0, 0, 100), CR = (50, 0, 50), CS = (50, 50, 0), SR = (0, 50, 50) and CSR = (33.33, 33.33, 33.33). Thus, it was possible to divide the species lists into the three dimensions. Weighted average values per cluster and GHC were calculated and inserted into the CSR-triangle. Our hypothesis was that the distribution of the strategies depends on the type of GHC. For this, we calculated an ANOVA to test for dependencies of individual strategies on the habitats and a NPMANOVA to see if the distribution of the three dimensions is dependent on the GHC.

3. Preparatory Results

3.1. Climate data

3.1.1. Climate data for all landscape samples

On the large scale it was of interest how far regional differences of climate change impacts have to be expected. A coarse cluster analysis was carried out for all landscape sample sites under consideration of changes in temperature and precipitation for the relevant grid cells. Calculated data from the climate scenarios were used for the cluster analysis without further consideration of elevation differences between the reference level of the model and the prevailing elevation of the sample sites. This approach smoothed out local climate differences, in particular in alpine areas. While changes in Vorarlberg are expected to be rather homogenous, the calculations for the Southern part of Austria showed a higher variation (Figure 6).

Figure 6: Climate cluster of the expected climate changes, values indicate cluster number.

Still, it is important to consider that the degree of the expected climate changes will vary substantially. In general a tendency of increasing humidity during early summer month and decreasing humidity during late summer and early autumn has to be expected. As such, landscape samples north of the Alpine divide showed different amplitudes of changes, but the main tendency of the individual months remains the same (Figure 7). Tendencies to wetter climate conditions between May and July as also in October and November, and to dryer climate conditions in August and September are evident. Individual clusters have to expect different intensities of climate changes.

More pronounced differences of the expected climate changes were visible in comparison between landscape sample in the North and the South of Austria (Figure 8) as well as along the Austrian West-East gradient (Figure 9). Eastern and Southern Austria regions are at higher risk to suffer on droughts in future. In contrary, Western Austria, in particular Vorarlberg has to expect reduced humidity only during late summer and early spring.

Figure 7: Expected changes of the Delta humidity in the course of the year for climate cluster north of the Alpine divide.

Figure 8: Comparison of expected changes of the Delta humidity in the course of the year for climate clusters of Northern Austria (28) and Southern Austria (38).

Figure 9: Comparison of expected changes of the Delta humidity in the course of the year for climate clusters of Eastern Austria (2), inner alpine valleys (5) and Western Austria (16).

3.1.2. Climate data in Vorarlberg

The regional cluster analyses of the climate parameter did not deliver reasonable, satisfying results, basically due to the large differences in precipitation and water balance. Table 3 summarises the current and the scenario climate parameters. The average yearly temperature as well as the average temperature for the period April to September will increase by 1.8° to 1.9°C according to the model calculations. Yearly precipitation will rise by >1000 mm whereupon about a quarter will fall within the vegetation period (Figure 10). Vegetation data for the ecograms and the sensitivity values can therefore not be pooled to improve robustness of the models.

Table 3: Climate parameter of the model for the current and the scenario period as well as the associated Delta. JMT = average yearly temperature; MT(04-09) = average temperature for period April to September; JWB = yearly water balance; WB(04-09) = waterbalance for period April to September, g= balance for grassland; w= balance for forest; JNS = yearly precipitation; NS(04-09) = precipitation for period April to September; values in mms

Current	JMT	MT(04-09)	JWBg	WB(04-09)g	JWBw	WB(04-09)w	JNS	NS(04-09)
Q_801	5.2	9.9	2176	577	2100	516	3077	1260
Q_807	4.8	9.5	2482	932	2404	869	3349	1580
Q_808	4.9	9.6	2418	852	2341	790	3293	1508
Q_809	5.8	10.7	1703	305	1625	243	2666	1032
Q_810	4.2	8.9	2436	726	2362	666	3288	1374
Q_811	2.5	7.0	2708	883	2637	825	3489	1479
Scenario								
Q_801	7.1	11.8	3319	818	3237	752	4248	1531
Q_807	6.6	11.3	3905	1262	3821	1195	4799	1949
Q_808	6.7	11.4	3786	1167	3703	1101	4688	1860
Q_809	7.8	12.5	2774	556	2690	489	3753	1303
Q_810	6.2	10.8	3511	918	3431	853	4401	1604
Q_811	4.4	8.9	3872	1132	3795	1070	4680	1768
Delta								
Q_801	1.9	1.8	1143	241	1137	236	1170	272
Q_807	1.9	1.8	1422	330	1417	326	1450	369
Q_808	1.9	1.8	1368	315	1362	311	1395	352
Q_809	1.9	1.8	1071	251	1066	246	1087	271
Q_810	1.9	1.9	1075	192	1069	187	1113	230
Q_811	1.9	1.9	1164	250	1158	245	1192	289

Figure 10: Temperature profile in the landscape samples of Vorarlberg in comparison between current conditions (Ist) and scenario values (Szenario)

3.1.3. Climate data in Upper-Austria

Cluster analysis grouped the landscape samples into four clusters (Figure 11). Main discriminator for the clustering was the monthly pattern of temperature and precipitation values. Climate scenario data for the period 2041 – 2050 indicated a mean temperature rise of 1.85°C to 2.17°C in the months April to September and a rise in water balance of 33 to 151 mm in this time period (Table 4).

Figure 11: Cluster analysis grouped the landscape samples into four climate clusters in respect to temperature and precipitation patterns. Expected changes in temperature sum (ΔT in °C) and precipitation (ΔF in mm) during the period of April to September for the four clusters are given in the legend.

Table 4: Climate parameter of the model for scenario period as well as the associated Delta. Cl = climate cluster; JMT = average yearly temperature; MT(04-09) = average temperature for period April to September; JWB = yearly water balance; WB(01-09) = waterbalance for period January to September, JNS = yearly precipitation; NS(01-09) = precipitation for period January to September; NS(04-09) = precipitation for period April to September; values in mm.

Cl	Q_#	JMT	MT(04-09)	JWB	WB(01-09)	JNS	NS(01-09)	NS(04-09)	Delta T	Delta NS
1	436	7.41	13.22	326	150	912	701	490		
1	437	7.48	13.32	282	122	881	681	482		
1	438	6.86	12.75	353	162	960	739	514		
1	439	6.89	12.78	337	152	948	731	510		
1	440	6.93	12.79	343	152	950	729	503		
1	441	7.11	13.02	288	124	908	705	501		
1	442	7.07	12.97	297	129	916	710	503		
mean Cl1		7.11	12.98	318	142	925	714	500	2.17	38
2	443	6.91	12.91	209	27	827	608	398		
2	444	6.91	12.92	207	22	822	602	391		
2	445	6.98	12.99	171	0	801	590	389		
mean Cl2		6.93	12.94	195	16	817	600	393	2.10	33
3	449	6.79	12.72	795	434	1110	803	517		
3	451	6.64	12.59	825	453	1142	827	532		
3	453	6.74	12.70	644	322	1032	740	468		
3	455	6.53	12.50	748	389	1108	796	503		
3	457	6.16	12.14	909	489	1227	883	557		
3	462	6.16	12.14	928	493	1227	878	549		
mean Cl3		6.50	12.47	808	430	1141	821	521	1.85	151
4	452	6.55	12.53	524	222	988	705	439		
4	460	6.46	12.44	563	248	1017	727	455		
4	461	6.16	12.14	777	397	1154	831	525		
4	463	6.61	12.59	433	158	935	666	415		
mean Cl4		6.44	12.42	574	256	1023	732	459	1.92	103

4. Main Results

4.1. Vorarlberg

4.1.1. Regression analysis

In Vorarlberg, linear regression analysis of the Ellenberg T-values with the temperature variables showed strong outliers of the landscape samples 801 and 807 (Figure 12). By removing these two samples the analysis was improved, still the result was not significant (p-value = 0.07234). Looking at the individual GHCs more differentiated, regression of T-values with temperature variables was not significant either. The regression for the habitats HER/LHE und HER/CHE showed only very weak relationships.

no significant results

Figure 12: a. linear regression (QQ-plot) of all landscape samples in Vorarlberg; b. linear regression (QQ-plot) without outlier landscape samples 801 and 807.

The regression analysis of the average Ellenberg W-values with the associated climate parameter yielded in a similar result. The relationships were rather weak and significant correlations could not be shown. Eliminating the samples 801 and 807 did not improve the p-value considerably. Regression analysis for the habitats did not deliver better results either.

4.1.2. Ecological envelope (ecogram)

Based on the vegetation data, an ecogram was constructed for each habitat in each landscape sample showing the percentage of T- and W-values. This should represent the realised ecological niche or climate space. As the landscape samples could not be successfully clustered, pooling of the data is not possible and the ecograms could only be developed on the level of the landscape sample and can therefore not be

regarded as robust. Basically, all habitats showed a main focus on higher W-values, whereas temperature values are scattered over a wider interval (Figure 13).

Figure 13: Ecograms of habitats in five landscape samples in Vorarlberg. The colour ramp shows the percentages of the frequency of the combination in temperature and water availability Ellenberg values. Abbreviations of GHC see Table 1.

4.1.3. Sensitivity Index

high sensitivity
to water
availability

Generally, the habitats displayed a higher sensitivity concerning the water availability than to temperature (Table 5). The range is however rather large

especially for the W-values: the habitat HER/LHE showed a range from 3.50 to 12.20, HER/CGE from 4.71 to 8.56. As the sample size was largest for these two habitats, the sensitivity index was most robust compared to the other categories.

Table 5: Sensitivity index for temperature and water availability values in the individual GHCs and landscape samples. Abbreviations of GHC see Table 1.

KUNR_I		FPH	FPH/DEC	HER/CHE	HER/LHE	SPV/AQU	TPH/DEC	URB/VEG
801	T				4.00			
	F				4.33			
807	T		0.72	0.81	1.50	1.10		
	F		2.25	4.71	3.50	8.20		
808	T			1.08	5.25	0.79		
	F			8.56	12.20	18.14		
809	T	2.00	2.50	1.02	3.50			
	F	1.50	1.00	4.81	7.33			
810	T	2.50		1.13	1.58		3.00	
	F	6.25		5.17	14.17		3.00	
811	T			1.08	1.17	1.85	0.90	0.00
	F			5.17	10.20	12.14	0.90	3.50

In GIS, the sensitivity values were linked to the geographic data. On this basis, the spatial distribution patterns of the sensitive habitat are easily cognizable and visualise the climate change impact better on the geographic level (Figure 14). For the visualisation purposes, the range of the index values was divided into four quantiles, named 'low sensitive', 'medium sensitive', 'sensitive' and 'high sensitive'. In Annex D all sensitivity maps are presented.

**spatial
representation
of sensitivity
index**

Figure 14: Visualisation of sensitivity index in four categories in one example landscape sample in Vorarlberg.

4.2. Upper-Austria

As more data for the landscape sample in Upper-Austria are available than in Vorarlberg, we focus on the results on this part of the project area. First, a short overview on the results is given where the most interesting habitats concerning impact on biodiversity became apparent. Thus, the individual habitats are regarded more in detail following the general overview. Issues discussed for most important habitats are (i) relationship with climate parameters, (ii) ecogram, (iii) sensitivity, (iv) strategy types and (v) possible impact due to climate change.

4.2.1. General overview

4.2.1.1. Regression analysis

importance of temperature

Looking at the mean T values of the landscape samples, regression analysis showed quite a strong relationship with mean annual temperature ($R^2 = 0.59$, p-value < 0.01), mean temperature April – September ($R^2 = 0.65$, p-value < 0.01; Figure 15.a) and both variables ($R^2 = 0.72$, p-value < 0.01).

no relationship with water availability values

For the mean W values, the analysis did not reveal any significant correlation with any of the climate parameters (Figure 15.b). The individual broader habitats were differently influenced by the climate variables. Habitats FPH ($R^2 = 0.58$, p-value < 0.01) and SPV/AQU ($R^2 = 0.59$, p-value < 0.01) showed significant relationships with temperature variables whereas other habitats like CUL/CRO, TPH/DEC and URB/ART did not (Figure 15.c and d.). A summary of the regression analysis is given in the Annex E.

4.2.1.2. Ecological envelope (ecogram)

Figure 16 displays the ecological envelope of the broader habitats per climate cluster in terms of temperature and water availability. The outmost lower left corners of the sub-quadrats show the high amount of indifferent species in the habitats. Medium values of category 5 (temperate species on medium moist soils) dominated all habitats although the spread of other Ellenberg values is different. FPH had a much narrower envelope in all clusters than the other broader habitats. Also, differences among the clusters became visible, e.g. HER/LHE occupied a large space in cluster 2 whereas in the others this space was tightened. CUL/CRO has a wide range in all clusters, even high T values. In the habitat of CUL/WOC, low T or W values were barely present.

4.2.1.3. Sensitivity

In general, GHCs showed a higher sensitivity concerning W than T values (Table 6). The habitats HER/LHE, HER/CHE, CUL/WOC and SPV/AQU had highest sensitivity index for W values (> 4.3), whereas CUL/CRO, URB/VEG, URB/ART and FPH (< 2.7) had the lowest. Higher sensitivity for T values (> 1.3) were calculated for habitats FPH and SPV/AQU, but the urban habitats, HER/CHE and CUL/WOC hardly showed any sensitivity to T values (< 0.5). Among the clusters, the broader habitats showed different sensitivity behaviour, e.g. sensitivity T index for FPH ranges from 1.1 to 2.0 or sensitivity W index for URB/VEG from 2.5 to 4.1. On the other hand, HER/LHE had a small T range (1.0 – 1.2) and SPV/AQU a small W range (3.9 – 4.4).

**higher
sensitivity to
water
availability than
temperature**

A further interesting aspect on the discussion about sensitivity was to look, if the sensitive habitats are also the more natural ones. In the course of the SINUS-project (Peterseil et al., 2004), hemeroby (Naveh and Liebermann, 1984) was assessed for each landscape element. These data were used to illustrate the naturalness of the individual broader habitats (Figure 17). The best regression models coincided with the broader habitats which showed higher naturalness values and also highest sensitivity values. This lead to the conclusion, that anthropogenic influence can modify systems to an extent where the relation to site conditions is weakened if not broken.

Figure 15: Scatterplot of a. mean T values per landscape samples versus mean temperature April – September with regression line ($R^2 = 0.65$, p -value < 0.01); b. mean W values versus mean precipitation April – September; c. mean T values of General Habitat Category “Sparsely Vegetated-Aquatic” with regression line ($R^2 = 0.59$, p -value < 0.01); d. mean T values of General Habitat Category “Urban-Artificial” ($R^2 = 0.01$).

Figure 16: ecological envelopes of the four climate clusters for each General Habitat Category, abbreviations of GHC see Table 1; colour ramp indicates percentages of occurrence of Ellenberg-values per combination of temperature values (T) and water availability values (W).

Table 6: Sensitivity Index for T (temperature) and W (water availability) in the individual General Habitat Categories and cluster; abbreviations for General Habitat Category see Table 1.

Cluster		CUL/CRO	CUL/WOC	FPH	FPH/DEC	HER/CHE	HER/LHE	SPV/AQU	TPH/DEC	URB/ART	URB/NON	URB/VEG
1	T	1.7	1.1	1.4	1.1	0.9	1.0	1.6			1.5	0.9
	W	2.3	3.9	2.6	2.7	4.3	3.5	3.9			3.3	2.5
2	T		1.1	2.0	1.2	1.22	1.1	1.7			1.2	1.2
	W		3.3	2.9	2.7	3.5	4.5	4.1			4.3	4.1
3	T	1.1	1.0	1.1	1.1	1.0	1.2	1.2	1.0	1.0	1.2	1.0
	W	3.6	4.5	3.2	3.4	4.9	5.0	4.3	4.0	3.6	3.7	3.2
4	T	1.0	0.9	1.3	1.2	1.0	1.1	1.0		1.1	0.8	0.9
	W	3.6	4.6	3.4	3.6	4.4	4.0	4.4		2.5	3.3	3.1

Figure 17: Naturalness of General Habitat Categories; higher y-values indicate higher naturalness; abbreviations of General Habitat Categories see Table 1; the box is presenting the quartiles below and above the median, whiskers delimitate 1.5 interquartile range (IQR) of the lower and the upper quartile.

Also, in this part of the project region, GIS enabled the visualisation of particularly (in)sensitive areas (example see Figure 18). The categorisation of the sensitivity index into the four quantiles was done independently from Vorarlberg as the indices differed too much in the subregions to allow for a common grouping of the sensitivity values. All sensitivity maps are given in Annex F.

Figure 18: Visualisation of sensitivity index in four categories in one example landscape sample in Upper-Austria.

4.2.1.4. Strategy types

The distribution of the Grime's strategy types was calculated for each cluster and each GHC. It became obvious, that the focus was always on the competitors

including CS-, CR-, CSR. Only the habitat CUL/CRO shifted its core more to the ruderal strategy (Figure 19).

habitats are dominated by competitor strategy type

Figure 19: Distribution of the life strategies in the different GHCs in percent. Abbreviations of the GHC see Table 1.

ruderals in CUL/CRO, competitors in FPH

Valuing the different strategies enabled the location of the individual habitats within Grime's triangle (Figure 20). There, a separation of the habitat CUL/CRO (in general arable fields) in direction ruderal strategy can be noted rather clearly. This can be explained by the regular disturbance which is inherent to this habitat. Also the GHC connected to URB (urban areas) showed a tendency direction to ruderal strategy. On the other hand, all forest types were located at the top end of the competitor strategy.

dependency of C- and R-strategy types on GHC and climate cluster

The ANOVA clearly revealed that C- as well as the R-strategies were dependent on the habitat type (p-value < 0.05) but not the stress-tolerants (Table 7). The distribution among the three strategy dimensions was on the one hand reliant on the broader habitat, but on the other hand also on the climate cluster (Table 8) as proven by the NPMANOVA.

Figure 20: Location of the General habitat categories within Grime's triangle. Especially CUL/CRO was separated of the other habitats. Abbreviations of the GHC see Table 1.

Table 7: ANOVA-results; $\Pr(>F) < 0.05$ shows a significant relationship between the General Habitat Category (GHC) and the R- and C-strategies. C=competitors, S=stress tolerants, R=ruderals.

<i>Anova: GHC~C</i>					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GHC	11	4018.039	365.2762	5.828375	4.28E-05
Residuals	32	2005.506	62.67206		
<i>Anova: GHC~S</i>					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GHC	11	396.0626	36.00569	1.793648	0.097116
Residuals	32	642.3679	20.074		
<i>Anova: GHC~R</i>					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GHC	11	5443.598	494.8726	27.00427	4.21E-13
Residuals	32	586.4229	18.32571		

Table 8: NPMANOVA results reveal a significant relation between the distribution of the strategies with both GHC and climate cluster. Df=Degrees of Freedom, SumsOfSqs=sums of squares, MeanSqs=mean squares, F.Model=F statistics, R2=partial R-squared and Pr(>F)=P values of F-statistics.

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
GHC	11	0.5819602	0.0529055	13.2475818	0.7434	0.001	***
Cluster	1	0.0691437	0.0691437	17.3136462	0.0883	0.001	***
GHC*Cluster	10	0.0479163	0.0047916	1.1998276	0.0612	0.347	
Residuals	21	0.0838655	0.0039936		0.1071		
Total	43	0.7828856			1.0000		

R-script: `adonis(formula=csr.gew[,3:5]~csr.gew$GHC*csr.gew$Cluster,method="bray")`

For most of the habitats, the location within the strategy triangle showed a similarity between climate cluster 1 and 2 as well as climate cluster 3 and 4. Looking at the climate parameters of the respective landscape samples, these also revealed the same pattern. As already described above, the main discriminator for the climate clusters where the temperature- and precipitation values for the period April to September. Already here, resemblance between clusters 1 / 2 and clusters 3 / 4 was borne to some extent. Temperature rise is forecasted for clusters 1 / 2 by 2.10°C to 2.17°C, precipitation will increase by 33 mm to 38 mm. Scenario values for clusters 3 / 4 are an increase of temperature by 1.85°C and 1.92°C respectively 151 mm and 103 mm precipitation (Table 9). The outcome of this is the similarities of the habitat niches in the strategy triangle according to the clusters.

Regarding the relationships of the strategy types with the individual climate parameters, the picture looked a bit different. Not only the competitors reacted most sensitive to the average yearly temperature ($R^2 = 0.6155$, p-value < 0.001) and the average temperature of the vegetation period ($R^2 = 0.5962$, p-value < 0.001), but also the stress tolerant plants ($R^2 = 0.7851$ and $R^2 = 0.7699$ respectively, both p-values < 0.001). It is important to note the direction of the regression, showing the higher the average temperature, the less stress tolerants, indicating that the cold temperatures are the driving factors for the S-strategy in this project region (Figure 21.a). Whereas the ruderals did not show very strong correlations with temperature values, they revealed higher R^2 values with water balance parameters (Figure 21.b). The variable precipitation in the vegetation period did not deliver a significant model with any of the strategy types (Annex G).

more natural
habitats → best
models →
highest
sensitivity

As mentioned before, more natural habitats coincided with the ones of best models and highest sensitivity. The next step was therefore to analyse these regarding their relation of strategy types with climate parameters. We selected mainly the woody habitats (FPH, FPH/DEC, TPH/DEC), herb-rich meadows (HER/LHE) and water bodies (SPV/AQU).

Table 9: Mean values of climate parameters for the climate clusters. JMT = average yearly temperature; MT(04-09) = average temperature for period April to September; JWB = yearly water balance; WB(01-09) = waterbalance for period January to September, JNS = yearly precipitation; NS(04-09) = precipitation for period April to September. Abbreviation of General Habitat Categories see Table 1.

			GHC	C	S	R
Cluster 1	JMT (°C) = 7	MT(04-09) (°C) = 13	CUL/CRO	52	6	42
			CUL/WOC	75	12	13
			FPH	94	3	3
	JWB (mm) = 318	WB(01-09) (mm) = 142	FPH/DEC	79	10	10
			HER/CHE	71	14	15
			HER/LHE	70	11	19
			SPV/AQU	77	13	10
	JNS (mm) = 925	NS(04-09) (mm) = 500	TPH/DEC	69	18	11
			URB/ART	77	6	17
			URB/GRA	75	13	13
	Delta temperature (°C)	Delta precipitation (mm)	URB/NON	73	11	15
	2.17	38	URB/VEG	66	9	25
Cluster2	JMT (°C) = 7	MT(04-09) (°C) = 13	GHC	C	S	R
			CUL/CRO	33	7	60
			CUL/WOC	80	9	11
	JWB (mm) = 195	WB(01-09) (mm) = 16	FPH	90	7	3
			FPH/DEC	81	10	8
			HER/CHE	73	12	15
	JNS (mm) = 817	NS(04-09) (mm) = 393	HER/LHE	67	10	23
			SPV/AQU	81	10	8
			URB/ART	82	7	12
	Delta temperature (°C)	Delta precipitation (mm)	URB/NON	75	13	12
	2.1	33	URB/VEG	60	10	30
Cluster3	JMT (°C) = 7	MT(04-09) (°C) = 12	GHC	C	S	R
			CUL/CRO	43	7	50
			CUL/WOC	63	16	21
			FPH	73	17	10
	JWB (mm) = 808	WB(01-09) (mm) = 430	FPH/DEC	76	15	9
			HER/CHE	60	20	19
			HER/LHE	60	19	20
			SPV/AQU	63	22	13
	JNS (mm) = 1141	NS(04-09) (mm) = 521	TPH/DEC	66	22	12
			URB/ART	62	15	24
	Delta temperature (°C)	Delta precipitation (mm)	URB/NON	63	15	22
	1.85	151	URB/VEG	58	17	25
Cluster4	JMT (°C) = 6	MT(04-09) (°C) = 12	GHC	C	S	R
			CUL/CRO	50	6	44
			CUL/WOC	61	16	23
			FPH	76	15	9
	JWB (mm) = 574	WB(01-09) (mm) = 256	FPH/DEC	74	15	11
			HER/CHE	63	18	18
			HER/LHE	61	19	19
			SPV/AQU	63	21	14
	JNS (mm) = 1023	NS(04-09) (mm) = 459	TPH/DEC	85	11	5
			URB/ART	68	13	20
	Delta temperature (°C)	Delta precipitation (mm)	URB/NON	56	21	23
	1.92	103	URB/VEG	55	18	26

Figure 21: Scatterplot of a. mean values of stress-tolerants versus mean yearly temperature with regression line ($R^2 = 0.7851$, $p\text{-value} < 0.001$); b. mean values of ruderals versus yearly water balance with regression line ($R^2 = 0.3945$, $p\text{-value} < 0.01$).

mainly C- and S-strategies showed significant regressions with climate parameters

Again, mainly C- and S-strategies showed significant regressions with average yearly temperature, average temperature for vegetation period, yearly water balance, water balance for the period January to September and yearly precipitation (a list of all linear models is in the Annex H). On the contrary, habitat CUL/CRO and TPH/DEC had no dependency on any climate variable. On the other hand, HER/CHE, FPH and CUL/WOC, a relation to temperature, precipitation and waterbalance could be detected. These results lead to the conclusion, that there is no pronounced connection between naturalness and strategy types.

no pronounced connection between naturalness and strategy types.

However, especially these last mentioned habitat types are exposed to a large variety of anthropogenic influence factors. As there is no clear correlation given, some more natural areas are less permeable for climate induced migration of plants, others more susceptible. Additionally, the temporal aspect of the climate factors may not be disregarded.

climate 'bottle necks'

In the scenario calculations of larger periods (~50 years), anomalies in climate over a few years are observed which could be traced back to large-scale influences. Such climate 'bottle necks' could maybe affect vegetation assemblages selectively depending on their resilience.

Estimating the impact of this information on biodiversity has to be regarded cautiously. Habitats with a low sensitivity and high anthropogenic influence such as intensive agricultural areas are less likely to suffer from climate change than habitats with a high sensitivity especially those, where the regression showed a strong correlation between climate parameters and Ellenberg values. For those habitats where models provided only low significance levels, the impact of climate change cannot be projected at all. The main determinants for any argument on climate change impacts, resilience and tipping points, could not be grasped with this project because of limited examination possibilities and data.

In the following section, we focus on rather contrasting habitat types and discuss them in details concerning their statistical results and possible impacts on their biodiversity due climate change. We selected (i) intensively used habitats (CUL/CRO + CUL/WOC), (ii) grassland habitats (HER/CHE + HER/LHE), and (iii) forest habitats (FPH + FPH/DEC)

4.2.2. *GHC of intensive agriculture: CUL/CRO + CUL/WOC*

In general, the agricultural habitats could not be significantly linked to the tested climate parameters, only CUL/CRO showed a rather weak but significant regression with temperature values of the vegetation period ($R^2 = 0.17$, $p\text{-value} < 0.05$; Table 10).

The ecological envelope for CUL/CRO was somewhat similar for all three climate clusters (for cluster 2, the sample size was too little for the definition of the ecogram), except in cluster 1, where the medium water availability values were not present for the medium temperature values. In return, these medium W-values were present for the low T-values (Figure 22). For woody crops (CUL/WOC), especially cluster 3 and 4 showed a focus on higher T-values and higher W-values. The medium Ellenberg temperature values were not present in their ecological envelope and revealed a large gap within the ecogram.

Table 10: Summary of regression analysis; formulas, degrees of freedom (df) and R^2 ; * indicates $p\text{-value} < 0.05$.

formula linear regression	landscape sample/GHC	df	R^2	
Average Ellenberg T ~ mean temperature April – September	CUL/CRO	13	0.17	*
	CUL/WOC	13	0.37	
Average Ellenberg T ~ mean temperature April – September + mean annual temperature	CUL/CRO	12	0.30	
	CUL/WOC	12	0.39	
Average Ellenberg W ~ annual Water balance + Water balance January – September + annual precipitation + precipitation January – September + precipitation April – September	CUL/CRO	9	0.22	
	CUL/WOC	9	0.54	

Sensitivity values followed the general picture with higher sensitivity to water availability then temperature (Table 11). WOC showed in all four clusters lower T sensitivity values than CRO whereas the opposite could be seen for W-values. In climate cluster 3 and 4 with an expected rise of more than 100 mm precipitation, the sensitivity to water availability with 4.5 respectively 4.6 for WOC were classified as “high sensitive”.

Figure 22: Ecograms of habitats CUL/CRO and CUL/WOC in the four climate clusters. The colour ramp shows the percentages of the frequency of the combination in temperature and water availability Ellenberg values. Abbreviations of GHC see Table 1.

Cluster		CUL/CRO	CUL/WOC
1	T	1.7	1.1
	W	2.3	3.9
2	T	NA	1.1
	W	NA	3.3
3	T	1.1	1.0
	W	3.6	4.5
4	T	1.0	0.9
	W	3.6	4.6

Table 11: Sensitivity Index for T (temperature) and W (water availability) in the individual General Habitat Categories and cluster; abbreviations for General Habitat Category see Table 1.

Table 12: Distribution of the life strategies in the different GHCs in percent. Abbreviations of the GHC see Table 1. Abbreviations for life-strategies see Box 3.

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	CUL/CRO	23	0	30	30	4	9	26	0	0
2	CUL/CRO	13	0	8	38	0	15	38	0	0
3	CUL/CRO	75	0	27	31	3	16	23	0	1
4	CUL/CRO	58	0	28	31	3	16	21	0	2
mean			0	23	33	3	14	27	0	1

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	CUL/WOC	42	0	55	5	2	38	0	0	0
2	CUL/WOC	37	0	62	5	0	30	3	0	0
3	CUL/WOC	118	2	35	9	12	31	9	1	1
4	CUL/WOC	65	0	35	17	6	34	8	0	0
mean			0	47	9	5	33	5	0	0

Concerning the strategy types, these agricultural habitats showed the highest proportions of ruderals and their associated types. Especially, the habitat CUL/CRO included typical ruderal vegetation of more than 70% r-related life strategies (Table 12). Stress-tolerant species were not found at all and also only a minor proportion of

competitor species and its variances. On the other hand, competitors were more present in the woody crops, and a large percentage of intermediate strategy types at the expense of the ruderals. This picture was also presented in Grime's triangle (Figure 23), especially CRO of climate cluster 2 was placed into direction ruderals, whereas for WOC the location of the climate cluster moved towards the C-corner. Here, also the separation of climate cluster 1 and 2 (with higher temperature rise but lower precipitation values) to climate cluster 3 and 4 (high rise in precipitation but less rise in temperature) was clearly visible.

Figure 23: Location of the habitats CUL/CRO and CUL/WOC within Grime's triangle. Abbreviations of the GHC see Table 1.

Putting the proportion of the strategy types into the linear relation with the climate parameters, again the regressions were rather weak and not significant for CUL/CRO at all, whereas for woody crops nearly all climate parameters showed significant regressions except for precipitation (April-September) and the ruderal strategy type (Figure 24).

In the European perspective, Bindi and Olesen (2011) summarised possible responses of agriculture to climate change. Overall, there is the scenario that cropland will decrease by nearly half in the worst conditions. Still, crop productivity is supposed to slightly increase. They speculate, that technological developments like new crop varieties and better cropping practices will counteract the effects of climate change to a large extent if not exceed. Possible effects might be a decrease of soil organic carbon due to faster soil decomposition with higher temperatures and a higher Net Primary Productivity based on higher C-input. The occurrence of more extreme weather events and higher variability in weather conditions might lead also to a higher unevenness in yield from year to year.

**crop
productivity
might slightly
increase**

**unevenness in
yield from year
to year**

There is speculation that warmer winters might lead to more pests and plant diseases but this argument is associated to high uncertainties because of lack of predictability of cop pathogen behaviour.

For the continental region (as defined by Metzger et al., 2005), Olesen et al. (2011) reported the consideration of local experts concerning amongst others winter wheat, spring barley, and grain maize. For these crops, mainly pests, diseases and nitrogen losses were considered to become major problems, to a less extent also the problematics of droughts, weeds, hail damage, soil erosion and seasonal variability.

Figure 24: Scatterplot of a. mean values of ruderals in CUL/CRO versus mean temperature (April – September) with regression line ($R^2 = 0.2522$, n.s.); b. mean values of ruderals in CUL/CRO versus yearly water balance with regression line ($R^2 = 0.0003$, n.s.); c. mean values of ruderals in CUL/WOC versus mean temperature (April – September) with regression line ($R^2 = 0.2392$, n.s.); d. mean values of ruderals in CUL/WOC versus yearly water balance with regression line ($R^2 = 0.5835$, p-value < 0.001).

An even more regional study focused on the Central European Region of Czech Republic and Northern and Eastern Austria (Trnka et al., 2011). They analysed the expected changes in agroclimatic conditions with the AgriClim Model software package which identified different agroclimatic zones in the study region. Our landscape samples were currently located in the Sugar-beet growing region and the Cereal-Potato growing region.

**reduction in
Cereal-Potato
growing,
expansion of
Sugar-beet**

In their model, all scenarios resulted in a large reduction of the latter region and a relatively fast expansion of the Sugar-beet growing region and even maize production region. In general, they conclude that by 2050 only 2-24% of the agricultural land will not be facing agroclimatic zone change.

The length of the growing season will increase about nearly a month by 2050 spread between spring and autumn. Also, the proportion of days suitable for sowing and harvesting should increase.

longer growing season

Possible mitigation strategies and actions mainly are seen in changing crop varieties, sowing dates as well as adaptations in applications of fertilizer and pesticides. On the continental scale, also modifications in land allocation and farming systems and the development of new land management technologies need to be considered (Bindi and Olesen, 2011).

changing crop varieties and sowing dates

They discuss also the possibility of enhancing the resilience of the whole system. Organic farming may exhibit a higher resilience to climate change impacts as these systems in general are more diversified than conventional farmland and offer more options for system changes. The longer growing season will foster the introduction of crops or cultivars with longer growth duration whereas crops which are not adapted to warmer conditions will experience yield reductions (Trnka et al., 2011).

enhancing resilience

From other investigations (Knoflacher et al., 2002) a high erosion risk on agricultural areas is evident for this region which will increase with precipitation intensities. However, mitigation measures are already now required on sites with high soil losses, for example on ridge of hills or steep slopes. Best strategies to avoid further soil degradation on such sites are alterations from arable land to permanent grassland or – better to agroforestry, for example orchards with permanent grasscover (Kumar, 2006, Lin, 2007, Verchot et al., 2007). Permanent revegetation is also necessary on footslopes close to surface waters, but because of other reasons. Overfertilisation of agricultural land in combination with increased runoff causes eutrophication of surface waters. To avoid the negative environmental effects it is necessary to focus revegetation on cultures with high retention capacities for nutrients and sufficient robustness against sedimentation, for example fast growing tree species of regional origin in combination with permanent soil cover. Such cultivations can be used as short or medium term rotation agroforests for biomass production if root stocks will remain in the soil.

Site specific reactivation of agroforests can be part of adaptation and mitigation strategies on agricultural land to climate change (Calfapietra et al., 2010) in this region. Multiple layers of vegetation cover reduce significantly soil erosion and contribute to long term soil development with the effect of carbon storage. The retention of nutrients and soil particles reduces the risk of eutrophication and of additional carbon dioxide or methane emissions from surface waters. However, it is crucial that landowners learn to understand the multifunctionalities of agroforests and the long term benefits for their economic activities.

4.2.3. GHC grasslands: HER/CHE + HER/LHE

Grassland habitats revealed significant but still rather low regressions with the climate parameters, where herb rich grassland performed in general better than the

grass-species dominated land (Table 13). Also, Ellenberg temperature values could be better linked to climate parameters than water availability values which followed the general trend (see above).

Table 13: Summary of regression analysis; formulas, degrees of freedom (df) and R²; * indicates p-value < 0.05, ** indicates p-value < 0.01.

formula linear regression	landscape sample/GHC	df	R ²	
Average Ellenberg T ~ mean temperature April – September	HER/CHE	18	0.22	*
	HER/LHE	17	0.38	* *
Average Ellenberg T ~ mean temperature April – September + mean annual temperature	HER/CHE	17	0.36	*
	HER/LHE	16	0.43	*
Average Ellenberg W ~ annual Water balance + Water balance January – September + annual precipitation + precipitation January – September + precipitation April – September	HER/CHE	14	0.16	*
	HER/LHE	13	0.58	

The ecological envelopes for grasslands in all climate clusters looked somewhat similar where the full range of water availability values was presented. Except for climate cluster 2 in the herb rich grasslands, the medium temperature values were missing alike in the ecograms of the other agricultural habitats (Figure 25) leaving a blank area in the centre of the envelopes. A peak can be seen in the W-values between 4 and 6 and T-values of 5.

Figure 25: Ecograms of habitats HER/CHE and HER/LHE in the four climate clusters. The colour ramp shows the percentages of the frequency of the combination in temperature and water availability Ellenberg values. Abbreviations of GHC see Table 1.

Sensitivity values followed the general picture with higher sensitivity to water availability than temperature (Table 14). Both GHCs had similar sensitivity categories especially for water availability again the highest class whereas for T-values, the habitats were regarded as “medium sensitive” to “sensitive”.

Table 14: Sensitivity Index for T (temperature) and W (water availability) in the individual General Habitat Categories and cluster; abbreviations for General Habitat Category see Table 1.

Cluster		HER/CHE	HER/LHE
1	T	0.9	1.0
	W	4.3	3.5
2	T	1.22	1.1
	W	3.5	4.5
3	T	1.0	1.2
	W	4.9	5.0
4	T	1.0	1.1
	W	4.4	4.0

The distribution of strategy types in the grassland habitats was more balanced than for crops and woody crops (Table 15). Still, the highest proportions are given for competitors and the intermediate strategy types. To some extent, ruderals were again found, whereas the stress-tolerant species played nearly no role at all in the life strategies. The csr-types occurred in a higher proportion in the grass-species dominated grasslands while in the herb rich grassland the cr-type increased being in line with the definition of the strategy types of Box 3. This distinction was also visible in Grime’s triangle, where especially the location of climate cluster 1 and 2 for the LHE was situated more towards the R-axes compared to CHE (Figure 26). For both habitats the grouping of climate clusters 1 and 2 as well as of clusters 3 and 4 was pronounced.

Table 15: Distribution of the life strategies in the different GHCs in percent. Abbreviations of the GHC see Table 1. Abbreviations for life-strategies see Box 3.

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	HER/CHE	83	2	43	7	7	34	5	1	0
2	HER/CHE	61	0	44	8	3	31	13	0	0
3	HER/CHE	229	1	33	9	21	31	3	2	0
4	HER/CHE	138	1	34	12	18	28	5	1	0
mean			1	39	9	12	31	7	1	0

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	HER/LHE	113	0	42	17	9	24	8	0	1
2	HER/LHE	75	0	37	20	7	20	15	0	1
3	HER/LHE	254	1	33	12	17	28	7	1	1
4	HER/LHE	167	1	35	12	16	28	7	1	1
mean			0	37	15	12	25	9	0	1

Figure 26: Location of the habitats HER/CHE and HER/LHE within Grime's triangle. Abbreviations of the GHC see Table 1.

Putting the proportion of the strategy types into the linear relation with the climate parameters, the regression for HER/CHE gave significant results with all factors but with precipitation from April to September. Especially, competitors and stress-tolerants resulted in the highest R^2 (Figure 27 a. and b.). The herb rich grasslands on the other side had weaker relations and only between competitors and temperature values and stress-tolerants with temperature and water balance (Figure 27 c. and d.). Interesting is the direction of the relationship between water balance and competitors: the regression showed in negative relation – the higher the water balance the fewer competitors were present, also visible in the Grime's triangle with the separation of the clusters 3 and 4 below the other two.

For grassland habitats, the literature offered rather diverse discussion points. On the European perspective, different scenarios resulted in a decrease of grassland area between 6 and 58%, which is a wide range and leaves space for many considerations and arguments (Bindi and Olesen, 2011). Agricultural zoning of Trnka et al. (2011) indicated no dominant forage and grassland production zone for our landscape samples, still, we had a considerable proportion of these habitats in our analysis.

They considered the region to be reduced by half by 2020 and disappeared in 2050 due to water deficiencies during summer time. As this region is nowadays also situated on poorer soils and in more complex geomorphological conditions, the adaption to changed climate conditions as well as an alternative land management might be more difficult.

enhance genetic variability and ecotypes

Another aspect for these grassland habitats is the limited capacity of perennial clonal species, like common grass species as f.ex. *Arrhenaterum elatius*, to adapt rapidly to changing conditions (Beierkuhnlein et al., 2011). In this paper, the conclusion was to enhance the genetic variability within the populations of species as the chance of the occurrence of individual ecotypes adapted to more extreme climatic conditions is higher. This would enable the maintenance of ecosystem functioning in temperate grasslands.

Figure 27: Scatterplot of a. mean values of competitors in HER/CHE versus mean temperature (April – September) with regression line ($R^2 = 0.7086$, , $p\text{-value} < 0.001$); b. mean values of competitors in HER/CHE versus yearly water balance with regression line ($R^2 = 0.6324$, , $p\text{-value} < 0.001$); c. mean values of competitors in HER/LHE versus mean temperature (April – September) with regression line ($R^2 = 0.3006$, , $p\text{-value} < 0.05$); d. mean values of competitors in HER/LHE versus yearly water balance with regression line ($R^2 = 0.1932$, n.s.).

An important consideration for the management of grasslands was expressed by Bernhardt-Roemermann et al. (2011): they analysed the impact of temperature and precipitation together with mowing frequencies on the biomass yields, structural and functional diversity and evenness. They concluded that management treatments with intermediate disturbance regimes maximized biomass yields when also the influence of climatic variables is less important in comparison to different aspects of diversity.

**reduction of
grassland area**

4.2.4. GHC forests: FPH + FPH/DEC

Forest habitats revealed significant regressions with the climate parameters, where FPH performed in general better than FPH/DEC (Table 16). Interestingly, FPH showed similar R^2 for temperature as well as for water related climate variables in contrast to the other habitats. For the regression of FPH/DEC with water balance and precipitation values, the sample size was too small.

Table 16: Summary of regression analysis; formulas, degrees of freedom (df) and R²; * indicates p-value < 0.05, ** indicates p-value < 0.01.

formula linear regression	landscape sample/GHC	df	R ²	
Average Ellenberg T ~ mean temperature April – September	FPH	15	0.58	**
	FPH-DEC	16	0.24	*
Average Ellenberg T ~ mean temperature April – September + mean annual temperature	FPH	14	0.60	**
	FPH-DEC	15	0.38	*
Average Ellenberg W ~ annual Water balance + Water balance January – September + annual precipitation + precipitation January – September + precipitation April – September	FPH	14	0.60	**
	FPH-DEC	0	NA	NA

The ecological envelopes for forests in all climate clusters looked somewhat similar where the full range of water availability values was presented. The temperature Ellenberg values were separated into two main lines – very low T-values and medium to high T-values representing the tree respectively the understory species in the woody habitats (Figure 28). Especially for higher temperature values, also higher water values were present in the envelope. A peak can be seen in the W-values and T-values of 5.

Sensitivity values followed the general picture with higher sensitivity to water availability then temperature (Table 17). Both GHCs had similar sensitivity categories except for climate cluster 2, where FPH was classified into the highest T sensitivity class “high sensitivite”, whereas in the other clusters the sensitivity was declared “sensitive”.

Figure 28: Ecograms of habitats FPH and FPH/DEC in the four climate clusters. The colour ramp shows the percentages of the frequency of the combination in temperature and water availability Ellenberg values. Abbreviations of GHC see Table 1.

Table 17: Sensitivity Index for T (temperature) and W (water availability) in the individual General Habitat Categories and cluster; abbreviations for General Habitat Category see Table 1.

Cluster		FPH	FPH/DEC
1	T	1.4	1.1
	W	2.6	2.7
2	T	2.0	1.2
	W	2.9	2.7
3	T	1.1	1.1
	W	3.2	3.4
4	T	1.3	1.2
	W	3.4	3.6

Table 18: Distribution of the life strategies in the different GHCs in percent. Abbreviations of the GHC see Table 1. Abbreviations for life-strategies see Box 3.

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	FPH	59	0	73	3	2	22	0	0	0
2	FPH	56	0	71	2	13	14	0	0	0
3	FPH	146	1	40	5	22	26	2	1	2
4	FPH	107	0	46	4	22	25	0	2	1
mean			0	58	4	15	22	1	1	1

Cluster	GHC	Number of species	<>%	c%	cr%	cs%	csr%	r%	s%	sr%
1	FPH/DEC	97	1	57	5	7	27	3	0	0
2	FPH/DEC	72	0	61	4	7	28	0	0	0
3	FPH/DEC	170	1	39	8	21	28	0	2	1
4	FPH/DEC	158	0	44	8	20	25	1	1	1
mean			0	50	6	14	27	1	1	0

The distribution of strategy types in the forest habitats exhibited a clear focus on the competitors with a minor proportion of csr-intermediate type (Table 18). To some extent, cs- and cr-types were found, whereas the stress-tolerant and ruderal species played nearly no role at all in the life strategies. The csr-types occurred in a higher proportion in FPH/DEC at the expense of the competitors in contrast to FPH.

This distinction was also visible in Grime's triangle, where especially the location of climate cluster 1 and 2 for the FPH/DEC was situated more towards the csr-area compared to FPH (Figure 29). For both habitats the grouping of climate clusters 1 and 2 as well as of clusters 3 and 4 was pronounced.

Putting the proportion of the strategy types into the linear relation with the climate parameters, the regression for FPH gave significant results with all factors but with precipitation from April to September. Especially, competitors and stress-tolerants resulted in the highest R^2 (Figure 30 a. and b.). FPH/DEC on the other side had weaker relations and only between competitors and temperature values and stress-tolerants with temperature and water balance (Figure 30 c. and d.). Interesting is the direction of the relationship between water balance and competitors: the regression showed in negative relation – the higher the water balance the fewer competitors

were present, also visible in the Grime's triangle with the separation of the clusters 3 and 4 below the other two.

Figure 29: Location of the habitats FPH and FPH/DEC within Grime's triangle. Abbreviations of the GHC see Table 1.

Large part of the differences and weak relationships of FPH/DEC can be attributed to the classification of the land use types into the GHC – in FPH, forests as such were included, whereas in FPH/DEC only small woody elements were present such as woodlots and hedges. In the small elements, the distinct features of forests are not as pronounced but the classification of the individual species according life strategy and Ellenberg remained the same for both GHCs.

On the European level, Alcamo et al. (2007) stated that native conifers are likely to be replaced by deciduous trees in western and central Europe. Vulnerability of conifer plantations in our landscape samples is therefore even higher as environmental conditions in our project region will be less and less favourable for conifers. Hazards like storm events will increase but their impact will strongly depend on the actual forest management.

**forest
ecosystems seem
to be especially
prone to climate
change**

Milad et al. (2011) elaborated an extensive review on the possible consequences and challenges of climate change in Central European forests. They summarise 130 papers dealing with different aspects of forest ecology in the view of climate change and nature conservation. They assume that forest ecosystems seem to be especially prone to climate change but that interdependencies between the ecosystems, climate change and other anthropogenic aspects hamper strong predictions about alteration in responses. In the following, we shortly summarise their main finding and conclusions:

Figure 30: Scatterplot of a. mean values of competitors in FPH versus mean temperature (April – September) with regression line ($R^2 = 0.7348$, , $p\text{-value} < 0.001$); b. mean values of competitors in FPH versus yearly water balance with regression line ($R^2 = 0.6071$, , $p\text{-value} < 0.001$); c. mean values of competitors in FPH/DEC versus mean temperature (April – September) with regression line ($R^2 = 0.3854$, , $n.s.$); d. mean values of competitors in FPH/DEC versus yearly water balance with regression line ($R^2 = 0.2135$, $n.s.$).

Each forest species will react individually to shifting conditions so that inter-species relationships and dependencies might change. Thus, new species compositions might develop locally. The colonisation of new areas with favourable environments will a.o. depends on the migration rate of the species and can therefore lag considerably behind the change rate intensified by the problem of highly fragmented and intensively used landscape.

**new species
compositions**

With the changing climate the frequency of extreme events is likely to increase which has an enormous impact on the disturbance regime. Natural selection of disturbance tolerant genotypes, mortality and the risk of fire might increase. Great uncertainties are associated with the projections about the behaviour on pathogen and pest outbreaks depending on the species' biology. Increase in wind speed and storm frequency as well as heavy precipitation events will lead to damages in the stand, higher erosion and landslides.

**more hazards,
altered
disturbance
regime**

incongruities between flowering event and pollinators activity	As already discussed with agricultural habitats, also here, the prolongation of the vegetation period will take place and can lead to incongruities between interacting phases of species such as flowering event and pollinators activity.
genetic diversity, phenotypic plasticity might mitigate	High genetic diversity and phenotypic plasticity might mitigate negative effects of elevated temperature and changed precipitation pattern. On the other hand, trees are long-living organism with a long generation time and thus face difficulties to adapt to rapid environmental changes within a short period. Pioneer species might benefit from this aspect because of their regeneration strategy. Especially tree seedlings are rather sensitive to drought and heat and thus natural regeneration might be hampered. On the other hand, increasing concentration of CO ₂ might improve the regeneration capacity of forests. The increase in disturbances enhances early-successional stages and therefore providing the opportunity to readjust the ecosystem to changing conditions more easily. In general, short-lived, generalistic R-strategists will be promoted. In often disturbed areas late-successional forests eventually will be missing and thus habitat for many species dependent on this successional stage.
higher productivity	On the local level, literature exists for rather specific questions for case studies: Campioli et al. (2012) concluded for Belgian forests that the most severe disturbances were caused by extreme climatic events. Their productivity is likely to be enhanced in future due to atmospheric deposition and soil fertilisation going in line with the increase in atmospheric CO ₂ concentration. In Hungary, especially in the northeastern part, afforestation may even reduce projected climate change through higher evapotranspiration and precipitation as well as lower surface temperatures for the entire summer period (Galos et al., 2011). The sensitivity of forest stands to wind throw in Germany was mainly driven by a high proportion of coniferous trees together with a complex terrain and poor soils (Klaus et al., 2011).
species specific reactions	Scherrer et al. (2011) stressed the fact that tree species will respond very specific to water shortage because they are very variable in rooting depth and physiological traits relate to water balance. They found that <i>Acer pseudoplatanus</i> to be the most drought sensitive species followed by <i>Fagus sylvatica</i> , <i>Tilia platyphyllos</i> and <i>Prunus avium</i> and the two ring-porous species <i>Fraxinus excelsior</i> and <i>Quercus petraea</i> being clearly the least sensitive ones. At drier sites, increasing summer temperatures and drought might change the competitive abilities of tree species in favour of those that are able to maintain transpirational fluxes and cooler canopies such as <i>Fraxinus excelsior</i> and <i>Quercus petraea</i> .
changing management as mitigation strategy	<p>General mitigation strategies for forest involve the changes in species composition of forest stands towards a set of better adapted species and genotypes. Especially, the planting of deciduous trees in conifer stands together with adaptive forest management can enhance the resilience towards wind and other extreme weather events (Alcamo et al., 2007).</p> <p>Milad et al. (2011) stresses the point that measures to mitigate climate change, such as managing forests for carbon sequestration, can counteract objectives of</p>

biodiversity conservation. One example is the selection of non-native but productive tree species, raising severe conflicts between economical and ecological orientated stakeholders. Another point is the reduction in rotation periods. Since commercial forestry already reduces lifetimes of trees by harvesting before they reach their biological maturity, a further reduction could be particularly harmful to nature conservation objectives.

Flexible management strategies and concepts promoting resilience or sustainability of the ecosystem should especially minimise soil compaction, degradation, runoff and erosion because water balance and soil state are key factors in facilitating ecosystem responses to climate change. Establishing tree species on unsuitable sites in the past could be a reason for earlier responses of trees to climate change in some regions. In Germany, *Picea abies* has also been planted on shallow sites with low water retention capacity, where warmer and drier conditions become noticeable in increasing calamities and reduced productivity to date, the same in Austria. But decisions of forest managers about appropriate tree species will be especially difficult if climatic conditions at a given site change rapidly.

**promoting
resilience**

On the other hand, it is also recommended to convert unsuitable monocultures into mixed forests which may have positive effects on nature conservation purposes as well. Even though, intensive research is going on, many questions and aspects concerning the responses of forests still remain open, especially on the very local scale. All modelled changes in species composition, species diversity and groundwater recharge are based on rather general conditions and applicable for large areas in Europe, the detailed development of the forest stand may depend strongly on sites, stand composition and management strategies.

5. Discussion

5.1. Ecological envelopes

Aggregation of species-data via Ellenberg values to a generalised level already proved useful for describing changes in vegetation caused by alterations in climatic conditions (Morecroft et al., 2009). Thuiller et al. (2005) already found, that temperature and moisture conditions are mainly responsible for changes in species ranges and turnovers. Hence, we developed an ecological envelope with the Ellenberg values integrating these components. The species number of 683 plant species, which contributed to the ecological envelope of the broader habitats, covers the species diversity of the region sufficiently, as Englisch et al. (2005) have described 200 – 600 plant species in the location of the landscape samples. We found that Ellenberg T values of landscape samples can be related to temperature values of regional climate models quite well. In contrast to that, the Ellenberg water availability-indicator W corresponds not directly to precipitation values in the regression models. This can be explained by the fact, that humidity of a specific site is influenced by additional factors at small spatial scales, like geomorphological properties, soil proportions or amelioration measures (Ellenberg, 1988).

Although it is most unlikely, that climate change will have the same impact throughout the different locations of the landscape samples, clustering of the climate parameters revealed certain similarities between the landscape samples. These regional clusters made it possible to enhance the robustness of the ecological envelope due to the increased sample size achieved by adding up the samples of the landscapes to the level of clusters. In general, current climatic conditions of the project region show rarely any extreme situations and a little dynamics in terms of climate change (Loibl et al., 2009).

Ohlemüller (2011) stressed the fact that the *“spatial configuration and heterogeneity of shifting isotherms and associated climate space are crucial for understanding species’ responses to these shifts over space and time”*. He acknowledged three major aspects for species concerning their climate space: (i) areal extent of specific climatic settings, (ii) how distant these areas are and (iii) if barriers hamper the migration to these areas. These aspects drive the geographic distribution of the species. The climate space for the individual species might increase or decrease in the future, it can even happen that some conditions might disappear at all whilst new climate spaces might arise.

**careful
interpretation of
climate envelope
models**

Climate envelopes and models alone are always associated with some drawbacks and detailed predictions and projections need to be interpreted with care (a.o. Bittner et al., 2011, Botkin et al., 2007, Ferrier and Guisan, 2006, Mokany and Ferrier, 2011). The models are only as good as the underlying climate data are (Ohlemueller, 2011). Dynamic processes such as dispersal and migration rate or natural disturbance regimes are hardly implemented in bioclimatic envelopes (Botkin et al., 2007) but do all drive the distribution of species (Ohlemueller, 2011). These factors depend on a whole bundle of parameters like species traits, competition, spatial habitat configuration and climatic conditions (Meier et al., 2012). Variations in genotypes

and phenotypes within a species are rarely considered as well but do have an enormous potential for the adaption to future environmental condition (Botkin et al., 2007, Bunce et al., 2008). Being able to either track the current climate space or to occupy the new one will be the crucial point for the species survival (Ohlemueller, 2011).

Hence, the adjustments of species ranges and distributions are complex and species-specific. Meier et al. (2012) concluded that early-successional species might be able to follow climate change almost instantaneously while mid- to late-successional species were predicted to migrate very slow, thus being more susceptible to extinction.

adjustments of species ranges and distributions are complex and species-specific

The way forward to better understand ecological responses to global change are clearly the combination of climate space analysis with new approaches in species, population and community modelling (Ohlemueller, 2011). Having these literature discussions in mind, we only confer possible climate change impacts in our project region, since we were limited in our data resources to apply such extensive models for details projecting.

5.2. Life strategies

In general, the proportions of different life strategies in our habitats clearly reflected their use, on the one hand a large amount of ruderals in agricultural habitat types and the dominance of competitors in forest habitat types. Lomba et al. (2011) showed in their analysis that only stress-tolerant species richness was correlated with climatic predictors whereas in our results also competitors could be correlated to climate parameters. S-strategists are known to be dependent on the environmental conditions on micro-scale which in principle do not capture the general landscape settings (Grime, 2001).

We also showed the clear link of ruderals and competitors with the GHC confirming the strong dependency of species composition on land use activities already presented by Lomba et al. (2011). They showed that diversity metrics were better explained by landscape predictors than physical ones. The functional traits of plant species are therefore an important aspect for considering the impacts of changing environmental gradients (Lomba et al., 2011, Steinmann et al., 2009).

5.3. Impact on biodiversity

In general, it must be stated that species turnover will most likely occur in the broader habitats, since altered ecological niches will not be occupied by present species, and newly arriving species are gained (Milad et al., 2011, Thuiller et al., 2005, Wiens et al., 2011). Loss of specific broader habitats will probably occur, when extreme environmental conditions do not allow for an adaptation of the ecological envelope. On the other hand, niches and species diversity might even be increased due to the influence of altered disturbance regimes (Milad et al., 2011). For other landscapes like high mountain areas, where vegetation already is exposed to a more

species turnover

extreme environment, even little changes will have a more severe impact on the existing species ranges (Thuiller et al., 2005) and plant communities (Trivedi et al., 2008).

These impacts can be assessed by the sensitivity of the broader habitats. The IPCC (2001b) defined sensitivity as the degree to which a species is affected either adversely or beneficially, by climate change. Normand et al. (2007) assessed species' sensitivity with bioclimatic models, Vasquez and Simonetti (1999) defined a sensitivity index based on literature review of vulnerability of life history traits and Roloff et al. (2009) developed a climate-species-matrix. We defined the sensitivity of habitats independently of species in order to avoid bias in species distribution data and biogeographical range.

Broader habitats showed a much higher sensitivity to W than T values, because many plant species are categorised as indifferent to temperature, but are classified to one of the twelve Ellenberg's W categories. Consequently, the ratio of sensitive to indifferent species for the sensitivity index W was much higher. It is to expect that the high rise in annual precipitation in cluster 3 and 4 of > 100 mm will have a high impact on the broader habitats due to the fact of the high sensitivity W index, although we cannot capture the direct link of precipitation with the regression models, since the system of water availability is quite complex.

The best regression models for temperature were achieved for the broader habitats FPH, HER/LHE and SPV/AQU (aquatic vegetation) which also showed a medium to high sensitivity T index. As these habitats were also the ones with highest naturalness, it can be concluded that the temperature rise will have a higher impact on the more natural landscape elements than on the ones with higher anthropogenic influence.

**decline of
suitable habitat
for forest,
wetland and
grassland
species**

This conclusion goes in line with Vos et al. (2008), where a decline of suitable habitat for forest, wetland and grassland species is predicted. Many other authors stressed the fact, that interdependencies between land use, landscape fragmentation, nitrogen deposition and climate change might aggravate the problem of predicting the impact on biodiversity by climate change alone, since all these aspects go hand in hand (Botkin et al., 2007, Milad et al., 2011).

One of the Botkin's "*eight ways to improve biodiversity forecasting*" (Botkin et al., 2007) brings this clearly to the point:

(iii) "*Account for multiple causes of changes in biodiversity*"

They argued for an integration of many human aspects into biodiversity modelling, since society is putting pressure on biodiversity by many ways such as land conversion, pollution, introduction of exotic species and many more. The need of disentangling the effect of climate change from other factors is plainly given according to their paper. Especially the loss of key species will have strong impacts on the ecosystem (Milad et al., 2011).

All these driving forces might lead to species compositions which were not given yet and do not resemble today's known assemblages (Wiens et al., 2011). Hence, species interactions will alter and new inter-species relationships will establish. These new interactions will also affect whether species remain limited to their current environmental conditions or whether they can inhabit a new climate space (Ohlemueller, 2011).

On the level of habitat diversity, Bittner et al. (2011) stressed the fact that habitat types are complex structures not only shaped by species compositions and climatic conditions but a whole range of other abiotic conditions. The habitats' distributions reflect historical and actual traditions, management, cultural and political circumstances. For the prediction and management of habitats in agricultural landscapes, it is necessary to better understand the causes of biodiversity in agricultural landscapes (Lomba et al., 2011). Especially in agricultural landscapes, species richness and composition is largely driven by land use (Wrbka et al., 2004; Zechmeister et al., 2003). The awareness that large amount of existing biodiversity is located in our agricultural landscapes has grown and shaped many recent studies (a.o. Billeter et al., 2008, Lomba et al., 2011) and projects (f. ex. EBONE).

habitat types are complex structures

<http://www.ebone.wur.nl/UK/>

As outlined in chapter 4.2.2, land management practices might change in order to adapt to new conditions (Bindi and Olesen, 2011, Trnka et al., 2011). This might eventually lead to a different species composition adjusted to new sowing and harvesting dates.

For forest habitats, the impact on biodiversity still remains blurry. There is the suggestion that impacts might be strongest for plant and tree species due to their relatively narrow climate space (Milad et al., 2011). On the other hand, they also discuss amongst other aspects that windthrow events might even increase biodiversity by creating a heterogeneous structure of cleared and uncleared patches. Furthermore, species adapted to dead wood as well as understory plants may profit due to more forest damages and enhanced light conditions.

5.4. Mitigation measures

The implications of the results for landscape planning are two-fold. Since landscape planning is organised on the provincial scale, this can be seen of advantage for planning mitigation measures of such regional impacts of climate change. On the other hand, institutional landscape planning does not intervene in land use activities, so the maintenance of habitats could be enhanced rather by subsidy schemes like the Austrian agri-environmental scheme, if these subsidies are targeted enough (Wrbka et al., 2008).

landscape planning measures

The expected changes in climatic condition will have also consequences for conservation planning and activities in the region. The establishment of Natura2000 sites aimed to maintain habitats in a favourable conservation status (Council of the European Union, 1992). However, the changes in the natural conditions of the

implications for nature conservation

habitats are not taken into account by this strategy. The risks of extinction for European plants may be large; species loss and turnover of more than 50% are projected for the continental biogeographic region (Thuiller et al., 2005). Normand et al. (2007) conclude that it is not realistic to preserve the current status of specific habitat types in place in small regions, but only on the European scale. Consequently, it is very important to improve migration possibilities of species (Normand et al., 2007; Vos et al., 2008).

The wide range of factors driving the species assemblages need to be considered in the management plans elaborated for the conservation of species and habitats of interest. Changing climatic conditions can lead to the need that this management may need to be directed toward species not considered in current management plans (Wiens et al., 2011). In general, conservation areas are targeted to preserve rare or endemic species. But very often, these species are specialists for very specific edaphic features or microclimatic conditions independently from the macro-climatic level. Consequently, bioclimatic models do only apply to a minor amount for these species and thus for conservation needs (Milad et al., 2011).

As temperature increase in the project region is below the European mean, the expected impact is more likely to arise from the rather big increase in precipitation, especially as our results suggest a high sensitivity to water availability. Dry habitats are therefore at a large risk to be extinct in the region whereas wet habitats will encounter only minor problems. However, this study can only present general trends for habitats in agricultural landscapes with average environmental conditions. Meaningful conclusions for habitats under conservation priorities or for landscapes with more pronounced environmental stress need further research, since sampling design would need to be revised as these rare habitats are underrepresented in our sampling design.

Not explicitly considered in the scenarios but of high relevance for the future development of biodiversity conditions are general mitigation strategies of the human society. Mitigation of climate change in a broader sense includes in particular measures to reduce emissions of greenhouse gases or to sequester carbon dioxide. There is no serious scientific doubt on urgent needs to reduce greenhouse gas emissions from human activities, and to implement political measures. However, it is also urgent necessary to assess comprehensively the consequences of individual measures, to avoid additional risks. This is in particular valid for the propagation of large scale applications of biomass and biomaterial technologies. Several euphemisms were created during the last decade by influential lobby groups to persuade public opinion, for example green technologies, or “bio” in different combinations. But there is a big difference between ecologically adapted exploitation of vegetation or animals for human needs and large scale applications of the technologies. Ecologically adapted small scale exploitation of plant and animals can contribute to biomass protection and enhance the flexibility to meet the challenges of uncertainties. However, it needs also adaptations in the structure of processing systems to be economically viable for enterprises. Large scale applications of these technologies are dependent on standardised raw materials to remain economically

attractive. Systemic consequences of such strategies are large monoculture plantations and genetical manipulations of organisms, already propagated in scientific articles (Ragauskas et al., 2006). Such technologies are already realised in several regions of the world, and there is also a high probability for the introduction in Europe in particular for non-food applications, in particular energy conversion or for new materials. This will jeopardise the biodiversity additional to the climate impacts.

Much more sustainable is the diversification of strategies under full awareness of the uncertainties of climate changes (Millar et al., 2007). Spatial combinations of different management intensities will reduce the risk to put all eggs in one basket. Such approaches are compatible with ecological adapted small scale transformations of production systems to more sustainable characteristics, as mentioned above. Heterogeneous landscapes, like in mountain areas or Upper Austria, provide ideal conditions to increase flexibility toward uncertain changes of environmental conditions. However, it is in the hand of the local population to take the right decisions and in the hand of scientist to inform them about the best options.

6. References

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Annex A: General Habitat Category (GHC) and the full name (description) according to Bunce et al. (2008, 2011).

GHC	Description
URB/NON	Urban-Non-vegetated
URB/ART	Urban-Artificial
URB/VEG	Urban-Vegetables
URB/TRE	Urban-Woody
URB/GRA	Urban-Herbaceous
CUL/SPA	Crops-Cultivated bare ground
CUL/CRO	Crops-Cultivated herbaceous crops
CUL/WOC	Crops-Woody crops
SPV/SEA	Sparsely Vegetated-Sea
SPV/MAR	Sparsely Vegetated-Marine
SPV/AQU	Sparsely Vegetated-Aquatic
SPV/TER	Sparsely Vegetated-Terrestrial
SPV/ICE	Sparsely Vegetated-Ice and snow
HER/SHY	Vegetated Herbaceous-Submerged hydrophytes
HER/EHY	Vegetated Herbaceous-Emergent hydrophytes
HER/HEL	Vegetated Herbaceous-Helophytes
HER/LHE	Vegetated Herbaceous-Leafy hemicryptophytes
HER/CHE	Vegetated Herbaceous-Caespitose hemicryptophytes
HER/THE	Vegetated Herbaceous-Therophytes
HER/SUC	Vegetated Herbaceous-Succulents
HER/GEO	Vegetated Herbaceous-Geophytes
HER/HCH	Vegetated Herbaceous-Herbaceous chamaephytes
HER/CRY	Vegetated Herbaceous-Cryptogams
DCH/DEC	Dwarf chamaephytes (< 0.05 m)-Winter deciduous
LPH/DEC	Low phanerophytes (0.30-0.6 m)-Winter deciduous
SCH/DEC	Shrubby chamaephytes (0.05-0.30 m)-Winter deciduous
MPH/DEC	Mid phanerophytes (0.6 – 2 m)-Winter deciduous
FPH/DEC	Forest phanerophytes (>5 m)-Winter deciduous
NLE/DEC	Non-leafy evergreen-Winter deciduous
TPH/DEC	Tall phanerophytes (2- 5 m)-Winter deciduous
DCH/EVR	Dwarf chamaephytes (< 0.05 m)-Evergreen
LPH/EVR	Low phanerophytes (0.30-0.6 m)-Evergreen
SCH/EVR	Shrubby chamaephytes (0.05-0.30 m)-Evergreen
MPH/EVR	Mid phanerophytes (0.6 – 2 m)-Evergreen
FPH/EVR	Forest phanerophytes (>5 m)-Evergreen
NLE/EVR	Non-leafy evergreen-Evergreen
TPH/EVR	Tall phanerophytes (2- 5 m)-Evergreen
DCH/CON	Dwarf chamaephytes (< 0.05 m)-Coniferous
LPH/CON	Low phanerophytes (0.30-0.6 m)-Coniferous
SCH/CON	Shrubby chamaephytes (0.05-0.30 m)-Coniferous
MPH/CON	Mid phanerophytes (0.6 – 2 m)-Coniferous
FPH/CON	Forest phanerophytes (>5 m)-Coniferous
NLE/CON	Non-leafy evergreen-Coniferous
TPH/CON	Tall phanerophytes (2- 5 m)-Coniferous

DCH/SPI	Dwarf chamaephytes (< 0.05 m)-Summer deciduous and/or spiny cushion
LPH/SPI	Low phanerophytes (0.30-0.6 m)-Summer deciduous and/or spiny cushion
SCH/SPI	Shrubby chamaephytes (0.05-0.30 m)-Summer deciduous and/or spiny cushion
MPH/SPI	Mid phanerophytes (0.6 – 2 m)-Summer deciduous and/or spiny cushion
FPH/SPI	Forest phanerophytes (>5 m)-Summer deciduous and/or spiny cushion
NLE/SPI	Non-leafy evergreen-Summer deciduous and/or spiny cushion
TPH/SPI	Tall phanerophytes (2- 5 m)-Summer deciduous and/or spiny cushion

Annex B: Plant species list of occurring species in the vegetation relevés in the landscape samples.

<i>Abies alba</i>	<i>Acer campestre</i>	<i>Acer platanoides</i>	<i>Acer pseudoplatanus</i>	<i>Achillea millefolium</i>
<i>Achillea millefolium</i> agg.	<i>Aconitum lycoctonum</i>	<i>Aconitum variegatum</i>	<i>Aconitum variegatum</i> agg.	<i>Actaea spicata</i>
<i>Adenostyles alliariae</i>	<i>Adenostyles glabra</i>	<i>Aegopodium podagraria</i>	<i>Aesculus hippocastanum</i>	<i>Aethusa cynapium</i>
<i>Agropyron</i> sp.	<i>Agrostis canina</i> agg.	<i>Agrostis capillaris</i>	<i>Agrostis gigantea</i>	<i>Agrostis rupestris</i>
<i>Agrostis stolonifera</i>	<i>Agrostis stolonifera</i> agg.	<i>Ajuga reptans</i>	<i>Alchemilla</i> sp.	<i>Alchemilla vulgaris</i> agg.
<i>Alisma plantago-aquatica</i>	<i>Alisma plantago-aquatica</i> agg.	<i>Alliaria petiolata</i>	<i>Allium angulosum</i>	<i>Allium schoenoprasum</i>
<i>Allium</i> sp.	<i>Alnus alnobetula</i>	<i>Alnus glutinosa</i>	<i>Alnus incana</i>	<i>Alopecurus pratensis</i>
<i>Alopecurus pratensis</i> agg.	<i>Amaranthus retroflexus</i>	<i>Anagallis arvensis</i>	<i>Andromeda polifolia</i>	<i>Anemone nemorosa</i>
<i>Angelica archangelica</i>	<i>Angelica sylvestris</i>	<i>Antennaria dioica</i>	<i>Anthemis arvensis</i>	<i>Anthoxanthum alpinum</i>
<i>Anthoxanthum odoratum</i>	<i>Anthoxanthum odoratum</i> agg.	<i>Anthriscus sylvestris</i>	<i>Anthriscus sylvestris</i> agg.	<i>Anthyllis vulneraria</i>
<i>Anthyllis vulneraria</i> ssp. <i>alpestris</i>	<i>Apera spica-venti</i>	<i>Arctium lappa</i>	<i>Arenaria serpyllifolia</i> agg.	<i>Armoracia rusticana</i>
<i>Arnica montana</i>	<i>Arrhenatherum elatius</i>	<i>Artemisia</i> sp.	<i>Artemisia vulgaris</i>	<i>Artemisia vulgaris</i> agg.
<i>Aruncus dioicus</i>	<i>Aster bellidiastrum</i>	<i>Aster novi-belgii</i>	<i>Astragalus glycyphyllos</i>	<i>Astrantia major</i>
<i>Athyrium filix-femina</i>	<i>Atriplex hortensis</i>	<i>Atriplex patula</i>	<i>Avenella flexuosa</i>	<i>Avenula pubescens</i>
<i>Bartsia alpina</i>	<i>Bellis perennis</i>	<i>Betonica officinalis</i>	<i>Betula pendula</i>	<i>Betula pubescens</i>
<i>Bidens tripartitus</i>	<i>Blysmus compressus</i>	<i>Brachypodium sylvaticum</i>	<i>Briza media</i>	<i>Bromus erectus</i> agg.
<i>Bromus hordeaceus</i>	<i>Bromus inermis</i>	<i>Bromus ramosus</i>	<i>Bromus</i> sp.	<i>Bromus stenophyllus</i>
<i>Bromus sterilis</i>	<i>Calamagrostis arundinacea</i>	<i>Calamagrostis epigejos</i>	<i>Calamagrostis varia</i>	<i>Calla palustris</i>
<i>Callitriche palustris</i> agg.	<i>Calluna vulgaris</i>	<i>Caltha palustris</i>	<i>Calycocorsus stipitatus</i>	<i>Calystegia sepium</i> agg.
<i>Campanula cochleariifolia</i>	<i>Campanula glomerata</i>	<i>Campanula patula</i>	<i>Campanula persicifolia</i>	<i>Campanula rotundifolia</i>
<i>Campanula scheuchzeri</i>	<i>Campanula trachelium</i>	<i>Capsella bursa-pastoris</i>	<i>Cardamine amara</i>	<i>Cardamine pratensis</i>
<i>Cardamine</i> sp.	<i>Carex acuta</i>	<i>Carex acutiformis</i>	<i>Carex alba</i>	<i>Carex appropinquata</i>
<i>Carex brizoides</i>	<i>Carex canescens</i>	<i>Carex caryophyllea</i>	<i>Carex davalliana</i>	<i>Carex digitata</i>
<i>Carex echinata</i>	<i>Carex elata</i>	<i>Carex elongata</i>	<i>Carex ferruginea</i>	<i>Carex flacca</i>
<i>Carex flava</i>	<i>Carex frigida</i>	<i>Carex gracilis</i>	<i>Carex hirta</i>	<i>Carex leporina</i>
<i>Carex muricata</i> agg.	<i>Carex nigra</i>	<i>Carex nigra</i> agg.	<i>Carex pallescens</i>	<i>Carex panicea</i>
<i>Carex paniculata</i>	<i>Carex pilosa</i>	<i>Carex riparia</i>	<i>Carex rostrata</i>	<i>Carex sempervirens</i>
<i>Carex</i> sp.	<i>Carex sylvatica</i>	<i>Carex vesicaria</i>	<i>Carlina acaulis</i>	<i>Carlina frigida</i>
<i>Carpinus betulus</i>	<i>Carum carvi</i>	<i>Centaurea cyanus</i>	<i>Centaurea jacea</i>	<i>Centaurea scabiosa</i>
<i>Centaurea scabiosa</i> ssp. <i>alpestris</i>	<i>Cerastium arvense</i>	<i>Cerastium holosteoides</i>	<i>Cerastium</i> sp.	<i>Cerinthe glabra</i>
<i>Chaerophyllum aureum</i>	<i>Chaerophyllum bulbosum</i>	<i>Chaerophyllum hirsutum</i>	<i>Chaerophyllum hirsutum</i> agg.	<i>Chaerophyllum</i> sp.
<i>Chaerophyllum villarsii</i>	<i>Chamaecyparis</i> sp.	<i>Chelidonium majus</i>	<i>Chenopodium album</i>	<i>Chenopodium album</i> agg.
<i>Chenopodium</i>	<i>Chrysosplenium</i>	<i>Circaea lutetiana</i>	<i>Cirsium arvense</i>	<i>Cirsium oleraceum</i>

<i>bonus-henricus</i>	<i>alternifolium</i>			
<i>Cirsium palustre</i>	<i>Cirsium rivulare</i>	<i>Cirsium vulgare</i>	<i>Clematis vitalba</i>	<i>Clinopodium vulgare</i>
<i>Colchicum autumnale</i>	<i>Convallaria majalis</i>	<i>Convolvulus arvensis</i>	<i>Conyza canadensis</i>	<i>Cornus mas</i>
<i>Cornus sanguinea</i>	<i>Corylus avellana</i>	<i>Crataegus monogyna</i>	<i>Crataegus monogyna</i> ssp. <i>monogyna</i>	<i>Crepis aurea</i>
<i>Crepis biennis</i>	<i>Crepis capillaris</i>	<i>Crepis paludosa</i>	<i>Crocus albiflorus</i>	<i>Cuscuta epithymum</i> agg.
<i>Cynosurus cristatus</i>	<i>Dactylis glomerata</i>	<i>Dactylis glomerata</i> agg.	<i>Dactylis glomerata</i> ssp. <i>glomerata</i>	<i>Dactylorhiza maculata</i>
<i>Danthonia decumbens</i>	<i>Daphne mezereum</i>	<i>Daucus carota</i>	<i>Deschampsia cespitosa</i>	<i>Deschampsia cespitosa</i> agg.
<i>Dianthus carthusianorum</i>	<i>Dianthus deltoides</i>	<i>Dianthus sylvestris</i>	<i>Digitaria sanguinalis</i>	<i>Drosera rotundifolia</i>
<i>Dryopteris carthusiana</i>	<i>Dryopteris dilatata</i>	<i>Dryopteris filix-mas</i>	<i>Echinochloa crus-galli</i>	<i>Eleocharis quinqueflora</i>
<i>Elymus repens</i>	<i>Epilobium angustifolium</i>	<i>Epilobium hirsutum</i>	<i>Epilobium lanceolatum</i>	<i>Epilobium montanum</i>
<i>Epilobium palustre</i>	<i>Epilobium parviflorum</i>	<i>Epilobium</i> sp.	<i>Epilobium tetragonum</i>	<i>Epipactis helleborine</i>
<i>Equisetum arvense</i>	<i>Equisetum fluviatile</i>	<i>Equisetum palustre</i>	<i>Equisetum pratense</i>	<i>Equisetum sylvaticum</i>
<i>Erigeron annuus</i>	<i>Eriophorum angustifolium</i>	<i>Eriophorum latifolium</i>	<i>Eriophorum scheuchzeri</i>	<i>Eriophorum vaginatum</i>
<i>Erysimum cheiranthoides</i>	<i>Eupatorium cannabinum</i>	<i>Euphorbia cyparissias</i>	<i>Euphorbia helioscopia</i>	<i>Euphorbia peplus</i>
<i>Euphrasia minima</i>	<i>Euphrasia rostkoviana</i>	<i>Euphrasia rostkoviana</i> agg.	<i>Evonymus europaea</i>	<i>Fagus sylvatica</i>
<i>Fallopia convolvulus</i>	<i>Festuca gigantea</i>	<i>Festuca nigrescens</i>	<i>Festuca ovina</i> agg.	<i>Festuca pratensis</i>
<i>Festuca pulchella</i>	<i>Festuca pulchella</i> ssp. <i>jurana</i>	<i>Festuca pulchella</i> ssp. <i>pulchella</i>	<i>Festuca rubra</i>	<i>Festuca rubra</i> agg.
<i>Festuca</i> sp.	<i>Filipendula ulmaria</i>	<i>Filipendula ulmaria</i> ssp. <i>denudata</i>	<i>Fragaria moschata</i>	<i>Fragaria vesca</i>
<i>Fragaria viridis</i>	<i>Frangula alnus</i>	<i>Fraxinus excelsior</i>	<i>Galeopsis pubescens</i>	<i>Galeopsis</i> sp.
<i>Galeopsis speciosa</i>	<i>Galeopsis tetrahit</i>	<i>Galeopsis tetrahit</i> agg.	<i>Galinsoga ciliata</i>	<i>Galinsoga parviflora</i>
<i>Galium album</i>	<i>Galium anisophyllum</i>	<i>Galium aparine</i>	<i>Galium aparine</i> agg.	<i>Galium lucidum</i>
<i>Galium mollugo</i>	<i>Galium mollugo</i> agg.	<i>Galium odoratum</i>	<i>Galium palustre</i>	<i>Galium parisiense</i> agg.
<i>Galium</i> sp.	<i>Galium spurium</i>	<i>Galium uliginosum</i>	<i>Galium verum</i>	<i>Galium verum</i> agg.
<i>Genista germanica</i>	<i>Gentiana asclepiadea</i>	<i>Gentiana punctata</i>	<i>Gentianella campestris</i>	<i>Geranium molle</i>
<i>Geranium molle</i> agg.	<i>Geranium palustre</i>	<i>Geranium pratense</i>	<i>Geranium pusillum</i>	<i>Geranium robertianum</i>
<i>Geranium robertianum</i> agg.	<i>Geranium sanguineum</i>	<i>Geranium</i> sp.	<i>Geranium sylvaticum</i>	<i>Geum rivale</i>
<i>Geum urbanum</i>	<i>Glechoma hederacea</i>	<i>Glechoma hederacea</i> agg.	<i>Globularia nudicaulis</i>	<i>Glyceria declinata</i>
<i>Glyceria fluitans</i>	<i>Glyceria fluitans</i> agg.	<i>Glyceria notata</i>	<i>Gnaphalium norvegicum</i>	<i>Gnaphalium sylvaticum</i>
<i>Gnaphalium uliginosum</i>	<i>Gymnadenia conopsea</i>	<i>Gypsophila repens</i>	<i>Hedera helix</i>	<i>Helianthemum grandiflorum</i>
<i>Heracleum sphondylium</i>	<i>Hieracium lactucella</i>	<i>Hieracium laevigatum</i>	<i>Hieracium murorum</i>	<i>Hieracium pilosella</i>
<i>Hieracium</i> sp.	<i>Hieracium umbellatum</i>	<i>Hieracium villosum</i>	<i>Holcus lanatus</i>	<i>Holcus mollis</i>
<i>Humulus lupulus</i>	<i>Hypericum maculatum</i>	<i>Hypericum maculatum</i> agg.	<i>Hypericum perforatum</i>	<i>Hypochoeris radicata</i>
<i>Impatiens glandulifera</i>	<i>Impatiens noli-tangere</i>	<i>Impatiens parviflora</i>	<i>Iris pseudacorus</i>	<i>Juglans regia</i>
<i>Juncus arcticus</i>	<i>Juncus articulatus</i>	<i>Juncus bulbosus</i>	<i>Juncus effusus</i>	<i>Juncus filiformis</i>
<i>Juncus inflexus</i>	<i>Juncus</i> sp.	<i>Juncus tenuis</i>	<i>Knautia arvensis</i>	<i>Knautia arvensis</i> agg.
<i>Knautia drymeia</i>	<i>Knautia maxima</i>	<i>Lamiastrum montanum</i>	<i>Lamium maculatum</i>	<i>Lamium purpureum</i>
<i>Lapsana communis</i>	<i>Larix decidua</i>	<i>Lathyrus pratensis</i>	<i>Legousia speculum-veneris</i>	<i>Lemna minor</i>
<i>Leontodon autumnalis</i>	<i>Leontodon helveticus</i>	<i>Leontodon hispidus</i>	<i>Leucanthemum atratum</i>	<i>Leucanthemum atratum</i> agg.
<i>Leucanthemum ircutianum</i>	<i>Leucanthemum vulgare</i>	<i>Leucanthemum vulgare</i> agg.	<i>Ligusticum mutellina</i>	<i>Ligustrum vulgare</i>
<i>Linaria alpina</i>	<i>Linaria vulgaris</i>	<i>Linum catharticum</i>	<i>Lolium multiflorum</i>	<i>Lolium perenne</i>

<i>Lonicera caerulea</i>	<i>Lonicera xylosteum</i>	<i>Lotus corniculatus</i>	<i>Lotus corniculatus</i> agg.	<i>Luzula alpina</i>
<i>Luzula campestris</i> agg.	<i>Luzula luzulina</i>	<i>Luzula luzuloides</i>	<i>Luzula multiflora</i>	<i>Luzula pilosa</i>
<i>Luzula sylvatica</i>	<i>Lychnis flos-cuculi</i>	<i>Lychnis viscaria</i>	<i>Lycium europaeum</i>	<i>Lycopus europaeus</i>
<i>Lysimachia nemorum</i>	<i>Lysimachia nummularia</i>	<i>Lysimachia punctata</i>	<i>Lysimachia vulgaris</i>	<i>Lythrum salicaria</i>
<i>Maianthemum bifolium</i>	<i>Malus domestica</i>	<i>Malva neglecta</i>	<i>Matricaria chamomilla</i>	<i>Matricaria matricarioides</i>
<i>Medicago lupulina</i>	<i>Medicago sativa</i> agg.	<i>Medicago varia</i>	<i>Melampyrum nemorosum</i> agg.	<i>Melampyrum pratense</i>
<i>Melampyrum</i> sp.	<i>Melampyrum sylvaticum</i> agg.	<i>Melilotus officinalis</i>	<i>Mentha aquatica</i>	<i>Mentha arvensis</i>
<i>Mentha longifolia</i>	<i>Mentha</i> sp.	<i>Mentha verticillata</i> agg.	<i>Menyanthes trifoliata</i>	<i>Mercurialis perennis</i>
<i>Molinia arundinacea</i>	<i>Molinia caerulea</i>	<i>Molinia caerulea</i> agg.	<i>Mycelis muralis</i>	<i>Myosotis arvensis</i>
<i>Myosotis palustris</i> agg.	<i>Myosotis scorpioides</i>	<i>Myosotis</i> sp.	<i>Myosoton aquaticum</i>	<i>Nardus stricta</i>
<i>Nasturtium officinale</i>	<i>Oenothera biennis</i> agg.	<i>Onobrychis viciifolia</i>	<i>Origanum vulgare</i>	<i>Orobanche minor</i>
<i>Oxalis acetosella</i>	<i>Oxalis stricta</i>	<i>Papaver rhoeas</i>	<i>Paris quadrifolia</i>	<i>Parnassia palustris</i>
<i>Pastinaca sativa</i>	<i>Pedicularis foliosa</i>	<i>Pedicularis sylvatica</i>	<i>Persicaria bistorta</i>	<i>Persicaria hydropiper</i>
<i>Persicaria lapathifolia</i>	<i>Petasites albus</i>	<i>Petasites hybridus</i>	<i>Petasites paradoxus</i>	<i>Peucedanum ostruthium</i>
<i>Phalaris arundinacea</i>	<i>Phegopteris connectilis</i>	<i>Phleum hirsutum</i>	<i>Phleum pratense</i>	<i>Phleum pratense</i> agg.
<i>Phleum rhaeticum</i>	<i>Phragmites australis</i>	<i>Phyteuma orbiculare</i>	<i>Picea abies</i>	<i>Picea pungens</i>
<i>Picris hieracioides</i>	<i>Pimpinella major</i>	<i>Pimpinella saxifraga</i>	<i>Pimpinella saxifraga</i> agg.	<i>Pinguicula vulgaris</i>
<i>Pinus mugo</i>	<i>Pinus nigra</i>	<i>Pinus sylvestris</i>	<i>Pisum sativum</i>	<i>Plantago lanceolata</i>
<i>Plantago major</i>	<i>Plantago media</i>	<i>Pleurospermum austriacum</i>	<i>Poa alpina</i>	<i>Poa annua</i>
<i>Poa annua</i> agg.	<i>Poa cenisia</i>	<i>Poa nemoralis</i>	<i>Poa nemoralis</i> agg.	<i>Poa palustris</i>
<i>Poa pratensis</i>	<i>Poa pratensis</i> agg.	<i>Poa</i> sp.	<i>Poa trivialis</i>	<i>Poa trivialis</i> agg.
<i>Polygonatum latifolium</i>	<i>Polygonatum multiflorum</i>	<i>Polygonatum verticillatum</i>	<i>Polygonum aviculare</i>	<i>Polygonum aviculare</i> agg.
<i>Polypodium vulgare</i>	<i>Polypodium vulgare</i> agg.	<i>Polystichum aculeatum</i>	<i>Polytrichum</i> sp.	<i>Populus canadensis</i>
<i>Populus nigra</i>	<i>Populus tremula</i>	<i>Potamogeton</i> sp.	<i>Potentilla anserina</i>	<i>Potentilla argentea</i>
<i>Potentilla argentea</i> agg.	<i>Potentilla aurea</i>	<i>Potentilla erecta</i>	<i>Potentilla reptans</i>	<i>Prenanthes purpurea</i>
<i>Primula elatior</i>	<i>Primula elatior</i> agg.	<i>Primula farinosa</i>	<i>Primula</i> sp.	<i>Primula veris</i>
<i>Primula vulgaris</i>	<i>Prunella vulgaris</i>	<i>Prunus avium</i>	<i>Prunus domestica</i>	<i>Prunus domestica</i> ssp. <i>domestica</i>
<i>Prunus padus</i>	<i>Prunus padus</i> ssp. <i>borealis</i>	<i>Prunus spinosa</i>	<i>Prunus spinosa</i> agg.	<i>Pseudotsuga menziesii</i>
<i>Pteridium aquilinum</i>	<i>Pulmonaria officinalis</i>	<i>Pulmonaria officinalis</i> agg.	<i>Pulsatilla alpina</i> agg.	<i>Pulsatilla alpina</i> ssp. <i>austriaca</i>
<i>Pyrus communis</i> agg.	<i>Quercus robur</i>	<i>Ranunculus aconitifolius</i>	<i>Ranunculus acris</i>	<i>Ranunculus acris</i> agg.
<i>Ranunculus acris</i> ssp. <i>acris</i>	<i>Ranunculus auricomus</i> agg.	<i>Ranunculus flammula</i>	<i>Ranunculus flammula</i> agg.	<i>Ranunculus montanus</i>
<i>Ranunculus nemorosus</i>	<i>Ranunculus repens</i>	<i>Ranunculus</i> sp.	<i>Raphanus raphanistrum</i>	<i>Reseda lutea</i>
<i>Rhinanthus alectorolophus</i>	<i>Rhinanthus glacialis</i>	<i>Rhinanthus minor</i>	<i>Rhinanthus serotinus</i>	<i>Ribes rubrum</i> agg.
<i>Rorippa palustris</i>	<i>Rorippa sylvestris</i>	<i>Rosa canina</i>	<i>Rosa canina</i> agg.	<i>Rubus caesius</i>
<i>Rubus fruticosus</i> agg.	<i>Rubus idaeus</i>	<i>Rumex acetosa</i>	<i>Rumex acetosella</i> agg.	<i>Rumex alpestris</i>
<i>Rumex conglomeratus</i>	<i>Rumex crispus</i>	<i>Rumex obtusifolius</i>	<i>Rumex obtusifolius</i> ssp. <i>transiens</i>	<i>Rumex</i> sp.
<i>Sagina nodosa</i>	<i>Sagittaria sagittifolia</i>	<i>Salix alba</i>	<i>Salix appendiculata</i>	<i>Salix appendiculata</i> agg.
<i>Salix aurita</i>	<i>Salix caprea</i>	<i>Salix cinerea</i>	<i>Salix cinerea</i> agg.	<i>Salix fragilis</i>
<i>Salix fragilis</i> agg.	<i>Salix myrsinifolia</i>	<i>Salix retusa</i>	<i>Salix</i> sp.	<i>Salvia glutinosa</i>
<i>Salvia pratensis</i>	<i>Salvia pratensis</i> agg.	<i>Sambucus nigra</i>	<i>Sambucus racemosa</i>	<i>Sanguisorba officinalis</i>
<i>Saxifraga aizoides</i>	<i>Scabiosa lucida</i>	<i>Scirpus sylvaticus</i>	<i>Scleranthus annuus</i>	<i>Scorzonera humilis</i>
<i>Scrophularia nodosa</i>	<i>Scrophularia umbrosa</i>	<i>Sedum maximum</i>	<i>Sedum telephium</i>	<i>Sedum telephium</i> agg.
<i>Senecio cordatus</i>	<i>Senecio nemorensis</i>	<i>Senecio ovatus</i>	<i>Senecio</i> sp.	<i>Sesleria albicans</i>

<i>Setaria pumila</i>	<i>Setaria viridis</i>	<i>Sherardia arvensis</i>	<i>Silene dioica</i>	<i>Silene latifolia</i>
<i>Silene nutans</i>	<i>Silene sp.</i>	<i>Silene vulgaris</i>	<i>Silene vulgaris ssp. angustifolia</i>	<i>Sinapis arvensis</i>
<i>Sisymbrium officinale</i>	<i>Solanum dulcamara</i>	<i>Soldanella alpina</i>	<i>Solidago gigantea</i>	<i>Solidago virgaurea</i>
<i>Sonchus arvensis</i>	<i>Sonchus oleraceus</i>	<i>Sorbus aucuparia</i>	<i>Sparganium emersum</i>	<i>Sparganium erectum</i>
<i>Spergula arvensis</i>	<i>Sphagnum sp.</i>	<i>Stachys palustris</i>	<i>Stachys recta</i>	<i>Stachys recta agg.</i>
<i>Stachys sylvatica</i>	<i>Stellaria alsine</i>	<i>Stellaria graminea</i>	<i>Stellaria media</i>	<i>Stellaria media agg.</i>
<i>Stellaria nemorum agg.</i>	<i>Succisa pratensis</i>	<i>Symphoricarpos rivularis</i>	<i>Symphytum officinale</i>	<i>Symphytum officinale agg.</i>
<i>Taraxacum officinale agg.</i>	<i>Taraxacum palustre agg.</i>	<i>Teucrium scordium agg.</i>	<i>Teucrium scorodonia</i>	<i>Teucrium sp.</i>
<i>Thesium alpinum</i>	<i>Thlaspi arvense</i>	<i>Thuja occidentalis</i>	<i>Thymus praecox agg.</i>	<i>Thymus pulegioides</i>
<i>Thymus sp.</i>	<i>Tilia cordata</i>	<i>Tilia platyphyllos</i>	<i>Tofieldia calyculata</i>	<i>Tragopogon orientalis</i>
<i>Tragopogon pratensis</i>	<i>Tragopogon pratensis agg.</i>	<i>Trichophorum cespitosum</i>	<i>Trifolium aureum</i>	<i>Trifolium badium</i>
<i>Trifolium campestre</i>	<i>Trifolium hybridum</i>	<i>Trifolium medium</i>	<i>Trifolium ochroleucon</i>	<i>Trifolium pratense</i>
<i>Trifolium repens</i>	<i>Trifolium resupinatum agg.</i>	<i>Trifolium sp.</i>	<i>Triglochin palustre</i>	<i>Tripleurospermum inodorum</i>
<i>Trisetum distichophyllum</i>	<i>Trisetum flavescens</i>	<i>Trisetum flavescens agg.</i>	<i>Trollius europaeus</i>	<i>Tussilago farfara</i>
<i>Typha latifolia</i>	<i>Ulmus glabra</i>	<i>Ulmus minor agg.</i>	<i>Urtica dioica</i>	<i>Vaccinium gaultherioides</i>
<i>Vaccinium myrtillus</i>	<i>Vaccinium oxycoccos</i>	<i>Vaccinium uliginosum</i>	<i>Vaccinium vitis-idaea</i>	<i>Valeriana dioica</i>
<i>Valeriana montana</i>	<i>Valeriana officinalis agg.</i>	<i>Veratrum album</i>	<i>Veratrum sp.</i>	<i>Verbascum lychnitis</i>
<i>Verbascum thapsus</i>	<i>Veronica arvensis</i>	<i>Veronica beccabunga</i>	<i>Veronica chamaedrys</i>	<i>Veronica chamaedrys agg.</i>
<i>Veronica officinalis</i>	<i>Veronica persica</i>	<i>Veronica serpyllifolia</i>	<i>Veronica sp.</i>	<i>Viburnum lantana</i>
<i>Viburnum opulus</i>	<i>Vicia cracca</i>	<i>Vicia cracca agg.</i>	<i>Vicia sepium</i>	<i>Vicia sp.</i>
<i>Vicia tenuifolia</i>	<i>Viola arvensis</i>	<i>Viola odorata</i>	<i>Viola palustris</i>	<i>Viola reichenbachiana</i>
<i>Viola sp.</i>	<i>Viola tricolor</i>	<i>Viola tricolor agg.</i>		

Annex C: Sample size of broader habitats and number of plant species found per landscape sample in n General Habitat Category (n species); abbreviations for General Habitat Category see Table 1.

landscape sample	CUL/CRO	CUL/WOC	FPH	FPH/DEC	HER/CHE	HER/LHE	SPV/AQU	TPH/DEC	URB/ART	URB/NON	URB/VEG
436			9 (19)	3 (17)	13 (8)	23 (9)	3 (15)			2 (9)	
437			3 (12)	1 (12)	4 (19)	8 (45)	2 (53)			2 (21)	3 (17)
438	2 (5)	4 (15)		1 (10)	6 (13)	1 (5)				3 (41)	2 (16)
439		2 (15)	2 (18)	5 (32)	18 (36)	4 (15)	2 (39)			6 (32)	1 (4)
440	2 (10)	6 (18)	8 (34)	6 (39)	30 (30)	9 (47)	2 (25)			6 (41)	1 (6)
441	1 (4)	11 (35)	3 (22)	6 (47)	41 (53)	35 (58)	9 (50)			10 (71)	7 (54)
442	1 (5)	9 (27)	1 (13)	5 (35)	24 (37)	22 (68)	4 (40)			8 (78)	5 (32)
443		4 (23)	8 (48)	3 (26)	21 (33)	30 (56)	9 (48)			6 (35)	1 (32)
444		6 (25)	2 (17)	10 (49)	29 (38)	20 (43)	8 (49)			10 (56)	2 (27)
445		6 (32)	1 (15)	8 (51)	16 (46)	33 (45)	7 (58)			10 (68)	3 (16)
449	11 (29)	6 (54)			20 (57)	28 (72)	3 (39)		6 (41)	3 (22)	15 (60)
451	23 (47)		4 (54)	6 (66)	18 (79)	7 (49)	2 (69)		5 (60)	6 (54)	4 (62)
452	21 (35)	1 (44)	8 (63)	9 (90)	25 (81)	16 (82)	17 (106)		2 (43)	1 (6)	8 (30)
453	16 (41)	9 (76)	11 (99)	15 (110)	69 (134)	45 (152)	35 (159)	1 (7)	1 (11)	5 (67)	8 (48)
455	28 (55)	4 (42)	15 (78)	31 (140)	95 (177)	68 (193)	27 (158)	4 (50)	14 (102)	11 (64)	16 (91)
457					4 (37)						

460	7 (22)	4 (37)	8 (68)	11 (67)	32 (82)	18 (110)	6 (87)	4 (45)	1 (23)	11 (53)
461	20 (39)	3 (25)	5 (36)	23 (110)	37 (94)	33 (92)	8 (81)		2 (28)	12 (39)
462	20 (43)	5 (45)	1 (30)	7 (70)	32 (115)	32 (161)	11 (108)	3 (24)	3 (20)	7 (48)
463	7 (21)		4 (36)	3 (27)	11 (24)	6 (67)	7 (56)	1 (15)	2 (9)	7 (23)
801							1 (4)			
807				1 (11)	18 (79)	1 (3)	2 (8)			
808					18 (54)	2 (12)	3 (15)			
809			1 (4)	1 (6)	14 (58)	2 (5)				
810			1 (6)		3 (17)	3 (14)		1 (3)		
811					8 (31)	2 (11)	3 (18)	2 (10)		1 (2)

Annex D: Sensitivity maps of landscape samples in the sub-region of Vorarlberg.

Annex E: Summary of regression analysis; formulas, degrees of freedom (df) and R²; * indicates p-value < 0.05, ** indicates p-value < 0.01. Abbreviations for General Habitat Category see Table 1.

formula linear regression	landscape sample/GHC	df	R ²	
Average Ellenberg T ~ mean annual temperature	landscape sample	18	0.59	**
Average Ellenberg T ~ mean temperature April – September	landscape sample	18	0.65	**
Average Ellenberg T ~ mean temperature April – September + mean annual temperature	landscape sample	17	0.72	**
Average Ellenberg W ~ annual Water balance	landscape sample	18	0.01	
Average Ellenberg W ~ Water balance January – September	landscape sample	18	0.00	

Average Ellenberg W ~ annual precipitation	landscape sample	18	0.00	
Average Ellenberg W ~ precipitation January – September	landscape sample	18	0.00	
Average Ellenberg W ~ precipitation April – September	landscape sample	18	0.04	
Average Ellenberg W ~ annual Water balance + Water balance January – September + annual precipitation + precipitation January – September + precipitation April – September	landscape sample	14	0.23	
Average Ellenberg T ~ mean temperature April – September	CUL/CRO	13	0.17	
	CUL/WOC	13	0.37	*
	FPH	15	0.58	**
	FPH/DEC	16	0.24	*
	HER/CHE	18	0.22	*
	HER/LHE	17	0.38	**
	SPV/AQU	16	0.59	**
	TPH/DEC	4	0.24	
	URB/ART	10	0.01	
	URB/VEG	16	0.33	*
Average Ellenberg T ~ mean temperature April – September + mean annual temperature	CUL/CRO	12	0.30	
	CUL/WOC	12	0.39	
	FPH	14	0.60	**
	FPH/DEC	15	0.38	*
	HER/CHE	17	0.36	*
	HER/LHE	16	0.43	*
	SPV/AQU	15	0.62	**
	TPH/DEC	3	0.31	
	URB/ART	9	0.12	
	URB/VEG	15	0.33	*
	URB/NON	16	0.53	**
Average Ellenberg W ~ annual Water balance + Water balance January – September + annual precipitation + precipitation January – September + precipitation April – September	CUL/CRO	9	0.22	
	CUL/WOC	9	0.54	
	FPH	11	0.17	
	HER/CHE	14	0.16	
	HER/LHE	13	0.58	*
	SPV/AQU	12	0.19	
	URB/ART	6	0.13	
	URB/VEG	12	0.24	
	URB/NON	13	0.38	

Annex F: Sensitivity maps of landscape samples in the sub-region of Upper-Austria.

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Annex G: Summary of regression analysis; formulas, R^2 ; sig.= significance level, * indicates p -value < 0.05, ** indicates p -value < 0.01, * indicates p -values < 0.001 independently from GHC. AvOfC: average abundance of competitors, AvgOfS: average abundance of stress-tolerants, AvgOfR: average abundance of ruderals.**

formula of linear model (lm)	sig.	multiple R^2
lm(AvgOfS~yearly mean temp.)	***	0.7851
lm(AvgOfS~mean temp. (04-09))	***	0.7699
lm(AvgOfC~yearly mean temp.)	***	0.6155
lm(AvgOfC~mean temp. (04-09))	***	0.5962
lm(AvgOfC~yearly water balance)	***	0.5756
lm(AvgOfS~yearly water balance)	***	0.5153
lm(AvgOfC~yearly precipitation)	***	0.5138
lm(AvgOfS~yearly precipitation)	***	0.5029
lm(AvgOfC~water balance (01-09))	***	0.5027
lm(AvgOfS~water balance (01-09))	**	0.4299
lm(AvgOfR~yearly water balance)	**	0.3945

lm(AvgOfC~precipitation (01-09))	**	0.3639
lm(AvgOfR~water balance (01-09))	**	0.36
lm(AvgOfS~precipitation (01-09))	**	0.3552
lm(AvgOfR~yearly precipitation)	*	0.3145
lm(AvgOfR~yearly mean temp.)	*	0.2584
lm(AvgOfR~mean temp. (04-09))	*	0.2434
lm(AvgOfR~precipitation (01-09))	*	0.2204
lm(AvgOfC~precipitation (04-09))	-	-
lm(AvgOfR~precipitation (04-09))	-	-
lm(AvgOfS~precipitation (04-09))	-	-

Annex H: Summary of regression analysis; formulas, sig. = significance level, R²; * indicates p-value < 0.05, ** indicates p-value < 0.01, * indicates p-values < 0.001. Abbreviations for General Habitat Category see Table 1. AvOfC: average abundance of competitors, AvgOfS: average abundance of stress-tolerants, AvgOfR: average abundance of ruderals.**

formula of linear model (lm)	sig.	R ²
lm(AvgOfC[GHC=="CUL/CRO"]~ yearly average temp. [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ yearly average temp. [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ yearly average temp. [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~ mean temp. (04-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ mean temp. (04-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ mean temp. (04-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~ yearly water balance [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ yearly water balance [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ yearly water balance [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~ water balance (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ water balance (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ water balance (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~ yearly precipitation [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ yearly precipitation [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ yearly precipitation [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~ precipitation (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~ precipitation (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~ precipitation (01-09) [GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/CRO"]~precipitation (04-09)[GHC=="CUL/CRO"])	-	
lm(AvgOfR[GHC=="CUL/CRO"]~precipitation (04-09)[GHC=="CUL/CRO"])	-	
lm(AvgOfS[GHC=="CUL/CRO"]~precipitation (04-09)[GHC=="CUL/CRO"])	-	
lm(AvgOfC[GHC=="CUL/WOC"]~ yearly average temp. [GHC=="CUL/WOC"])	**	0.5631
lm(AvgOfR[GHC=="CUL/WOC"]~ yearly average temp. [GHC=="CUL/WOC"])	-	
lm(AvgOfS[GHC=="CUL/WOC"]~ yearly average temp. [GHC=="CUL/WOC"])	***	0.6184
lm(AvgOfC[GHC=="CUL/WOC"]~ mean temp. (04-09) [GHC=="CUL/WOC"])	***	0.5884
lm(AvgOfR[GHC=="CUL/WOC"]~ mean temp. (04-09) [GHC=="CUL/WOC"])	-	
lm(AvgOfS[GHC=="CUL/WOC"]~ mean temp. (04-09) [GHC=="CUL/WOC"])	***	0.6505
lm(AvgOfC[GHC=="CUL/WOC"]~ yearly water balance [GHC=="CUL/WOC"])	***	0.7603
lm(AvgOfR[GHC=="CUL/WOC"]~ yearly water balance [GHC=="CUL/WOC"])	***	0.5835

lm(AvgOfS[GHC=="CUL/WOC"]~ yearly water balance [GHC=="CUL/WOC"])	*	0.4051
lm(AvgOfC[GHC=="CUL/WOC"]~ water balance (01-09) [GHC=="CUL/WOC"])	***	0.7206
lm(AvgOfR[GHC=="CUL/WOC"]~ water balance (01-09) [GHC=="CUL/WOC"])	**	0.5671
lm(AvgOfS[GHC=="CUL/WOC"]~ water balance (01-09) [GHC=="CUL/WOC"])	*	0.3716
lm(AvgOfC[GHC=="CUL/WOC"]~ yearly precipitation [GHC=="CUL/WOC"])	***	0.6859
lm(AvgOfR[GHC=="CUL/WOC"]~ yearly precipitation [GHC=="CUL/WOC"])	**	0.4525
lm(AvgOfS[GHC=="CUL/WOC"]~ yearly precipitation [GHC=="CUL/WOC"])	**	0.4629
lm(AvgOfC[GHC=="CUL/WOC"]~ precipitation (01-09) [GHC=="CUL/WOC"])	**	0.532
lm(AvgOfR[GHC=="CUL/WOC"]~ precipitation (01-09) [GHC=="CUL/WOC"])	*	0.3267
lm(AvgOfS[GHC=="CUL/WOC"]~ precipitation (01-09) [GHC=="CUL/WOC"])	*	0.4003
lm(AvgOfC[GHC=="CUL/WOC"]~precipitation (04-09)[GHC=="CUL/WOC"])	-	
lm(AvgOfR[GHC=="CUL/WOC"]~precipitation (04-09)[GHC=="CUL/WOC"])	-	
lm(AvgOfS[GHC=="CUL/WOC"]~precipitation (04-09)[GHC=="CUL/WOC"])	-	
lm(AvgOfC[GHC=="HER/CHE"]~ yearly average temp. [GHC=="HER/CHE"])	***	0.7248
lm(AvgOfR[GHC=="HER/CHE"]~ yearly average temp. [GHC=="HER/CHE"])	***	0.5216
lm(AvgOfS[GHC=="HER/CHE"]~ yearly average temp. [GHC=="HER/CHE"])	***	0.6086
lm(AvgOfC[GHC=="HER/CHE"]~ mean temp. (04-09) [GHC=="HER/CHE"])	***	0.7086
lm(AvgOfR[GHC=="HER/CHE"]~ mean temp. (04-09) [GHC=="HER/CHE"])	***	0.4855
lm(AvgOfS[GHC=="HER/CHE"]~ mean temp. (04-09) [GHC=="HER/CHE"])	***	0.6138
lm(AvgOfC[GHC=="HER/CHE"]~ yearly water balance [GHC=="HER/CHE"])	***	0.6324
lm(AvgOfR[GHC=="HER/CHE"]~ yearly water balance [GHC=="HER/CHE"])	**	0.438
lm(AvgOfS[GHC=="HER/CHE"]~ yearly water balance [GHC=="HER/CHE"])	***	0.5593
lm(AvgOfC[GHC=="HER/CHE"]~ water balance (01-09) [GHC=="HER/CHE"])	***	0.5563
lm(AvgOfR[GHC=="HER/CHE"]~ water balance (01-09) [GHC=="HER/CHE"])	**	0.3731
lm(AvgOfS[GHC=="HER/CHE"]~ water balance (01-09) [GHC=="HER/CHE"])	***	0.501
lm(AvgOfC[GHC=="HER/CHE"]~ yearly precipitation [GHC=="HER/CHE"])	***	0.5935
lm(AvgOfR[GHC=="HER/CHE"]~ yearly precipitation [GHC=="HER/CHE"])	**	0.3725
lm(AvgOfS[GHC=="HER/CHE"]~ yearly precipitation [GHC=="HER/CHE"])	***	0.5544
lm(AvgOfC[GHC=="HER/CHE"]~ precipitation (01-09) [GHC=="HER/CHE"])	*	0.2459
lm(AvgOfR[GHC=="HER/CHE"]~ precipitation (01-09) [GHC=="HER/CHE"])	**	0.4367
lm(AvgOfS[GHC=="HER/CHE"]~ precipitation (01-09) [GHC=="HER/CHE"])	**	0.4367
lm(AvgOfC[GHC=="HER/CHE"]~precipitation (04-09)[GHC=="HER/CHE"])	-	
lm(AvgOfR[GHC=="HER/CHE"]~precipitation (04-09)[GHC=="HER/CHE"])	-	
lm(AvgOfS[GHC=="HER/CHE"]~precipitation (04-09)[GHC=="HER/CHE"])	-	
lm(AvgOfC[GHC=="HER/LHE"]~ yearly average temp. [GHC=="HER/LHE"])	**	0.3582
lm(AvgOfR[GHC=="HER/LHE"]~ yearly average temp. [GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~ yearly average temp. [GHC=="HER/LHE"])	***	0.4988
lm(AvgOfC[GHC=="HER/LHE"]~ mean temp. (04-09) [GHC=="HER/LHE"])	**	0.3006
lm(AvgOfR[GHC=="HER/LHE"]~ mean temp. (04-09) [GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~ mean temp. (04-09) [GHC=="HER/LHE"])	-	
lm(AvgOfC[GHC=="HER/LHE"]~ yearly water balance [GHC=="HER/LHE"])	-	
lm(AvgOfR[GHC=="HER/LHE"]~ yearly water balance [GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~ yearly water balance [GHC=="HER/LHE"])	*	0.2898
lm(AvgOfC[GHC=="HER/LHE"]~ water balance (01-09) [GHC=="HER/LHE"])	-	
lm(AvgOfR[GHC=="HER/LHE"]~ water balance (01-09) [GHC=="HER/LHE"])	-	

lm(AvgOfS[GHC=="HER/LHE"]~ water balance (01-09) [GHC=="HER/LHE"])	*	0.2097
lm(AvgOfC[GHC=="HER/LHE"]~ yearly precipitation [GHC=="HER/LHE"])	-	
lm(AvgOfR[GHC=="HER/LHE"]~ yearly precipitation [GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~ yearly precipitation [GHC=="HER/LHE"])	*	0.245
lm(AvgOfC[GHC=="HER/LHE"]~ precipitation (01-09) [GHC=="HER/LHE"])	-	
lm(AvgOfR[GHC=="HER/LHE"]~ precipitation (01-09) [GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~ precipitation (01-09) [GHC=="HER/LHE"])	-	
lm(AvgOfC[GHC=="HER/LHE"]~precipitation (04-09)[GHC=="HER/LHE"])	-	
lm(AvgOfR[GHC=="HER/LHE"]~precipitation (04-09)[GHC=="HER/LHE"])	-	
lm(AvgOfS[GHC=="HER/LHE"]~precipitation (04-09)[GHC=="HER/LHE"])	-	
lm(AvgOfC[GHC=="FPH"]~ yearly average temp. [GHC=="FPH"])	***	0.7397
lm(AvgOfR[GHC=="FPH"]~ yearly average temp. [GHC=="FPH"])	***	0.6269
lm(AvgOfS[GHC=="FPH"]~ yearly average temp. [GHC=="FPH"])	***	0.7524
lm(AvgOfC[GHC=="FPH"]~ mean temp. (04-09) [GHC=="FPH"])	***	0.7348
lm(AvgOfR[GHC=="FPH"]~ mean temp. (04-09) [GHC=="FPH"])	***	0.6573
lm(AvgOfS[GHC=="FPH"]~ mean temp. (04-09) [GHC=="FPH"])	***	0.7246
lm(AvgOfC[GHC=="FPH"]~ yearly water balance [GHC=="FPH"])	***	0.6071
lm(AvgOfR[GHC=="FPH"]~ yearly water balance [GHC=="FPH"])	***	0.5588
lm(AvgOfS[GHC=="FPH"]~ yearly water balance [GHC=="FPH"])	***	0.5639
lm(AvgOfC[GHC=="FPH"]~ water balance (01-09) [GHC=="FPH"])	**	0.5009
lm(AvgOfR[GHC=="FPH"]~ water balance (01-09) [GHC=="FPH"])	**	0.4898
lm(AvgOfS[GHC=="FPH"]~ water balance (01-09) [GHC=="FPH"])	**	0.4435
lm(AvgOfC[GHC=="FPH"]~ yearly precipitation [GHC=="FPH"])	**	0.5185
lm(AvgOfR[GHC=="FPH"]~ yearly precipitation [GHC=="FPH"])	***	0.5256
lm(AvgOfS[GHC=="FPH"]~ yearly precipitation [GHC=="FPH"])	**	0.4545
lm(AvgOfC[GHC=="FPH"]~ precipitation (01-09) [GHC=="FPH"])	*	0.3185
lm(AvgOfR[GHC=="FPH"]~ precipitation (01-09) [GHC=="FPH"])	**	0.3811
lm(AvgOfS[GHC=="FPH"]~ precipitation (01-09) [GHC=="FPH"])	*	0.2449
lm(AvgOfC[GHC=="FPH"]~precipitation (04-09)[GHC=="FPH"])	-	
lm(AvgOfR[GHC=="FPH"]~precipitation (04-09)[GHC=="FPH"])	-	
lm(AvgOfS[GHC=="FPH"]~precipitation (04-09)[GHC=="FPH"])	-	
lm(AvgOfC[GHC=="FPH/DEC"]~ yearly average temp. [GHC=="FPH/DEC"])	**	0.422
lm(AvgOfR[GHC=="FPH/DEC"]~ yearly average temp. [GHC=="FPH/DEC"])	*	0.1594
lm(AvgOfS[GHC=="FPH/DEC"]~ yearly average temp. [GHC=="FPH/DEC"])	***	0.5349
lm(AvgOfC[GHC=="FPH/DEC"]~ mean temp. (04-09) [GHC=="FPH/DEC"])	**	0.3854
lm(AvgOfR[GHC=="FPH/DEC"]~ mean temp. (04-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfS[GHC=="FPH/DEC"]~ mean temp. (04-09) [GHC=="FPH/DEC"])	***	0.5064
lm(AvgOfC[GHC=="FPH/DEC"]~ yearly water balance [GHC=="FPH/DEC"])	-	
lm(AvgOfR[GHC=="FPH/DEC"]~ yearly water balance [GHC=="FPH/DEC"])	-	
lm(AvgOfS[GHC=="FPH/DEC"]~ yearly water balance [GHC=="FPH/DEC"])	**	0.3799
lm(AvgOfC[GHC=="FPH/DEC"]~ water balance (01-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfR[GHC=="FPH/DEC"]~ water balance (01-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfS[GHC=="FPH/DEC"]~ water balance (01-09) [GHC=="FPH/DEC"])	*	0.2997
lm(AvgOfC[GHC=="FPH/DEC"]~ yearly precipitation [GHC=="FPH/DEC"])	-	
lm(AvgOfR[GHC=="FPH/DEC"]~ yearly precipitation [GHC=="FPH/DEC"])	-	

lm(AvgOfS[GHC=="FPH/DEC"]~ yearly precipitation [GHC=="FPH/DEC"])	*	0.3067
lm(AvgOfC[GHC=="FPH/DEC"]~ precipitation (01-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfR[GHC=="FPH/DEC"]~ precipitation (01-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfS[GHC=="FPH/DEC"]~ precipitation (01-09) [GHC=="FPH/DEC"])	-	
lm(AvgOfC[GHC=="FPH/DEC"]~precipitation (04-09)[GHC=="FPH/DEC"])	-	
lm(AvgOfR[GHC=="FPH/DEC"]~precipitation (04-09)[GHC=="FPH/DEC"])	-	
lm(AvgOfS[GHC=="FPH/DEC"]~precipitation (04-09)[GHC=="FPH/DEC"])	-	

7. Dissemination

Renetzeder, C., Knoflacher, M., Loibl, W., Wrбка, T. (2008). CROSS - Climate Change Response of Sensitive Habitats and Landscapes in Austria. In: Löffler, J., Breuste, J., Lenz, R., Müller, F., Steinhardt, U., Walz, U. (eds). Global Change and Landscape Response. Die Rückkopplungen von Landschaften auf den Globalen Wandel (Tagungsband zur IALE Jahrestagung, Sektion Deutschland, 2008), p. 43.

oral presentation 31.10.2008

“Climate Change Response of Sensitive Habitats and Landscapes in Austria”

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Neueste weltweite Studien sehen im Klimawandel die größte Gefahr für Biodiversität in den kommenden Jahrzehnten. Österreichische Untersuchungen zeigen, dass aufgrund globaler Erwärmung Gefäßpflanzen der nivalen und alpinen Regionen an den Rand des Aussterbens gedrängt werden. Obwohl auch die Niederungen Österreichs mit einem höherem Anteil an halbnatürlichen Lebensräumen in den Kulturlandschaften wesentlich zu Österreichs Biodiversität beitragen, ist überraschenderweise relativ wenig über deren Sensibilität und den möglichen Einfluss von Klimawandel bekannt.

Diese Lücke soll nun gefüllt werden, indem für 10 Quadranten in repräsentativen österreichischen Landschaften das Auftreten von sogenannten „Broader Habitats“ mit hochauflösenden Klimamodell-Daten korreliert wird. Grundlage für die Definition der Broader Habitats liefert das Konzept der Raunkiaer'schen Lebensformen. Diese spiegeln vorhandene Standortbedingungen wider und eignen sich daher als objektive Basis, Habitate zu charakterisieren. Das Konzept ermöglicht es außerdem, Daten von Vegetationsaufnahmen sowie Landnutzungsdaten in diese Broader-Habitats-Kategorien zu übersetzen. Daher können verschiedene Datenquellen zur Untersuchung herangezogen werden, welche unabhängig von Artverbreitung und Landnutzungsintensität konsistente Informationen über Habitate liefern. Die Vegetationsaufnahmen dienen weiters zur Formulierung einer Art „Ökogramm“ (in Anlehnung an Ellenberg) bzw. eines „Ecological envelopes“ für die Habitate. Dieser Ist-Zustand wird mit regionalisierten Klimamodell-Daten des Projektes „reclip“ für die Jahre 1981-1990 korreliert. Damit können Auswirkungen der Modell-Ergebnisse der Szenarioperiode 2041-2050 aufgrund von Experten-Wissen auf die Habitate und ihre Biodiversität abgeschätzt werden.

Erste Ergebnisse des Klimamodells zeigen, dass nördlich des Alpenhauptkamms neben der erwarteten generellen Temperaturerhöhung auch deutliche Veränderungen der Humidität im Jahresablauf zu erwarten sind. Berechnungen speziell für den Süden Österreichs zeigen eine höhere Differenzierung der Klimaveränderungen. Genauere Auswirkungen auf die Habitate werden zur Zeit analysiert.

Renetzeder, C., Knoflacher, M., Loibl, W., Wrбка, T. (2009). CROSS - Climate Change Response of Sensitive Habitats and Landscapes in Austria. In: Breuste, J., Kozová, M., Finka, M. (eds). European IALE conference, Salzburg, Austria, p. 523.
oral presentation, the 14.07.2009

“Climate Change Response of Sensitive Habitats and Landscapes in Austria”

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Based on recent world-wide assessments, climate change is now regarded as a major biodiversity threat in coming decades. In Austria, recent empirical studies provide evidence, that global warming can drive vascular plant species of the nival and alpine belt on the edge of extinction. But despite the fact that lowland regions with a higher share of semi-natural habitats embedded in cultivated land are also substantially contributing to biodiversity in Austria surprisingly little is known about their sensitivity and possible responses to climate change.

The study is addressing this knowledge gap by presenting an approach that couples modelled high-resolution climate data with expert knowledge about the sensitivity of semi-natural and cultivated habitats in representative Austrian agricultural landscapes.

The concept of the so-called Broader Habitats builds the objective basis into which we can translate vegetation and habitat data and at the same time be independent from biogeographic species distribution and land use intensity. Ellenberg values of existing vegetation relevés help to formulate the ecological envelope of the habitats. These envelopes are correlated with climate model results for the period 1981-1990. By doing so, it is possible to assess the potential impact of changing temperature and precipitation patterns on regional biodiversity.

First results of the climate model show considerable changes in humidity patterns throughout the year next to the general trend of temperature rise north of the Alps, whereas in the south of Austria, the climate changes are much more differentiated. The correlation of the Ellenberg T values (temperature) with the model temperature with an $r^2 = 0.886$ proves the applicability of these values for the formulation of the ecological envelopes. Next steps will be the formulation of sensitivity-rules in order to produce models for the expected changes, the assessment of these changes and their implications for the existence of habitats or their shift in climatic preconditions.

Renetzeder C., Knoflacher M., Loibl W., Wrbka T. (2010). Are habitats of Austrian agricultural landscapes sensitive to climate change?. *Landscape and Urban Planning* 98, 150-159.

Are habitats of Austrian agricultural landscapes sensitive to climate change?

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ABSTRACT

Climate change amongst others is considered as a major threat to biodiversity. The aim of the present study was to assess the potential impact and regional variation of modelled climate change on selected Austrian habitats and agricultural landscapes for 20 landscape samples in the region of Upper-Austria. In order to avoid biases caused by the lack of data of species and their ecological requirements, we used a concept that addresses higher aggregated forms of biodiversity, the broader habitats. We defined their ecological envelope by applying Ellenberg's temperature and water availability values based on vegetation relevés and related these with the output of a regional climate model for the time periods 1981–1990 and 2041–2050. Further we defined a sensitivity index for assessing possible responses of broader habitats to future climatic conditions. Regression analysis revealed quite strong relationships for temperature values ($R^2 = 0.72$, p -value < 0.01) but not for water availability. Differences in R^2 were given regarding the individual broader habitats. Water availability had higher sensitivity indices than temperature. Forests, fallow land, field margins and aquatic habitats had the best regression models, the highest sensitivity and also showed rather high naturalness values. It was concluded that more natural habitats will suffer more because of climate change. Species loss and turnover can only be mitigated by improving migration possibilities. Consequences for nature conservation planning are discussed and need to be further explored.

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1. Introduction

Based on recent worldwide assessments, climate change is considered as a major threat to biodiversity together with habitat change, invasive alien species, overexploitation and pollution (Millenium Ecosystem Assessment, 2005). Evidence for changes in ecosystems related to climate have been documented for the high European Alps (Dullinger et al., 2004; Pauli et al., 2007), for the spreading of invasive species (Vogl et al., 2008), for threats on plant diversity in Europe (Pompe et al., 2008; Thuiller et al., 2005) or for important ecosystem services such as water availability and quality (Futter et al., 2009; Whitehead et al., 2009) and agricultural productivity (Olesen et al., 2007). A comprehensive review on ecological and evolutionary responses to recent climate change is given by Parmesan (2006).

Recently there has been an urgent need for evaluating the impacts of climate change over the biodiversity present in a region. For doing this, the coarse resolution of the global climate models had been pointed out as a serious limitation (O'Brien

et al., 2004). Some regional climate models such as that developed by Loibl et al. (2007) can now be used to assess the impact of climate changes in the future. A preliminary examination of this climate model exhibits different regional patterns of change throughout Austria—as there is no simple general north–south, east–west or valley–mountain trend (Loibl et al., 2007). On the contrary, very local change signals could affect biodiversity in Austrian landscapes in quite contrasting ways. A landscape is a sum of emergent properties derived from multiple processes interacting at different scales (Farina, 2000). This ecological entity shows strong differences related to local and regional climate conditions which in turn make them suitable for evaluating the impacts of climate change on biodiversity at the regional scale; a task needed to design a good decision-making framework within this scale.

In agricultural landscapes, species richness and composition is largely driven by land use (Wrбка et al., 2004; Zechmeister et al., 2003). Therefore, these landscapes need to be adapted to climate change by providing suitable networks for species shifts (Vos et al., 2008). Over the years different modelling approaches have been used to estimate climate change impacts in Austrian agricultural landscapes covering aspects of invasive species (Essl et al., 2009), soil erosion (Scholz et al., 2008), soil water content (Eitzinger et al., 2004) and agricultural crops (Alexandrov et al., 2002). However, there are no predictions of alterations in landscape

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biodiversity patterns driven by climate change for this country. Besides, data availability and knowledge on ecological characteristics of habitats and species with special emphasis on climate are scarce, making any kind of regional assessment almost impossible. To avoid biases caused by the lack of data of species and their ecological requirements, the use of concepts that address higher aggregated forms of biodiversity such as plant functional types, communities or habitats seems to be a possible solution. This approach has been successfully followed by key-studies in climate change research (Hély et al., 2006; Kleidon and Mooney, 2000).

In this study, we use the concept of the so-called “broader habitats” (Bunce et al., 2008), which aims at the elaboration of standard procedures to consistently monitor ecological changes in agricultural landscapes across Europe. The method is based on the aggregation of taxonomic information (e.g. species composition) into eco-morphological data (e.g. life-forms). It has been demonstrated, that life-forms, functional plant types and other similar groupings of species are well-performing response units which detect any large-to medium scale ecological change (Morecroft et al., 2009).

The prevailing environmental conditions of habitats are commonly described using Ellenberg indicator values (Ellenberg et al., 2001). These formalised values summarise complex environmental factors (e.g. groundwater level, soil moisture content, precipitation, humidity, etc.) into one figure and they do not refer to conditions at a specific moment but represent an integration over a period of time. With this widely used European system it is possible to describe the ecological envelope according to Ellenberg’s ecogram (Ellenberg, 1988) of broader habitats.

The aim of the present study is to assess the potential impact and regional variation of modelled climate change on selected Austrian habitats and agricultural landscapes by (i) identifying existing data sources for consistently describing broader habitats in Austrian agricultural landscapes, (ii) defining the ecological envelope of these broader habitats, (iii) correlating them with climate scenario data and (iv) defining a sensitivity index for assessing possible responses of broader habitats to future climatic conditions.

2. Methods

2.1. Conceptual framework

The major interrelations between climate and habitat data were assessed following the conceptual framework outlined as follows: The main focus lied on the aggregated biodiversity level of the broader habitats. Their ecological envelope was based on the Ellenberg values derived from the existing relevés. On the other side were the climate scenario data, which were extracted for the selected landscape samples. By defining the ecological envelope with climate data, we considered future changes caused by climate changes expected as effect of greenhouse gas increase. In order to assess how the broader habitat will react to the change in the system, sensitivity rules were defined for each habitat.

The biggest challenge was the harmonisation of the representation scales of climate and land use type data. Climate scenario models generally operate on larger scales. While the landscape data are representative for 1 km × 1 km raster cells, regional climate has been simulated for “landscape points” with a 10 km × 10 km grid spacing, representative for an area which is 100 times larger than the landscape samples. Thus it was necessary to test the accuracy of relationships between corresponding data of the climate model and the landscape samples by statistical analyses.

2.2. Landscape samples

Data on habitat and vegetation were taken from databases for Austria, derived from ecological research projects during the years 1997–2004 (Peterseil et al., 2004). For the present study, 20 landscape samples with 1 km² area were selected in Upper-Austria, a province in the North of Austria (Fig. 1). In general, this region is dominated by continental climate with a mean total precipitation ranging between 800 and 1500 mm per year. Geologically, these samples are located in the Bohemian uplands (dominated by granite and gneiss) and the Molasse zone (loamy and gravel sediments), providing the bedrock for brown soils, pseudogleys and semipodsols. The geomorphological features are dominated by soft hills with an altitudinal range between 350 and 880 m a.s.l. The selection of representative landscape samples was performed based on the map of Wrška et al. (2002), where main cultural landscape types have been delineated for Austria. Low mountain ranges, dominated by either forests or grasslands, are prominent within the northern landscape samples whereas the southern ones comprise more differentiated agricultural uses such as grasslands, crop- and fodder-production.

2.3. Data on habitat and vegetation

Consistent information on land use types was collected and stored in databases during the development of the above mentioned projects. Each landscape element in these 20 samples was assigned according to the General Habitat Categories (GHC; Bunce et al., 2008) of broader habitats by translating land use types into this system (Table 1). Vegetation relevés are randomly distributed among the landscape samples. But for nearly each broader habitat type, species data are available, all in all there were 683 species recorded (Appendix A). All data are stored in ArcGIS 9.2 Geodatabase (ESRI, Inc., Redlands, CA).

2.4. Climate scenario data: climate simulations—principles and applied datasets

Basically, climate data for the landscape samples were extracted from regional climate simulations carried out by the ‘reclip:more’ project for the entire Alpine area (Loibl et al., 2007, 2009). For conducting regional climate models (RCMs), input data from global climate models are essential. For the reclip:more simulations, data from the general circulation model (GCM) ECHAM5, a model simulating global climate down to 100 km × 100 km grid spacing has been applied (c.f. Roeckner et al., 2003). Here the ECHAM5 results, based on the IS92a greenhouse gas (GHG) concentration increase scenario were applied. The climate modelling literature proves that differences between GCM model results are mainly determined by differences in GHG concentration in the atmosphere releasing temperature increase, surface temperature increase and various other impacts (c.f. IPCC, 2001a). The IS92a scenario was one of the common GHG scenarios, referred as “business-as-usual” scenario, assuming a plausible course for global energy consumption related to certain activities, technologies, fuel compositions and finally greenhouse gas emissions into the atmosphere. Until recently, the IS92a scenario had been in wide use by the climate modelling community and thus GCM results based on this GHG reference scenario were selected as RCM input to simulate climate with a higher spatial resolution, as the 100 × 100 grid spacing provides too coarse results for climate change impact analysis at regional scale.

The here applied RCM data were conducted with the mesoscale climate model MM5—a limited-area, non-hydrostatic, terrain-following model, designed to simulate atmospheric circulation for regional scale in a certain area, integrating the global climate simulations (Dudhia et al., 2004). To integrate the GCM results into

Landscape types

- ◆ [205] forest dominated uplands
- [308] grassland dominated extra-alpine uplands
- ▲ [402] extra-alpine downlands; mixed agriculture, foddercrop production
- ◆ [404] extra-alpine basins and valley bottoms dominated by crop land

Fig. 1. Landscape types (Wrbka et al., 2002) of 20 landscape samples located in the bio-geographical regions of Upper-Austria. Forest and grassland use is dominating the northern landscape samples whereas crop- and fodder production are the main agricultural activities in the southern samples.

Table 1

General Habitat Categories (GHC) as defined by Bunce et al. (2008) of landscape samples and corresponding examples in Austrian agricultural landscapes.

GHC abbreviation	GHC-Description	Examples
CUL-CRO	Crops-Cultivated herbaceous crops	Root crops, corn fields, forage crops
CUL-WOC	Crops-Woody crops	Vineyards, orchards
FPH	Forest phanerophytes (>5 m)	Timber plantations, natural forests, solitary trees, hedgerows, woodlots
FPH-DEC	Forest phanerophytes (>5 m)-Winter deciduous	Timber plantations, natural forests, solitary trees, hedgerows, woodlots
HER-CHE	Vegetated Herbaceous-Caespitose hemicryptophytes	Meadows, pastures
HER-LHE	Vegetated Herbaceous-Leafy hemicryptophytes	Fallow land, field margins
SPV-AQU	Sparsely Vegetated-Aquatic	Streams, lakes
TPH-DEC	Tall phanerophytes (2–5 m)-Winter deciduous	Fallow land with shrubs
URB-ART	Urban-Artificial	Built up elements, paved areas, settlements
URB-GRA	Urban-Herbaceous	Suburban vegetated areas, detached houses with gardens
URB-NON	Urban-Non-vegetated	Roads, artificial lakes
URB-VEG	Urban-Vegetables	Gardens

RCMs, these models copy the GCM's atmospheric conditions (in our case every 6 h) along the boundary of the RCM' simulation domain and model the atmospheric processes and states within the defined domain for the smaller RCM grid-cells (in our case 10 km × 10 km) in small time steps (in our case 90 s) to consider the atmospheric dynamics between the grid cells. Hourly data are stored as results to extract further indicators for longer time periods (e.g. monthly means) for various climate-related research questions. Two time ranges had been simulated: the decade between 1981 and 1990 was selected as a climatically stable period to provide current climate reference data and the decade between 2041 and 2050 was selected to simulate the future climate. The recli:more simulation results which were used for the current habitat impact analysis are hourly temperature maxima, minima and averages as well as precipitation sums for the two decades, which were averaged to monthly means. Additional indicators for particular elevation ranges within the 10 km × 10 km raster cells were further estimated using a 1 km × 1 km digital elevation model and an elevation-related temperature—as well as a precipitation gradient. The potential evapotranspiration was calculated for estimations of the water balances of the landscape samples applying the Penman–Monteith method (Allen et al., 1998).

2.5. Statistical analysis

Spatial data exploration was performed with ArcGIS 9.2 (ESRI Inc., Redlands, CA), statistical analysis was conducted with R 2.7.1 (R Development Core Team, 2008). The Ellenberg indicator values (Table 2) were taken from Ellenberg et al. (2001). Ellenberg conceived these values as 'quasimetric' in order to allow averaging. Means of Ellenberg's *T* (temperature; ranging from 1 to 9) and *W* values (water availability; ranging from 1 to 12) were calculated per (1) landscape sample and (2) for GHC and landscape sample. Linear regression analysis was performed with all mean values versus climatic variables: *T* values versus "mean annual temperature" and "mean temperature April–September" as well as *W* values versus "annual water balance", "water balance January–September", "annual precipitation", "precipitation January–September" and "precipitation April–September".

2.6. Climate cluster

Based on mean total temperature and precipitation values per month, the landscape samples were clustered in SPSS 13.0 using the linkage between groups method (Backhaus et al., 2006). Clusters

Table 2
Ellenberg values ranges for temperature and water availability and their ecological meaning.

T	Temperature value	W	Water availability value
1	Very cold, only in very high altitudes	1	Very dry
2	Between 1 and 3	2	Between 1 and 3
3	Cold, mainly subalpine regions	3	Dry
4	Between 3 and 5 (mountainous regions)	4	Between 3 and 5
5	Temperate (low to mountainous regions)	5	Mainly on medium moist soils
6	Between 5 and 7	6	Between 5 and 7
7	Warm	7	Mainly on moist but not wet soils
8	Between 7 and 9	8	Between 7 and 9
9	Extremely warm	9	Wet, often oxygen-poor soils
		10	Periodically wet,
		11	Hydrophytes on water surface
		12	Submerged plants

were calculated on data of the time period 1981–1990 to achieve groups of landscape samples for comparisons between prevailing climate conditions during landscape survey periods and Ellenberg values. A minimum rescaled Euclidian distance of 10 was used to

achieve clusters comprising at least three sample sites. Cluster calculation over the whole year provided similar results as cluster calculations over the vegetation period. Additional cluster calculations with data from mountain areas with higher variability of

Fig. 2. Scatterplot of (a) mean T values per landscape samples versus mean temperature April–September with regression line ($R^2 = 0.65$, p -value < 0.01); (b) mean W values versus mean precipitation April–September; (c) mean T values of General Habitat Category “Sparsely Vegetated-Aquatic” with regression line ($R^2 = 0.59$, p -value < 0.01); (d) mean T values of General Habitat Category “Urban-Artificial” ($R^2 = 0.01$).

Fig. 3. Cluster analysis grouped the landscape samples into four climate clusters in respect to temperature and precipitation patterns. Expected changes in temperature sum (ΔT in $^{\circ}\text{C}$) and precipitation (ΔW in mm) during the period of April–September for the four clusters are given in the legend.

Table 3
Sensitivity index for T (temperature) and W (water availability) in the individual General Habitat Categories and cluster; abbreviations for General Habitat Category see Table 1.

Cluster		CUL/CRO	CUL/WOC	FPH	FPH/DEC	HER/CHE	HER/LHE	SPV/AQU	TPH/DEC	URB/ART	URB/NON	URB/VEG
1	T	1.7	1.1	1.4	1.1	0.9	1.0	1.6			1.5	0.9
	W	2.3	3.9	2.6	2.7	4.3	3.5	3.9			3.3	2.5
2	T		1.1	2.0	1.2	1.22	1.1	1.7			1.2	1.2
	W		3.3	2.9	2.7	3.5	4.5	4.1			4.3	4.1
3	T	1.1	1.0	1.1	1.1	1.0	1.2	1.2	1.0	1.0	1.2	1.0
	W	3.6	4.5	3.2	3.4	4.9	5.0	4.3	4.0	3.6	3.7	3.2
4	T	1.0	0.9	1.3	1.2	1.0	1.1	1.0		1.1	0.8	0.9
	W	3.6	4.6	3.4	3.6	4.4	4.0	4.4		2.5	3.3	3.1

climate conditions provided no sufficient results. The main reason for that effect was the spatial density of landscape samples. The spatial density of the landscape samples in the data set provided climatic singularities in regions with high spatial climate variability. However, it was sufficient for investigations in areas with lower climate variability like in the selected region of Upper Austria.

2.7. Ecological envelope

Based on the vegetation data, the species-associated Ellenberg values were taken to describe an ecological envelope (Ellenberg, 1988). For each habitat in each landscape cluster, ecological envelopes were produced with the focus on Ellenberg values T and W . The percentage of each Ellenberg T and W value was calculated and displayed, giving indication for the prevailing ecological factors of the individual habitats.

2.8. Sensitivity index

In order to assess how likely climate change is going to affect the ecological envelope of the broader habitats, we developed a sensitivity index inspired by the method of the saprobic index (Rolauffs et al., 2004). Reflecting the width of the ecological envelope, we counted the inverse number of Ellenberg T and W values per GHC and climate cluster, e.g. in a specific habitat, Ellenberg values '3', '4', '5', '6' are present, so the resulting value is $1/4 = 0.25$. Additionally, we calculated the ratio of number of present plants with Ellenberg values (1–9) and the number of plants without Ellenberg indica-

tion (0). Finally, adding these two ratios, we get an index for the sensitivity of a certain habitat in one cluster.

3. Results

3.1. Regression analysis

Looking at the mean T values of the landscape samples, regression analysis showed quite a strong relationship with mean annual temperature ($R^2 = 0.59$, p -value < 0.01), mean temperature April–September ($R^2 = 0.65$, p -value < 0.01 ; Fig. 2a) and both variables ($R^2 = 0.72$, p -value < 0.01). For the mean W values, the analysis did not reveal any significant correlation with any of the climate parameters (Fig. 2b). The individual broader habitats were differently influenced by the climate variables. Habitats FPH ($R^2 = 0.58$, p -value < 0.01) and SPV/AQU ($R^2 = 0.59$, p -value < 0.01) showed significant relationships with temperature variables whereas other habitats like CUL/CRO, TPH/DEC and URB/ART did not (Fig. 2c and d). A summary of the regression analysis is given in Appendix B.

3.2. Climate cluster

Cluster analysis grouped the landscape samples into four clusters (Fig. 3). Main discriminator for the clustering was the monthly pattern of temperature and precipitation values. Climate scenario data for the period 2041–2050 indicate a mean temperature rise of 1.85 – 2.17 $^{\circ}\text{C}$ in the months April to September and a rise in water balance of 33 – 151 mm in this time period.

Fig. 4. Ecological envelopes of the four climate clusters (a–d) for each General Habitat Category, abbreviations of General Habitat Categories see Table 1; grey-scale indicates percentages of occurrence of Ellenberg-values per combination of temperature values (T) and water availability values (W).

Fig. 5. Naturalness of General Habitat Categories; higher y-values indicate higher naturalness; abbreviations of General Habitat Categories see Table 1; the box is presenting the quartiles below and above the median, whiskers delimitate 1.5 interquartile range (IQR) of the lower and the upper quartile.

3.3. Ecological envelope

Fig. 4 displays the ecological envelope of the broader habitats per cluster in terms of temperature and water availability. The outmost lower left corners of the sub-quadrats show the high amount of indifferent species in the habitats. Medium values of category 5 (temperate species on medium moist soils) dominated all habitats although the spread of other Ellenberg values is different. FPH had a much narrower envelope in all clusters than the other broader habitats. Also, differences among the clusters became visible, e.g. HER/LHE occupied a large space in cluster 2 whereas in the others this space was tightened. CUL/CRO has a wide range in all clusters, even high T values. In the habitat of CUL/WOC, low T or W values were barely present.

3.4. Sensitivity index

In general, GHC's showed a higher sensitivity concerning W than T values (Table 3). The habitats HER/LHE, HER/CHE, CUL/WOC and SPV/AQU had highest sensitivity index for W values (>4.3), whereas CUL/CRO, URB/VEG, URB/ART and FPH (<2.7) had the lowest. Higher sensitivity for T values (>1.3) were calculated for habitats FPH and SPV/AQU, but the urban habitats, HER/CHE and CUL/WOC hardly showed any sensitivity to T values (<0.5). Among the clusters, the broader habitats showed different sensitivity behaviour, e.g. sensitivity T index for FPH ranges from 1.1 to 2.0 or sensitivity W index for URB/VEG from 2.5 to 4.1. On the other hand, HER/LHE had a small T range (1.0–1.2) and SPV/AQU a small W range (3.9–4.4).

In the course of the SINUS-project (Peterseil et al., 2004), hemeroby (Naveh and Liebermann, 1984) was assessed for each landscape element. These data were used to illustrate the naturalness of the individual broader habitats (Fig. 5). The best regression models coincided with the broader habitats which showed higher naturalness values.

4. Discussion and conclusions

Aggregation of species-data via Ellenberg values to a generalised level already proved useful for describing changes in vegetation

caused by alterations in climatic conditions (Morecroft et al., 2009). Thuiller et al. (2005) already found, that temperature and moisture conditions are mainly responsible for changes in species ranges and turnovers. Hence, we developed an ecological envelope with the Ellenberg values integrating these components. The species number of 683 plant species, which contributed to the ecological envelope of the broader habitats, covers the species diversity of the region sufficiently, as Englisch et al. (2005) have described 200–600 plant species in the location of the landscape samples. We found that Ellenberg T values of landscape samples can be related to temperature values of regional climate models quite well. In contrast to that, the Ellenberg water availability-indicator W corresponds not directly to precipitation values in the regression models. This can be explained by the fact, that humidity of a specific site is influenced by additional factors at small spatial scales, like geomorphological properties, soil proportions or amelioration measures (Ellenberg, 1988).

Although it is most unlikely, that climate change will have the same impact throughout the different locations of the landscape samples, clustering of the climate parameters revealed certain similarities between the landscape samples. These regional clusters made it possible to enhance the robustness of the ecological envelope due to the increased sample size achieved by adding up the samples of the landscapes to the level of clusters. In general, current climatic conditions of the project region show rarely any extreme situations and a little dynamics in terms of climate change (Loibl et al., 2009). It is likely that species turnover will occur in the broader habitats, since altered ecological niches will not be occupied by present species, and newly arriving species are gained (Thuiller et al., 2005). Loss of specific broader habitats will probably occur, when extreme environmental conditions do not allow for an adaptation of the ecological envelope. For other landscapes like high mountain areas, where vegetation already is exposed to a more extreme environment, even little changes will have a more severe impact on the existing species ranges (Thuiller et al., 2005) and plant communities (Trivedi et al., 2008).

These impacts can be assessed by the sensitivity of the broader habitats. The IPCC (2001b) defined sensitivity as the degree to which a species is affected either adversely or beneficially, by climate change. Normand et al. (2007) assessed species' sensitivity with bioclimatic models, Vasquez and Simonetti (1999) defined a sensitivity index based on literature review of vulnerability of life history traits and Roloff et al. (2009) developed a climate-species-matrix. We defined the sensitivity of habitats independently of species in order to avoid bias in species distribution data and biogeographical range.

Broader habitats showed a much higher sensitivity to W than T values, because many plant species are categorised as indifferent to temperature, but are classified to one of the twelve Ellenberg's W categories. Consequently, the ratio of sensitive to indifferent species for the sensitivity index W was much higher. It is to expect that the high rise in annual precipitation in cluster 3 and 4 of >100 mm will have a high impact on the broader habitats due to the fact of the high sensitivity W index, although we cannot capture the direct link of precipitation with the regression models, since the system of water availability is quite complex.

The best regression models for temperature were achieved for the broader habitats FPH, HER/LHE and SPV/AQU (aquatic vegetation) which also showed a medium to high sensitivity T index. As these habitats were also the ones with highest naturalness, it can be concluded that the temperature rise will have a higher impact on the more natural landscape elements than on the ones with higher anthropogenic influence. This conclusion goes in line with Vos et al. (2008), where a decline of suitable habitat for forest, wetland and grassland species is predicted.

The implications of the results for landscape planning are twofold. Since landscape planning is organised on the provincial scale, this can be seen of advantage for planning mitigation measures of such regional impacts of climate change (Jooss et al., 2009). On the other hand, institutional landscape planning does not intervene in land use activities, so the maintenance of habitats could be enhanced rather by subsidy schemes like the Austrian agri-environmental scheme, if these subsidies are targeted enough (Wrbka et al., 2008).

The expected changes in climatic condition will have also consequences for conservation planning and activities in the region. The establishment of Natura2000 sites aimed to maintain habitats in a favourable conservation status (Council of the European Union, 1992). However, the changes in the natural conditions of the habitats are not taken into account by this strategy. The risks of extinction for European plants may be large; species loss and turnover of more than 50% are projected for the continental biogeographic region (Thuiller et al., 2005). Normand et al. (2007) conclude that it is not realistic to preserve the current status of specific habitat types in place in small regions, but only on the European scale. In addition, the distribution of Annex I habitats in Europe outside of Natura 2000 sites is only known vaguely (Mücher et al., 2009). Consequently, it is very important to improve migration possibilities of species (Normand et al., 2007; Vos et al., 2008).

As temperature increase in the project region is below the European mean, the expected impact is more likely to arise from the rather big increase in precipitation, especially as our results

suggest a high sensitivity to water availability. Dry habitats are therefore at a large risk to be extinct in the region whereas wet habitats will encounter only minor problems. However, this study can only present general trends for habitats in agricultural landscapes with average environmental conditions. Meaningful conclusions for habitats under conservation priorities or for landscapes with more pronounced environmental stress need further research, since sampling design would need to be revised as these rare habitats are underrepresented in our sampling design.

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Appendix A.

Sample size of broader habitats and number of plant species found per landscape sample in *n* General Habitat Category (*n* species); abbreviations for General Habitat Category see Table 1.

Landscape sample	CUL/CRO	CUL/WOC	FPH	FPH/DEC	HER/CHE	HER/LHE	SPV/AQU	TPH/DEC	URB/ART	URB/NON	URB/VEG
436			9(19)	3(17)	13(8)	23(9)	3(15)			2(9)	
437			3(12)	1(12)	4(19)	8(45)	2(53)			2(21)	3(17)
438	2(5)	4(15)		1(10)	6(13)	1(5)				3(41)	2(16)
439		2(15)	2(18)	5(32)	18(36)	4(15)	2(39)			6(32)	1(4)
440	2(10)	6(18)	8(34)	6(39)	30(30)	9(47)	2(25)			6(41)	1(6)
441	1(4)	11(35)	3(22)	6(47)	41(53)	35(58)	9(50)			10(71)	7(54)
442	1(5)	9(27)	1(13)	5(35)	24(37)	22(68)	4(40)			8(78)	5(32)
443		4(23)	8(48)	3(26)	21(33)	30(56)	9(48)			6(35)	1(32)
444		6(25)	2(17)	10(49)	29(38)	20(43)	8(49)			10(56)	2(27)
445		6(32)	1(15)	8(51)	16(46)	33(45)	7(58)			10(68)	3(16)
449	11(29)	6(54)			20(57)	28(72)	3(39)		6(41)	3(22)	15(60)
451	23(47)		4(54)	6(66)	18(79)	7(49)	2(69)		5(60)	6(54)	4(62)
452	21(35)	1(44)	8(63)	9(90)	25(81)	16(82)	17(106)		2(43)	1(6)	8(30)
453	16(41)	9(76)	11(99)	15(110)	69(134)	45(152)	35(159)	1(7)	1(11)	5(67)	8(48)
455	28(55)	4(42)	15(78)	31(140)	95(177)	68(193)	27(158)	4(50)	14(102)	11(64)	16(91)
457					4(37)						
460	7(22)	4(37)	8(68)	11(67)	32(82)	18(110)	6(87)		4(45)	1(23)	11(53)
461	20(39)	3(25)	5(36)	23(110)	37(94)	33(92)	8(81)			2(28)	12(39)
462	20(43)	5(45)	1(30)	7(70)	32(115)	32(161)	11(108)		3(24)	3(20)	7(48)
463	7(21)		4(36)	3(27)	11(24)	6(67)	7(56)		1(15)	2(9)	7(23)

Appendix B.

Summary of regression analysis; formulas, degrees of freedom (df) and R^2 ; * indicates p -value < 0.05, ** indicates p -value < 0.01.

Formula linear regression	Landscape sample/GHC	df	R^2	
Average Ellenberg $T \sim$ mean annual temperature	Landscape sample	18	0.59	**
Average Ellenberg $T \sim$ mean temperature April–September	Landscape sample	18	0.65	**
Average Ellenberg $T \sim$ mean temperature April–September + mean annual temperature	Landscape sample	17	0.72	**
Average Ellenberg $W \sim$ annual water balance	Landscape sample	18	0.01	
Average Ellenberg $W \sim$ water balance January–September	Landscape sample	18	0.00	
Average Ellenberg $W \sim$ annual precipitation	Landscape sample	18	0.00	
Average Ellenberg $W \sim$ precipitation January–September	Landscape sample	18	0.00	
Average Ellenberg $W \sim$ precipitation April–September	Landscape sample	18	0.04	
Average Ellenberg $W \sim$ annual water balance + water balance January–September + annual precipitation + precipitation January–September + precipitation April–September	Landscape sample	14	0.23	
Average Ellenberg $T \sim$ mean temperature April–September	CUL-CRO	13	0.17	
	CUL-WOC	13	0.37	*
	FPH	15	0.58	**
	FPH-DEC	16	0.24	*
	HER-CHE	18	0.22	*
	HER-LHE	17	0.38	**
	SPV-AQU	16	0.59	**
	TPH-DEC	4	0.24	
	URB-ART	10	0.01	
	URB-VEG	16	0.33	*
Average Ellenberg $T \sim$ mean temperature April–September + mean annual temperature	CUL-CRO	12	0.30	
	CUL-WOC	12	0.39	
	FPH	14	0.60	**
	FPH-DEC	15	0.38	*
	HER-CHE	17	0.36	*
	HER-LHE	16	0.43	*
	SPV-AQU	15	0.62	**
	TPH-DEC	3	0.31	
	URB-ART	9	0.12	
	URB-VEG	15	0.33	*
	URB-NON	16	0.53	**
Average Ellenberg $W \sim$ annual water balance + water balance January–September + annual precipitation + precipitation January–September + precipitation April–September	CUL-CRO	9	0.22	
	CUL-WOC	9	0.54	
	FPH	11	0.17	
	HER-CHE	14	0.16	
	HER-LHE	13	0.58	*
	SPV-AQU	12	0.19	
	URB-ART	6	0.13	
	URB-VEG	12	0.24	
	URB-NON	13	0.38	

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Sensitivity of Broader Habitats to Climate Change in Austrian Agricultural Landscapes

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INTRODUCTION:

Climate change is one of the major threats to biodiversity together with habitat change, invasive alien species, overexploitation and pollution (Millenium Ecosystem Assessment, 2005). In Austria, recent empirical studies provide evidence, that global warming can drive vascular plant species of the nival and alpine belt on the edge of extinction (Pauli et al. 2007). But surprisingly little is known about the sensitivity and possible responses to climate change of lowland regions with a high share of semi-natural habitats embedded in cultivated land, although species richness and composition is largely driven by land use (Wrblka et al. 2004). The study is addressing this knowledge gap by presenting an approach that couples modelled high-resolution climate data (Loibl et al. 2007) with expert knowledge about the sensitivity of semi-natural and cultivated habitats in representative Austrian agricultural landscapes. Area-wide and consistent data on ecological characteristics of individual species are rare and therefore make regional assessment of climate change on biodiversity difficult. To avoid bias in results because of missing data on individual species, the use of a more aggregated level of biodiversity like functional plant types or habitats is preferable (e.g. Hély 2006).

METHODS:

The General Habitat Categories (GHC; Bunce et al. 2008) build the objective basis into which we can translate vegetation and habitat data and at the same time be independent from biogeographic species distribution and land use intensity. In 20 landscape samples with 1 km² area (Fig. 1), data on habitats and vegetation was available (Fig. 2). Ellenberg values of existing vegetation relevés were used to formulate the ecological envelope of the habitats in form of “eco-grammes” (Ellenberg 2001) as the next step. They helped to diversify the ecological conditions of the individual broader habitats. These envelopes were correlated with climate model results for the period 1981-1990. All landscape samples were clustered according to their changes in climatic conditions. In order to assess how the broader habitats will react to the change in the system, sensitivity rules were defined for each habitat inspired by the method of the saprobic index. Reflecting the width of the ecological envelope, we counted the inverse number of Ellenberg T and W values per GHC and climate cluster. Additionally, we calculated the ratio of number of present plants with Ellenberg values 1 to 9 and plants with value 0. Finally, adding these two ratios, we got an index for the sensitivity of a certain habitat.

Fig. 1: Landscape samples in the region of Upper-Austria. This region is dominated by continental climate with a mean total precipitation ranging between 800 to 1500 mm per year. Low mountain ranges, dominated by forests or grassland, are prominent in the northern samples whereas the southern ones comprise grasslands, crop- and fodder-production.

Fig. 2: Example landscape sample with different General Habitat Categories; CUL/CRO = Crops-Cultivated herbaceous crops; CUL/WOC = Crops-Woody crops; HER/LHE = ; HER/CHE = ; FPH = Forest phanerophytes (>5 m); FPH/DEC = Forest phanerophytes (>5 m)-Winter deciduous; FPH/CON = Forest phanerophytes (>5 m)-Coniferous; TPH/DEC = Tall phanerophytes (2- 5 m)-Winter deciduous; SPV/AQU = Sparsely Vegetated-Aquatic; URB/ART = Urban-Artificial; URB/GRA = Urban-Herbaceous; URB/NON = Urban-Non-vegetated; URB/VEG = Urban-Vegetables.

FIRST RESULTS:

Regression analysis revealed quite strong relationships for temperature values ($R^2 = 0.72$, p -value < 0.01) but not for water availability (Fig. 3 a, b). Differences in R^2 were given regarding the individual broader habitats; habitats FPH ($R^2 = 0.58$, p -value < 0.01) and SPV/AQU ($R^2 = 0.59$, p -value < 0.01) showed significant relationships with temperature variables whereas other habitats like CUL/CRO and TPH/DEC did not (Fig. 3 c, d). Cluster analysis grouped all landscape samples into four climate clusters. In climate cluster 1, a rise of 2.17°C and 38 mm of yearly precipitation is expected. Fig. 4 displays the ecological envelope of the broader habitats of climate cluster 1 in terms of temperature and water availability. The outmost lower left corners of the sub-quadrats show the high amount of indifferent species in the habitats. Medium values of category 5 (temperate species on medium moist soils) dominated all habitats although the spread of other Ellenberg values is different. Water availability had higher sensitivity indices than temperature (Fig. 5). Forests, fallow land, field margins and aquatic habitats had the best regression models, the highest sensitivity and also showed rather high naturalness values.

Fig. 3: Scatterplot of a. mean T values per landscape samples versus mean temperature April – September with regression line ($R^2 = 0.65$, p -value < 0.01); b. mean W values versus mean precipitation April – September; c. mean T values of General Habitat Category “Sparsely Vegetated-Aquatic” with regression line; d. mean T values of General Habitat Category “Urban-Artificial” ($R^2 = 0.01$).

Fig. 4: Ecological envelopes of the climate cluster 1 for each General Habitat Category, colour-ramp indicates percentages of occurrence of Ellenberg-values per combination of temperature values (T) and water availability values (W).

Fig. 5: a. Sensitivity index of water availability and b. of temperature values in an example landscape sample.

OUTLOOK:

As next step, we will investigate the relationship of the sensitivity index with the plant strategy types in the broader habitats. We also want to tackle the question if transition of habitats will mainly be induced by land-use changes or if these will be also caused by climate change. Based on all these aspects we will discuss the expected climate change related impacts on changes in biodiversity within the sample areas and explore adaptation strategies, evolving through self organisation and / or by changes in cultivation activities.

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