StartClim2011

Adaptation to climate change in Austria: "Forests"

Final Report

December 2012

lebensministerium.at

BMWF

ÖBf

bmwfj Bundesministerium für Wirtschaft, Familie und Jugend

Die Österreichische Hagelversicherung

BUNDESMINISTERIUM FÜR GESUNDHEIT

Verbund Austrian Hydro Power

ÖNB Oesterreichische Nationalbank

PERSPEKTIVEN FÜR UMWELT & GESELLSCHAFT umweltbundesamt

StartClim2011

Adaptation to climate change in Austria: "Forests"

Final Report

Project Leader

Institute of Meteorology
Department of Water, Atmosphere and Environment
BOKU - University of Natural Resources and Life Sciences Vienna
Univ.-Prof. Dr. Helga Kromp-Kolb

Contracting Parties

Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management
Austrian Federal Ministry of Science and Research
Austrian Federal Forests
Austrian Federal Ministry of Health
Austrian Federal Ministry of Economic Affairs, Family and Youth
Austrian National Bank
Austrian Hail Insurance
Federal Environment Agency
Verbund AHP

Administrative Coordination
Federal Environment Agency

Vienna, December 2012

StartClim2011
Adaptation to climate change in Austria: „Forests“

Project Leader: Institute of Meteorology
Department of Water, Atmosphere and Environment
BOKU – University of Natural Resources and Life Sciences, Vienna
Peter Jordan Strasse 82, 1190 Vienna
URL: http://www.austroclim.at/startclim/
http://www.wau.boku.ac.at/met.html

Editors

Helga Kromp-Kolb, Thomas Gerersdorfer and Ingeborg Schwarzl
Institute of Meteorology
Department of Water, Atmosphere and Environment
BOKU – University of Natural Resources and Life Sciences, Vienna

Vienna, December 2012

Contributions to StartClim2011

StartCim2011.A: Climatic influence on voltinism and spread of the spruce bark beetle, Ips typographus, in alpine areas
Institute of Forest Entomology, Forest Pathology & Forest Protection, BOKU: Axel Schopf, Emma Blackwell, Veronika Wimmer

StartClim2011.B: Analyzing Austria's forest disturbance regime as basis for the development of climate change adaptation strategies
Institute of Silviculture, BOKU: Rupert Seidl, Dominik Thom
Institute of Forest Protection, Federal Research and Training Center for Forests, Natural Hazards, and Landscape (BFW): Hannes Krehan, Gottfried Steyrer

StartClim2011.C: Effects of soil drying on the transpiration of Austrian tree species
Universitäy of Innsbruck: Georg Wohlfahrt, Stefan Mayr, Christoph Irschick, Sabrina Obwegeser, Petra Schattanek, Teresa Weber, Dorian Hammerl, Regina Penz

StartClim2011.D: Adapting Austrian forestry to climate change: Assessing the drought tolerance of Austria's autochthonous tree species
Institute of Botany, BOKU: Gerhard Karrer, Gabriele Bassler
Institute of Forest Ecology, BOKU: Helmut Schume, Bradley Matthews
Vienna Institute for Nature Conservation and Analyis, V.I.N.C.A: Wolfgang Willner

Scientific Coordination

Institute of Meteorology, Department of Water, Atmosphere and Environment
BOKU – University of Natural Resources and Life Sciences, Vienna
Univ. Prof. Dr. Helga Kromp-Kolb, Mag. Ingeborg Schwarzl, DI Thomas Gerersdorfer

Scientific Board

Dr. Jill Jäger, Sustainable Europe Research Institute (SERI), Vienna

Prof. Dr. Hartmut Graßl, Max Planck Institute for Meteorology/University Hamburg

SC Christian Küchli, Dr. Sabine Augustin, Federal Office for the Environment FOEN, Forest Division, Switzerland

Coordinating Group

Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management

Elfriede Fuhrmann, Helmut Hojesky, Birgit Kaiserreiner, Barbara Kronberger-Kießwetter, Andreas Pichler, Florian Rudolf-Miklau, Heinz Stiefelmeyer, Stefan Vetter

Austrian Federal Ministry of Health

Ulrich Herzog, Fritz Wagner, Robert Schlögel

Austrian Federal Ministry of Science and Research

Christian Smoliner, Ingrid Elue

Austrian Ministry of Economic Affairs, Family and Youth

Eva Dolak, Herwig Dürr, Monika Wallergraber

Austrian Federal Forests

Norbert Putzgruber

Austrian Hail Insurance

Kurt Weinberger, Josef Rohregger

Austrian National Bank

Johann Jachs

Federal Environment Agency

Karl Kienzl, Maria Balas, Sabine McCallum

Verbund AHP

Otto Pirker, Michael Tauber

Administrative Project Coordination

Federal Environment Agency
Maria Balas, Karl Kienzl, Sabine McCallum

Table of Contents

Abstract

StartClim has been engaged with the topic of adaptation to climate change since 2008.

In the light of the international year of forests, StartClim2011 focussed on the adaptation to climate change with regard to the theme “forests” in Austria. Accordingly, the projects support and contribute to the climate change adaptation strategy for Austria.

The work presented herein highlights increases in forest damage under changing climate conditions and the effects on the ecosystem functions and services of forests. Addressed also are the considerable potential and inevitable adaptations for silviculture which should be undertaken to ensure forest sustainability for the future.

Climatic influence on voltinism and spread of the spruce bark beetle, Ips typographus, in alpine areas

The aim of this study was to investigate the influence of microclimatic site and stand conditions on the dynamics of population density of the spruce bark beetle, Ips typographus, in a valley end of the Wilderness Area Dürrenstein without the influences of protective forestry measures. An analysis of the beetle's population density, in which the number of infested trees during the years 2003-2011 was examined together with the developmental influencing factors (temperature and irradiance) as well as crucial predisposing factors on site and stand level, was performed.

The results of this retrospective analysis show that high amounts of trees killed by bark beetles only occurred after extreme events, such as the avalanche in 2009, where massive amounts of potential breeding material was available. No direct or delayed relationship between temperature conditions during the vegetative period or the calculated number of potential generations and new infestations of trees was found. Of the total area of the Wilderness Area Dürrenstein, the south facing slopes were in notably higher predisposition classes. Grid cells for which the predisposition model PAS calculated a high risk level due to high percentages of spruce trees, stand age and storm vulnerability, terrain morphology, and snow damage were preferably infested. Bark beetle flight direction and distance were examined by treating infested spruce logs with fluorescent powder. More than 50% of all marked bark beetles were recaptured within a radius of 100m from the hatching site, predominantly in a south-westerly direction. 93% were recaptured within a radius of 500m. Although the mean monthly temperatures from May to August 2012 were 1.8°C above the climate normal period of 1971-2000 (climate station Mariazell), only one generation with one sister brood developed in the study area. The extent to which the areas predicted temperature increase of +1.1°C - 2°C (2021-2050) and +3°C - 3.9°C (2050-2071) will influence the until now predominantly univoltine development of Ips typographus requires further investigation.

Analysing Austria's forest disturbance regime as basis for the development of climate change adaptation strategies

Disturbance frequency and magnitude have increased considerably in Austria's forests in recent decades. Both climatic changes as well as changes in forest structure and composition have contributed to this intensification. Wind, bark beetles, and snow are the most important disturbance agents in Austria, damaging 3.1 Mill. m³, 2.2 Mill. m³, and 0.6 Mill. m³ on average per year, respectively, in the period 2002 to 2010 (i.e. in total 33.7% of the total harvest level in the same period). In addition, scenario analyses point towards a further increase of disturbance damage under changing climate conditions, with the potential to negatively impact important ecosystem services such as timber production, the protection against gravitational hazards, and the sequestration of carbon.

The objectives of this study were to improve the quantitative understanding of Austria's disturbance regime in the context of developing adaptation strategies in forest management. We analysed the spatio-temporal variation of wind, bark beetle, and snow damage at the

level of forest districts (n=72) for the years 2002 to 2010. Results show that a considerable portion (21.1% - 44.0%) of the spatial variation in disturbance damage in Austria could be explained by predisposing factors. Many of these factors can be either directly (e.g., through managing stand structure and composition) or indirectly (e.g., via a reduction of stem damage and alternative silvicultural systems) influenced by forest management. The most important factor for all three disturbance agents was tree species composition (i.e. the proportion of Norway spruce and/or conifers).

In contrast to predisposing factors, management was found to have only a minor potential influence on inciting factors of disturbance damage, which explained an additional 11.1% and 23.1% of the variation and were mainly related to weather indicators and disturbance interactions. The findings of the current study suggest that rising temperatures and an increasing variation in precipitation could further intensify disturbance regimes. This climate sensitivity underlines the importance of disturbance-focused climate change adaptation measures in order to sustainably fulfill important ecosystem functions and services also in the future. The current study highlights spatial as well as methodological hotspots in this regard, and documents the considerable potential of silvicultural measures in disturbance management (e.g., via the promotion of diverse and site-adapted stands), but also underlines the importance of considering the long lead times of adaptation in forest management.

Effects of soil drying on the transpiration of Austrian tree species

In order to avoid desiccation and ensuing damage to tissues, plants are able to adjust transpiration during periods of soil drying through adjustments of stomatal conductance. This protective regulatory mechanism, however, affects the uptake of carbon dioxide (i.e., photosynthesis), dry matter accumulation and thus timber yield, the near-surface climate and the water balance of ecosystems and landscapes. Within the frame of StartClim2011.C differences between European tree species in their response to soil drying were investigated. To this end a meta-analysis of the literature on this topic was combined with a drought experiment using potted tree seedlings.

The literature survey showed that while a large number of studies have been published on this topic, only a small percentage (ca. 20%) contained data that could be used in the meta-analysis. As a consequence, data were available only for a small number of tree species and an even smaller number of plant water relations parameters, which eventually prohibited drawing defensible conclusions about differences between tree species in their response to soil drying. The drought experiment showed that coniferous tree species reacted more cautiously to developing soil water shortage than deciduous tree species. Coniferous tree species down-regulated stomatal conductance at the very early stages of drought, which caused them to be less affected by xylem embolism as compared to deciduous tree species. Depending on the intensity and duration of drought periods and the root-exploitable soil volume, the coniferous tree species' strategy of dealing with drought periods appears superior compared to deciduous tree species. This conclusion however needs further corroboration by studies on adult trees in their natural environment. If confirmed, the results of this study imply that coniferous tree species may gain importance for reforestation in Austria in the future. The results of this and additional future studies are expected to lead to improved forest management strategies (selection of tree species and varieties for reforestation, management techniques, etc.) under changing environmental conditions.

Adapting Austrian forestry to climate change: Assessing the drought tolerance of Austria's autochthonous tree species

One option that has been muted as a potential climate change adaptation strategy for Forestry is the introduction of non-autochthonous provenances or non-native species which are thought to be better adapted to the projected changes in climate. However, such action should only be considered once autochthonous reproductive material has been proven to be inferior. If potentially adapted autochthonous provenances exist, utilisation of these sources

would allow forestry in Austria to avoid (potentially unnecessary) ecological uncertainty and changes to the forest sector associated with large scale introductions of exotic species.

As warmer and drier summers are expected for Austria, this study investigates the existence of potentially drought adapted provenances within the Austrian populations of 22 tree species of silvicultural and ecological importance. By calculating mean ecological indicator values of site moisture from vegetation relevés of the Austrian Vegetation Database this study demonstrates the range in moisture conditions tolerated by Austrian tree species. The sites were also analysed in terms of aspect and elevation to investigate non-climatic effects on site moisture conditions. Furthermore, the 10th percentile was taken as the cut off value to identify the dry sites inhabited by each of the respective species (i.e., the driest 10%). These sites represent the locations of potentially drought tolerant provenances and thus potentially useful sources of reproductive material in fostering climate change adaptation. For potential users interested in the locations of the provenances identified here, the data used and generated by this project will be made available upon request.

1 The StartClim research programme

The StartClim climate research programme is a flexible instrument. Because of the short project duration it can react quickly to topical aspects of climate and climate change. It is financed by a donor consortium consisting of nine institutions (see page 4).

StartClim addresses the topic of adaptation to climate change since 2008. It provides valuable contributions to the development and implementation of an Austrian strategy in this regard.

The projects in StartClim2011 focus on adaptation to climate change with regard to the theme “forests”. Different aspects which are of great importance for the adaptation to climate change for forests are investigated. The projects investigate voltinism and the spread of the spruce bark beetle in alpine areas, the increase of disturbance in Austria's forests, the effects of soil drying on the transpiration of Austrian tree species, and the drought tolerance of Austria’s autochthonous tree species.

The StartClim2011 report contains an overview of the results in German and English along with separately bound documentation in which the individual projects are described in detail by the respective project teams. All reports and documents about StartClim2011 will be made available for download at http://www.austroclim.at/startclim, the StartClim website. A limited number of CDs with all StartClim reports and folders with a short summary will also be published.

2 StartClim2011.A: Climatic influence on voltinism and spread of the spruce bark beetle, Ips typographus, in alpine areas

High amounts of potential breeding materials are essential for mass outbreaks of the spruce bark beetle. This is often present after storms, snow damage or avalanche events. If these are followed by warm and dry weather conditions, a rash population increase of the beetle can be triggered. Apart from the beetle's high reproductive capacity, climatic conditions mainly influence the development and the number of generations per year. In order to estimate the risk of bark beetle outbreaks and to initiate control measures in good time, it is necessary to have knowledge about the vulnerability of the stands and sites to disturbances through extreme weather events (predisposition). It is also crucial to have knowledge about the possible number of beetle generations per year (voltinism of the beetle) as well as their dispersal behaviour.

The aim of this study was to investigate the influence of microclimatic site and stand conditions on the dynamics of population density of the spruce bark beetle, Ips typographus, without the influences of protective forestry measures in a valley end of the Wilderness Area Dürrenstein. An analysis of the beetle's population density, in which the number of infested trees during the years 2003-2011 was examined together with the developmental influencing factors (temperature and irradiance) as well as predisposing factors at site and stand level, was performed. The spruce bark beetle's dispersal was studied after infested logs had been treated with fluorescent powder and the beetles were then captured in pheromone traps placed around the hatching site at different distances. The findings of this project served to simulate a scenario about the beetle's dispersal at a projected warming of +1.6°C and +3.4°C.

The results of the retrospective analysis show that high amounts of trees killed by bark beetles only occurred after extreme events such as the avalanche in 2009, after which massive amounts of potential breeding material was available. No direct or delayed relationship between temperature conditions during the vegetative period or the calculated number of potential generations and new infestations of trees was found. Even the exceptionally warm summer of 2003 did not result in a rise of the beetle's population density. Of the total area of the Wilderness Area Dürrenstein the south facing slopes were in notably higher predisposition classes. 423 of the 3788 grid cells (30x30m) were infested by the spruce bark beetle during the period from 2003 to 2011. Grid cells where the predisposition model PAS calculated a high risk level due to high percentages of spruce trees, stand age, storm vulnerability, terrain morphology, and snow damage were preferably infested (Fig. 1). 1478 spruce bark beetles marked with fluorescent powder were caught in the eleven pheromone traps in the Hundsau area (Fig. 2). This represents a capturing rate of approximately 22% of the beetles from the hatching site. More than 50% of all marked bark beetles were recaptured within a radius of 100m from the hatching site, predominantly in a south-westerly direction. 93% were recaptured within a radius of 500m.

Although the mean monthly temperatures from May to August 2012 were 1.8°C above the climate normal period of 1971-2000 (climate station Mariazell), only one generation with one sister brood developed in the study area. The extent to which the areas predicted temperature increase of +1.1°C - 2°C (2021-2050) and +3°C - 3.9°C (2050-2071) will influence the until now predominantly univoltine development of Ips typographus requires further investigation.

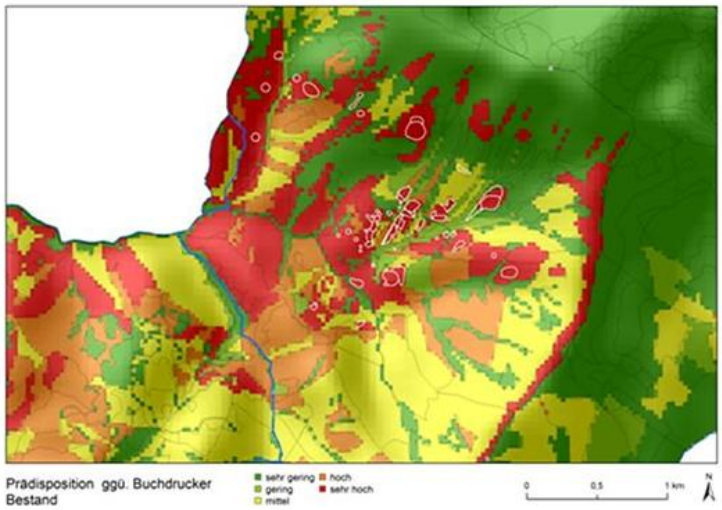

Fig. 1: Classification of the study site “Hundsau“ in predisposition classes. White borders: Areas that were infested by Ips typographus from 2003 to 2011.

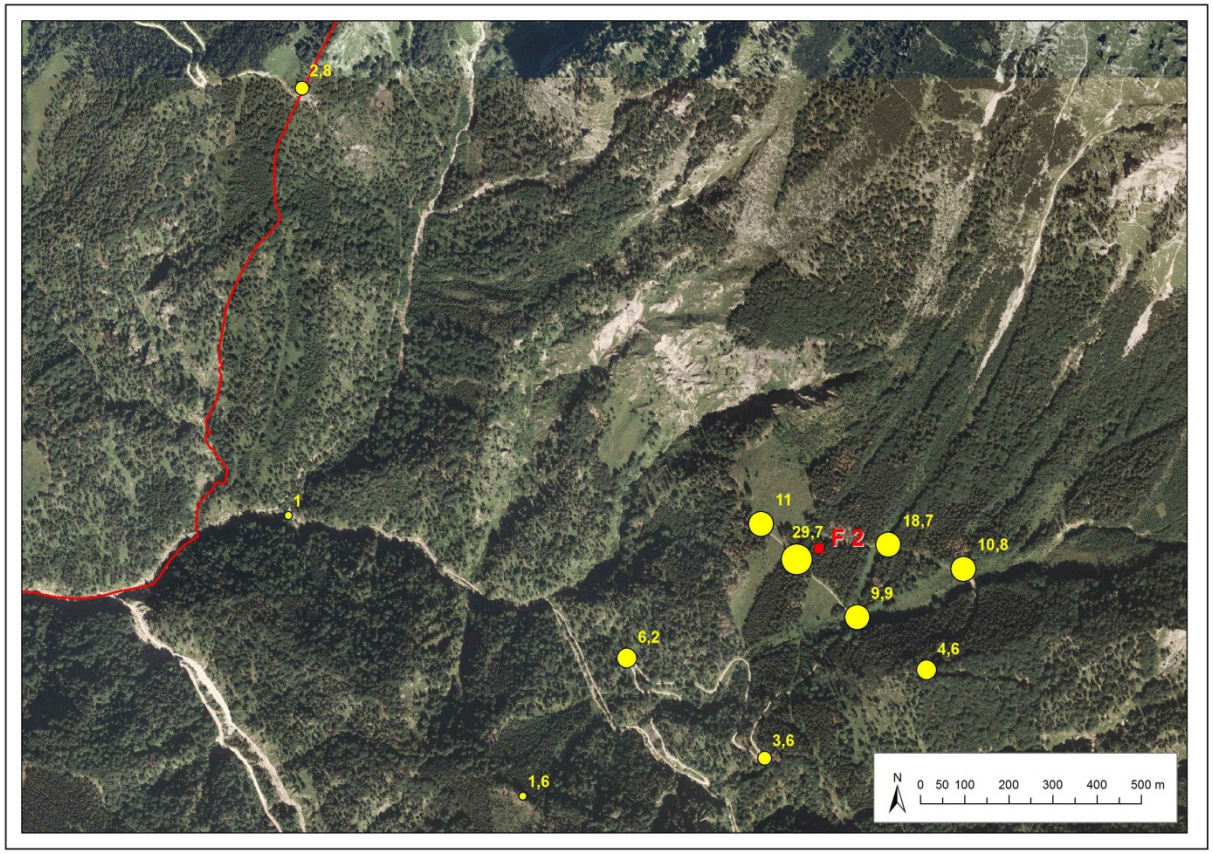

Fig. 2: Trap rate of marked spruce bark beetles during the test period 13.06.2012 to 30.08.2012 in the Hundsau area expressed in percentage per pheromone trap. F2= Hatching point of marked bark beetles.

3 StartCim2011.B: Analysing Austria's forest disturbance regime as basis for the development of climate change adaptation strategies

Disturbance frequency and magnitude have increased considerably in Austria's forest ecosystems in recent decades. Both climatic changes as well as changes in forest structure and composition have contributed to this intensification. Wind, bark beetles, and snow are the most important disturbance agents in Austria, damaging 3.1 Mill. m³, 2.2 Mill, m³, and 0.6 Mill. m³ on average per year, respectively, in the period 2002 to 2010 (i.e. in total 33.7% of the total harvest level in the same period). In addition, scenario analyses point towards a further increase of disturbance damage under changing climate conditions, with the potential to negatively impact important ecosystem services such as timber production, the protection against gravitational natural hazards, and the sequestration of carbon. Thus, disturbance management is an issue of increasing importance in silviculture. In this context, the Austrian Climate Change Action Plan includes improved disturbance management as one of the main climate change adaptation measures in forestry. Furthermore, the Ministerial Conference on the Protection of Forests in Europe urged for an increasing focus on disturbances in order to ensure the sustainability of Europe's forests and their functions in their recently ratified Oslo declaration.

The objectives of this contribution were to improve the quantitative understanding of Austria's disturbance regime in the context of developing adaptation strategies in forest management. We analysed the spatio-temporal variation of wind, bark beetle, and snow damage at the level of forest districts (n=72) for the years 2002 to 2010. Particular aims of the study were to highlight factors that determine predisposition of Austria's forests to disturbances (i.e. the risk of damage determined by slow, long-term factors such as climate, vegetation and forest stewardship), and to identify spatial hotspots of predisposition, i.e. regions of high priority for adaptation. An additional aim was to identify short-term inciting factors for disturbance damage (e.g., weather conditions, spatio-temporal interactions with previous disturbance damage or other disturbance agents) and analyse them with regard to their potential to serve as early warning indicators in disturbance management.

We used data from the Documentation of Forest Damage Factors of Austria as well as from the Austrian Forest Inventory in combination with climate and weather data in our analysis. After an exploratory investigation by means of correlation, the main analyses was conducted in two sequential steps: first analysing the spatial variation in predisposing factors by means of principal component regression, then subsequently (i.e. after controlling for the effect of varying predisposition in space) analysing the role of inciting factors with regard to the temporal variation in disturbance damage by means of multiple linear regression.

The results indicate that a considerable portion of the spatial variation in disturbance damage in Austria can be explained by predisposing factors (wind: 34.4%, bark beetles: 44.0%, snow: 21.1%). Many of these factors can be influenced by forest management either directly (e.g., by changing the species composition) or indirectly (e.g., by reducing stem damage, alternative silvicultural systems), highlighting the role and potential of silviculture in adapted disturbance management. Indicators of species composition, namely the share of conifers as well as the proportion of pure Norway spruce stands, had the strongest influence on disturbance predisposition. Adapting forest management towards more diverse and less conifer-dominated stands can thus reduce disturbance predisposition considerably (simultaneously for wind, bark beetle, and snow damage). Further important factors of predisposition which can be influenced by adapted forest management are growing stock (wind and bark beetle disturbance), the deviation from the potential natural vegetation composition (bark beetle disturbance), as well as stem damage from bark peeling and harvest damage (snow disturbance). The most important climate-related predisposition indicators were the variability in water supply as well as temperature, which both were positively associated with bark beetle damage.

In order to support the setting of priorities in the development and implementation of adaptation, predisposition hotspots were identified based on the results of the principle component regression analysis (Fig. 3). This analysis showed that large parts of Upper and Lower Austria west of the river Traisen are at particular risk from wind and bark beetle disturbance. Adaptation measures focusing on improved disturbance management are thus of particular importance in these regions. The eastern, pannonic parts of Austria, on the other hand, were found to have relatively low predisposition to all three investigated disturbance agents.

In contrast to slowly changing predisposing factors, which can be strongly influenced by forest management, inciting factors of disturbance occurrence were most strongly associated with indicators of weather and disturbance interactions, i.e. factors on which only little control can be exerted via adaptation measures. The strong influence of temporal disturbance interactions found for bark beetle damage can, however, be of relevance as an early warning indicator for forest management. Our analysis showed that for every m^3 of bark beetle damage in the current year, 0.56 m^3 of damage can be expected in the following year, which underlines the importance of monitoring and pest control in outbreak areas. Generally, an additional 11.1% and 23.1% of the variation in wind and bark beetle damage respectively, could be explained by inciting factors. Our two step approach thus explains 45.5% (wind) and 67.1% (bark beetles) of the overall spatio-temporal variation in disturbance damage during 2002-2010.

With regard to the climate sensitivity of Austria's disturbance regime our analysis suggests that increasing temperatures are likely to lead to further increases in bark beetle damage in Austria. In addition, increasing variability in precipitation and probability of wet snow events could further contribute to elevated damage from bark beetles and snow in the future. In this regard the complementary stand- to landscape-scale case study StartClim 2011.A, highlights the importance of the local context (e.g., topography, elevation) for the climate sensitivity of disturbance regimes, which, in combination with the strong nonlinearities of the involved disturbance processes, might result in a diversity of local climate responses. Furthermore, climate change will not only shift long-term climate conditions, but will also affect short-term weather events. A decreasing number of days with temperatures that support frozen soil conditions will, for instance, decrease the anchorage of trees in winter and increase the risk towards winter windstorms. Moreover, dynamic interactions (e.g., between wind and bark beetle disturbance, or bark beetle disturbance of the current and previous year) might further intensify the climate sensitivity of disturbance regimes. The importance of such interactions is also underlined by the findings of StartClim 2011.A, which identified windthrow as a main inciting factor for bark beetle damage in montane forest ecosystems. Overall, the high climate sensitivity of disturbance regimes underlines the importance of adaptation measures targeting disturbance management, in order to ensure the sustainable provisioning of forest functions and services also under future environmental conditions. In this regard the current study highlights factors with strong leverage on disturbance damage as well as spatial hotspots in Austria, and documents the considerable potential of silvicultural measures in disturbance management (e.g., via promoting diverse, site-adapted stands), but also underlines the importance of considering the long lead times of adaptation in forest management.

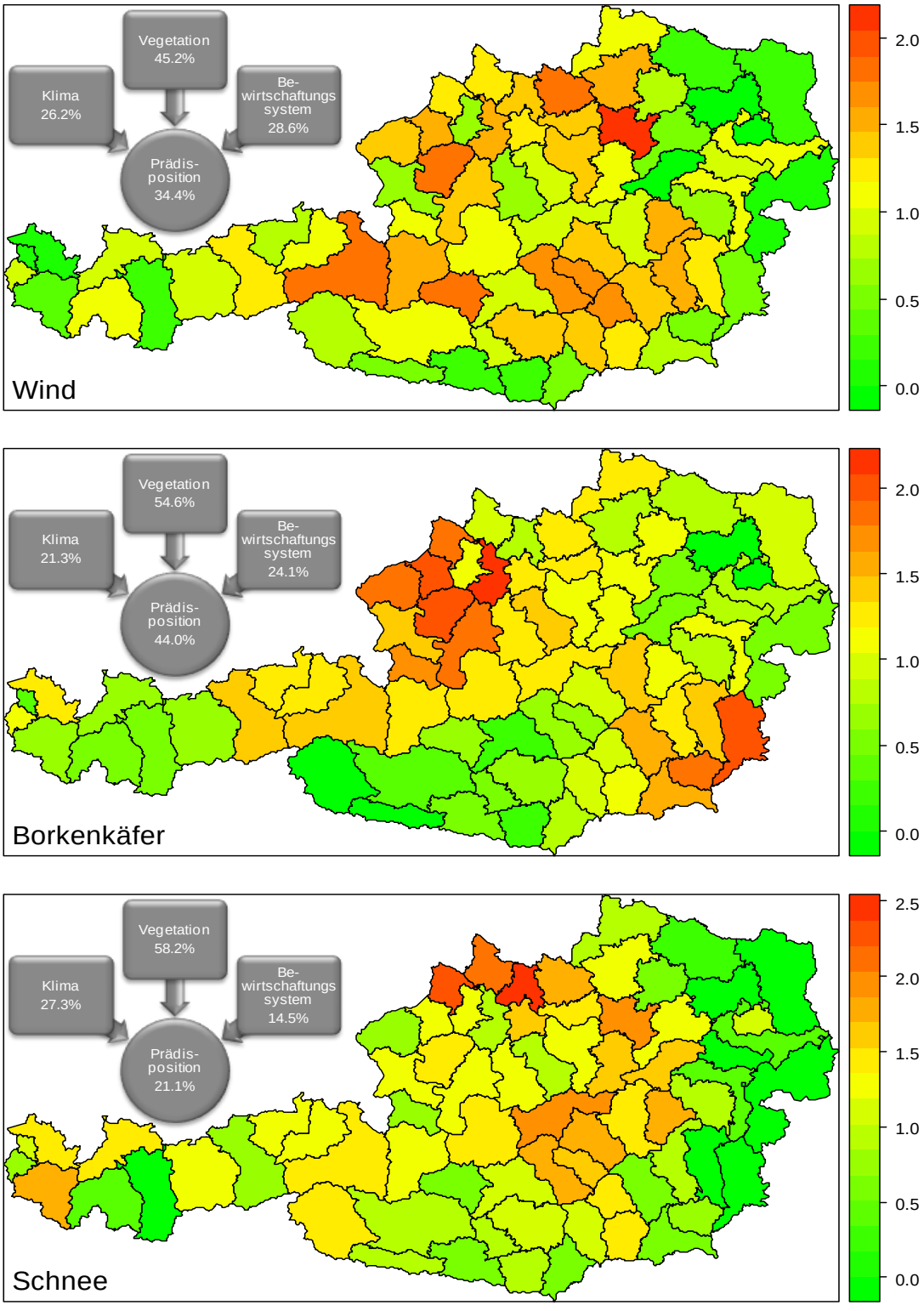

Fig. 3: Disturbance predisposition in Austria's forest districts relative to the country-level mean. A value of 1.5 indicates that a 50% higher damage level can be expected for a given district, compared to the country average. The inserts show the statistically-derived relative influence of factor groups on predisposition, and indicate the overall proportion of the variance explained in the analysis. Upper panel: wind, central panel: bark beetles, lower panel: snow.

4 StartClim2011.C: Effects of soil drying on the transpiration of Austrian tree species

Scenarios of climate change in the Greater Alpine region are still uncertain with regard to the magnitude of expected changes in precipitation, but tend to agree on a trend of increasing summer droughts shifting northwards from the Mediterranean region. Precipitation is likely to occur more often in form of heavy rainfalls with extended dry periods in between. In addition, higher temperatures are likely to cause a shift in winter precipitation from snow to rainfall and, in consequence, lead to changes in the amount and temporal dynamics of melt water. In Austria, more frequent, extended and/or more intensive drought periods have to be expected during the vegetation period.

How trees and plants in general react to soil drought depends, besides numerous environmental factors, on their hydraulic type: So-called "hydrostable" species follow a cautious strategy regarding water relations and react already at moderate decrease in leaf water potential (water availability in the leaf) with stomatal closure to avoid further water losses. In contrast, "hydrolabile" species risk higher water deficits before reducing stomatal aperture. The kind of stomata reactions and thus on the regulation of transpiration during soil drying have several consequences:

First, for trees stomatal closure prevents drought damage. In this context, a hydrostable strategy is advantageous. However, stomatal closure also leads to reduced carbon dioxide assimilation and, as a consequence, reduced growth. A hydrolabile strategy may thus be advantageous under moderate soil drought. These aspects are of relevance not only for timber yield, but, on a long term, also for changes in species composition and biodiversity. Increased or decreased biomass production is also likely to lead to enhanced or reduced carbon dioxide storage.

Second, there are effects on the energy balance of forests and on the near-surface climate. As the evaporation of water requires energy, transpiration causes cooling. A rapid decrease in transpiration during drought periods, which are frequently linked with high temperatures (“heat waves”), thus leads to an amplification of temperature increases. The cooling effect of the vegetation cover is reduced if hydrostable tree species dissipate energy in form of sensible instead of latent heat. Hydrostable tree species are thus not suitable for mitigating the urban heat island effect, e.g., with respect to anticipated climate change.

Third, differences in stomata regulation of hydrostable and hydrolabile species influence the water balance of forest ecosystems. In the frame work of a simplified water balance, precipitation is balance by either evaporation or run-off. In periods with low precipitation, the opening of stomata (i.e. high transpiration) by hydrolabile plant species contributes to a (further) decrease in run off. This affects downstream regions, as rivers there are fed by run off generated in higher regions in Austria (or the Alps), and thus adds a geopolitical dimension to this issue.

While tree specific differences were predominantly studied from an economic point of view, analysis of tree hydraulics enabling a quantification of the social and geopolitical implications mentioned above are missing up to now.

The overarching aim of the present study was to develop/improve datasets on the reaction of Austrian trees species upon soil drought and, in consequence, to improve the background for management decisions in forestry with respect to the selection of tree species compositions. In the project, species-specific differences in the reaction to soil drought and corresponding functional and structural traits were analysed. We hypothesised that there are inter-specific differences in reactions on soil drought, which are based on functional and structural properties of the studied tree species.

The project is based on a split strategy: A meta-analysis of relevant scientific literature was conducted. The aim of this project component was to extract appropriate data from existing

publications and data sets. The disadvantage of this strategy was the restricted comparability and availability of data due to different research methods, experimental setups and other factors influencing the results. Therefore, in addition 12 Austrian tree species as well as species expected to increase in abundance or have invasive potential, were analysed in a drought experiment. These tree species were exposed to increasing drought stress under controlled conditions and their stomatal response was studied.

The meta-analysis showed that a large number of studies on this topic has been undertaken and published (>1800 hits during literature search). However only a small fraction (<20%) of the data could be imported into the database. In all other cases, data were incomplete or not available in a usable form. It is concluded that on the level of research policy there is a need to guarantee the long-term availability of data that usually have been financed by public funds. As a consequence of the small number of usable studies, defensible and statistically significant results were difficult to obtain from the meta-analysis. The main reason for this was that a sufficient number of replicates (>30) was available only for a small number of tree species. In addition, few studies investigated the same parameters and in particular parameter combinations. These two limitations were responsible for factors such as study conditions, tree age, experimental methods and so forth interfering with the effects of species identity, which were the main target in this study. While this represents a sobering result, it confirms that the strategy of combining a meta-analysis with a drought experiment within which consistent methods were used under identical environmental conditions, was fully justified.

The drought experiment showed that transpiration of the investigated tree species responded differentially to soil drying (Fig. 4). The investigated coniferous tree species and some of the deciduous tree species such as sycamore maple and ash were characterised by a hydrostable strategy and reduced stomatal aperture already at slightly negative leaf water potentials (leaf water potentials represent an under-pressure and are thus reported in negative pressure units). The other deciduous tree species were characterised by a hydrolabile strategy and started down-regulating stomatal conductance at more strongly negative water potentials, which allowed these species to continue photosynthesis for extended time periods into the developing drought. The regulation of stomatal aperture thus represents a key aspect of plant water relations that has far-reaching consequences for plants and ecosystems.

Why are species forced to reduce transpiration at specific water potentials? For instance, in all species studied, stomatal conductance was near zero below a potential of -30bar (Fig. 4) as none of the species would risk opening stomata under these drought conditions. A decrease in leaf water content affects cellular structures and functions, but even more important are impairments in the plant water transport system. Embolism can block the water supply of plants and thus intensify drought stress, even when water availability in the soil increases again. Some plants are able to repair embolism by refilling conducting vessels, but this process is hardly understood and probably requires a lot of energy. For many species, especially conifers, which do not exhibit efficient repair processes, the avoidance of embolism is thus of major importance for these tree species.

The measurements conducted within this study investigated a central component of the plant water balance – transpiration and how it reacts to soil drying. In order to be able to transfer these results to real-world conditions, several additional aspects have to be considered: The extent and efficiency of the root system significantly affects plant water availability and thus the extent and intensity of drought stress during periods of low precipitation. One parameter that is of crucial importance in this regard is the ratio of transpiring leaf area to the extent of the root system. As observed in the drought stress experiment, plants may reduce drought stress also by shedding leaves (Fig. 5) and thus by reducing the amount of transpiring leaf area. The results of the drought stress experiments are likely not entirely transferable to adult trees because these differ in their hydraulic architecture from the saplings used in the experiment and because the potted saplings were likely limited by the available soil volume.

Last but not least, it should be noted that intra-specific variability (i.e. within the same species) in hydraulic parameters and adaptation strategies are still poorly understood.

Nevertheless, the data gathered within this project represent a great basis for additional research on this topic, in particular on the long-term effects of drought stress under real-world conditions in mixed species stands. Already now, the following recommendations may be derived from this study: Characterising the drought response of tree species (and ecotypes) is possible and represents a meaningful basis for the selection of tree species for re-forestation in drought-prone areas. For forest management our results imply that certain coniferous tree species will gain importance for re-forestation in the future. The results of this and necessary future studies will help to developed improved forestry management strategies (selection of tree species and varieties for re-forestation, management techniques, etc.) under changing climatic conditions.

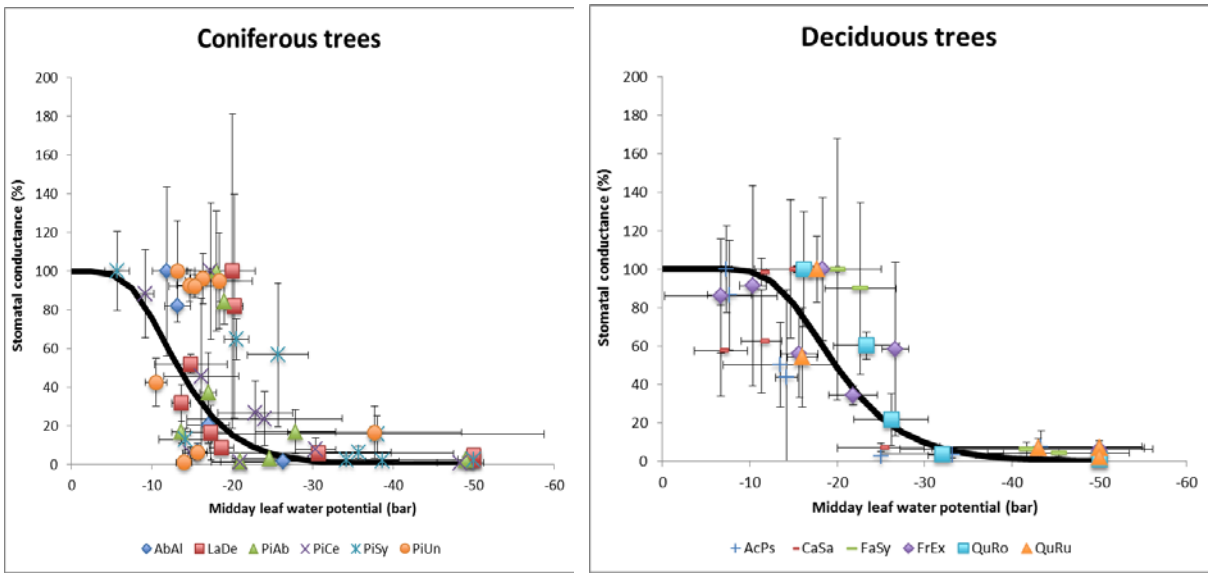

Fig. 4: Stomatal conductance versus midday leaf water potential (water stress increases as the leaf water potential becomes more negative) for coniferous (left) and deciduous (right) tree species. Data (average ± standard deviation) have been collected within the frame of the drought experiment. The following abbreviations were used for the tree species names: fir (AbAl), larch (LaDc), spruce (PiAb), stone pine (PiCe), Scots pine (PiSy), mountain pine (PiUn), sycamore maple (AcPs), European chestnut (CaSa), beech (FaSy), ash (FrEx), English oak (QuRo) und read oak (QuRu).

Fig. 5: Effects of drought on the investigated tree species. English oak (Quercus rubra; left) and mountain pine (Pinus uncinata; right) are shown in an exemplary fashion. For each species the left picture shows an individual that underwent the drought treatment, while the right picture shows a well-watered individual.

5 StartClim2011.D: Adapting Austrian forestry to climate change: Assessing the drought tolerance of Austria's autochthonous tree species

Over the next century, it is expected that mean temperatures will increase in Central Europe. In the Alps, mean temperatures are projected to increase by 2°C-2.5°C by 2050, although no clear change in precipitation patterns is expected until after 2050. However what is perhaps most significant is the forecasted increase in the frequency of extreme weather events. While drastic changes in mean annual precipitation are not expected, summer precipitation is expected to be reduced, while an increase in within-year variability is likely to result in an increased frequency of heat and precipitation extremes (i.e. increase in days without precipitation and heat waves events). The subsequent decrease in water availability plus the increase in evaporative demand due to temperature increases is thus likely to induce an increased incidence in plant drought stress.

According to the dynamic concept of stress of Seley and Stocker (modified by Larcher), plants, including trees can build up a certain amount of resistance when a stress is applied (acclimation). Meanwhile due to site heterogeneity at higher spatial resolutions, selection pressures over several generations at rather dry sites may facilitate the adaptation of such populations (i.e. provenances) to drought conditions. Locations of such provenances may thus be very interesting to Silviculturists.

Irrespective of the potential change in future precipitation patterns, periods of drought are nevertheless normal meteorological phenomena. Consequently, through evolution, trees have developed a number of morphological and physiological adaptations to cope during periods of limited rainfall. Generally, the ability of a tree to postpone dehydration depends primarily on a tree's root structure, water storage capacity in the xylem, and how the tree controls transpiration rates (i.e. stomatal control or adjustment of the evaporative leaf area – leaf or even branch sacrifice: Fig. 6).

Fig. 6: Left: Crown dieback of Poplar due to drought; right: Vessel elements of the diffuse-porous Hybrid Poplar (40-fold magnification)

In line with the "Pipe Model Theory of Tree Form" of Shinozaki, phenotypic plasticity and of course reduced growth, causes trees to adjust the root and conducting tissue to the reduced crown demand for water caused by the leaf shed and branch sacrifice responses to continued drought. For example, at the vessel element/tracheid level, drought acclimation causes a reduction in the cross-sectional area of the conducting tissue, though vessel density is disproportionately increased.

Due to the wide amplitude of site moisture conditions occupied by the populations of Austrian tree species, it is likely that dry sites due to climatic and/or topographic factors have facilitated, over several generations, the selection of drought adapted ecotypes. The search for these potentially adapted provenances was thus the main focus of this study.

Currently, relatively few data sources exist which forest managers can consult when selecting the most appropriate reproductive material for a given site. Regarding performance in terms of timber production (i.e. yield potential), extensive data on yield and increment from several thousand plots in Austria, covering the main production forest species, is made available by the national forest inventory. However, this data only provides an indication of production potential, and importantly, production potential under current site conditions. This study demonstrates the potential of using the Austrian Vegetation Database (Willner) in identifying the provenances likely to be best adapted to future climate conditions. Like the Austrian forest inventory, this database is extensive in its spatial coverage with over 36,000 vegetation relevés taken from all over Austria. Using Ellenberg's system of deriving indices of site moisture based on the ecological indicator values of the herb species recorded in the respective relevés, the database can be used to obtain indirect estimates of the relative range in site moisture conditions over which Austrian tree species occur. By using the 10th percentile as a cut-off point, this study demonstrates the database's potential in locating the driest sites (the driest 10%), where the respective species occur, and thus the likely locations where the most drought resistant ecotypes exist. The database may thus possess great potential in helping Austrian forestry foster adaptation strategies to climate change.

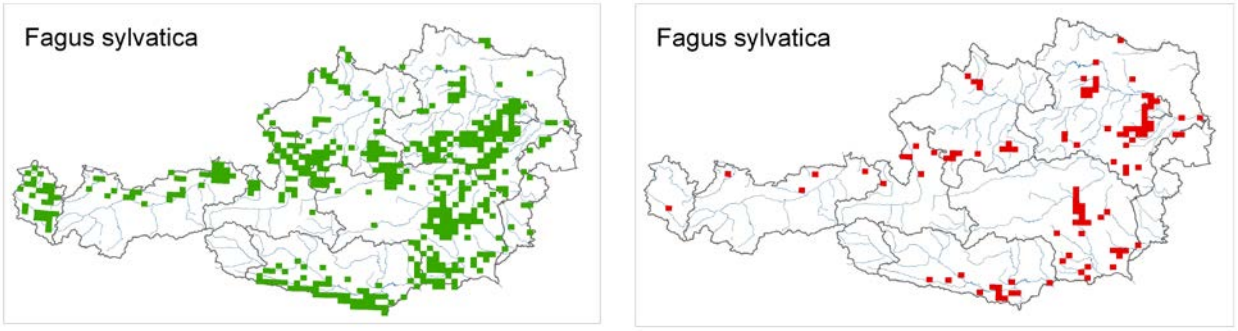

Fig. 7: Grid cells corresponding to the vegetation relevés of European Beech; Green: grids corresponding to all locatable relevés (91% of the total relevés were assigned grids), Red: grids corresponding to the locations of the relevés of the driest 10% (91% were as-signed grids).

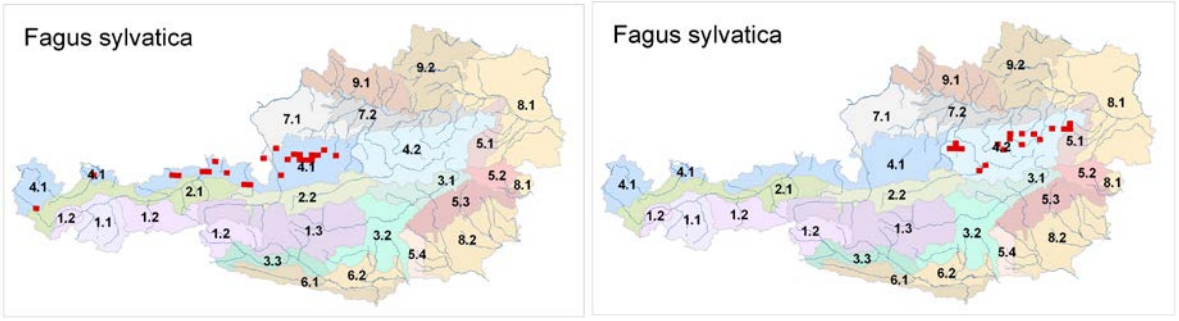

Fig. 8: Grid cells corresponding to the locations of the European Beech relevés of the driest 10% located within Forest Ecoregions 4.1 (left) and 4.2 (right).

In total, 22 Austrian tree species were analysed. Ecological indicator values of site moisture were calculated for those relevés of each species where the species occurrence at the site was either dominant or subdominant. The example of Beech illustrates the practical use of

the results of this dataset (Fig. 7) and other such studies (Fig. 8) showing the dry relevés separated between two forest ecoregions: the Northern Alpine Border – West (4.1) and the Northern Alpine Border East (4.2). The identification of potentially drought adapted provenances for the different forest ecoregions could help to identify useful sources of reproduction material to help Austrian forestry adapt to the project changes in climate. According to the Austrian Forest Reproductive Material Act provenances source from the same ecoregion represent the best sources of reproductive material to maintain the optimal performance of Austria's forests.

While the results here illustrate the potential of the Austrian Vegetation Database in facilitating the adaptation of Austrian forestry to climate change, there are nonetheless weaknesses in the database. Recordings from younger stands with a dense canopy and thus low light availability cannot be analysed due to the exclusive presence of shade tolerant herb species. Furthermore, similar correlations of plant optima with site nitrogen and moisture conditions can make fertilised sites in the eastern lowlands seem wetter than what they are. Additionally, planting of spruce outside of its natural range rendered some relevés from the warm lowlands rather useless. However in these cases, the projected changes in climate are likely to put extra pressure on the spruce populations outside their natural range. In such cases, a switch to species naturally found on such sites is thus recommended.

While more drought tolerant populations of each species exist, each species nevertheless exhibits some limit with regard to drought conditions. Thus in some cases, a change of species may nevertheless be advised if one is to adapt the given stand to future conditions. Ideally the degree of change should be kept as minimal as possible, e.g., the use of a more drought resistant species from the same genus. For instance, stands of pedunculate oak which are identified as vulnerable to climate change could be steadily adapted to climate change by introducing more drought tolerant Quercus species such as sessile oak. Such interventions are likely to reduce the risk of negative ecological side effects and the need for drastic changes within the forest sector itself.

While the pressure of climate change continues to force the case of foreign provenances or exotic species, their introduction, particularly exotic species, may have negative ecological effects. It is therefore important that in trying to adapt to the projected changes in climate, forestry does not ignore the autochthonous options available to it. This study illustrates that a potentially significant amount of inter- and intraspecific variation in drought tolerance is available within Austrian tree populations. Use of this data by forest managers and silviculturalists is thus strongly encouraged.

6 References

StartClim2011.A

ANNILA, E. (1969): Influence of temperature upon the development and voltinism of *Ips typographus* L. (Coleoptera, Scolytidae). Ann. Zool. Fennici 6, 161-208.

BAIER, P.; PENNERSTORFER, J.; SCHOPF, A. (2007): PHENIPS—A comprehensive phenology model of *Ips typographus* (L.) (Col., Scolytinae) as a tool for hazard rating of bark beetle infestation. Forest Ecol Manag 249, 171-186.

BAIER, P., PENNERSTORFER, J., SCHOPF, A. (2011): Evaluation of climate change induced effects on the predisposition of forests of the water protection zone "Wildalpen" to disturbances by bark beetles. A contribution to the final report of CC-WaterS work package 5: „Land Uses and Water Resources Safety". pp. 32.

BLACKWELL, E. (2011): Risk assessment of bark beetle outbreaks after an avalanche occurrence in the Dürrenstein Wilderness Area. Diploma thesis, pp 80.

BÖHM-BEZING, A. (1998): Untersuchungen über die Auswirkungen einer Berieselung von Fichtenrundholz (*Picea abies* Karst.), befallen mit Buchdrucker (*Ips typographus* L.). Diploma thesis, pp 85.

DUELLI, P., ZAHRADNIK, P., KNIZEK, M., KALINOVA, B. (1997): Migration in spruce bark beetles (*Ips typographus* L.) and the efficiency of pheromone traps. J. Appl. Ent. 121: 297-303.

FACCOLI, M. (2009): Effect of Weather on *Ips typographus* (Coleoptera Curculionidae) Phenology, Voltinism and Associated Spruce Mortality in the Southeastern Alps. Environ. Entomology. 38, (2): 307-316.

FRANKLIN, A.J., DEBRUYNE, C., GRÉGOIRE, J-C. (2000): Recapture of *Ips typographus* L. (Col. Scolytidae) with attractants of low release rates: localized dispersion and environmental influences. Agriculture and Forest Entomology 2, 259-270.

FRIEDL, S. (2008): Zum Einfluss von Niederschlag und Feuchtigkeit auf die Entwicklung von *Ips typographus* (L.) (Coleoptera, Scolytinae). Diploma thesis, pp 103.

KAUTZ, M., DWORSCHAK, K., GRUPPE, A., SCHOPF, R. (2011): Quantifying spatio-temporal dispersion of bark beetle infestations in epidemic and non-epidemic conditions. For Ecol Manag 262:598–608.

LAUSCH, A., FAHSE, L., HEURICH, M. (2011): Factors affecting the spatio-temporal dispersion of *Ips typographus* (L.) in Bavarian Forest National Park: A long-term quantitative landscape-level analysis. For Ecol Manag 261 (2011) 233–245.

NETHERER, S., NOPP-MAYR, U. (2005): Predisposition assessment systems (PAS) as supportive tools in forest management—rating of site and stand-related hazards of bark beetle infestation in the High Tatra Mountains as an example for system application and verification. Forest Ecol Manag, 207, 99-107.

SCHOPF, A., BAIER, P., NETHERER, S., PENNERSTORFER, J. (2004): Risikoabschätzung von Borkenkäfer-Massenvermehrungen im Nationalpark Kalkalpen.

WILD, M. (1953): Die Entwicklung des großen Fichtenborkenkäfers *Ips typographus* L. im Hochschwarzwald (1000-1200 m ü.M.) und ihre Abhängigkeit vom Klima 1947-1950. Bericht Naturforsch. Ges. Freiburg i.Br. 43, 121-176.

StartClim2011.B

AFI (2012). Austrian Forest Inventory. Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW). available online http://bfw.ac.at/rz/wi.auswahl?cros=3 (accessed 10/08/2012)

Albrecht, A., Schindler, D., Grebhan, K., Kohnle, U., Mayer, H. (2009). Storminess over the north-atlantic european region under climate change – A review. Allgemeine Forst- und Jagdzeitung, Vol. 180 (5-6), 109-118

Angst, A., Rüegg, R., Forster, B. (2012). Declining Bark Beetle Densities (Ips typographus, Coleoptera: Scolytinae) from Infested Norway Spruce Stands and Possible Implicati-ons for Management. Psyche doi:10.1155/2012/321084

Baier, P., Pennerstorfer, J., Schopf, A. (2007). PHENIPS – A comprehensive phenology mo-del of Ips typographus (L.) (Col., Scolytinae) as a tool for hazard rating of bark beetle infestation. Forest Ecology and Management 249, 171-186

Battisti, A., Stastny, M., Netherer, S., Robinet, C., Schopf, A., et al. (2005). Expansion of ge-ographic range in the pine processionary moth caused by increased winter tempera-tures. Ecol. Appl. 15, 2084–2096

BFW (2012). Österreichisches Borkenkäfer-Monitoring. Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft. http://bfw.ac.at/db/bfwcms.web?dok=5312 (accessed 2012-09-21)

Bivand, R.S., Pebesma, E.J., Gomez-Rubio, V. (2008). Applied spatial data analysis with R. New York: Springer. 374 pp

Blennow, K., Andersson, M., Bergh, J., Sallnäs, O., Olofsson, E. (2010). Potential climate change impacts on the probability of wind damage in a south Swedish forest. Clim. Change. 99, 261-278

BMLFUW (2012a). Datensammlung 2012 zum Österreichischen Waldbericht. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Wien.

BMLFUW (2012b). Die österreichische Strategie zur Anpassung an den Klimawandel. Teil 2 – Aktionsplan. Handlungsempfehlungen für die Umsetzung. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. Wien

Botterweg, P.F. (1982). Dispersal and flight behavior of the spruce bark beetle Ips typographus in relation to sex, size and fat content. Zeitschrift für angewandte Entomologie 94, 466-489

Brang, P., Schöneberger, W., Frehner, M., Schwitter, R., Thormann, J.J., et al. (2006). Man-agement of protection forests in the European Alps: an overview. For. Snow Landsc. Res. 80, 23-44

Breiman, L. (2001) Random forests. Machine Learning, 45, 5–32

Bugmann, H., Lindner, M., Lasch, P., Flechsig, M., Ebert, B., Cramer, W. (2000) Scaling is-sues in forest succession modelling. Clim Change 44:265-289

Canadell, J.G., Raupach, M.R. (2008). Managing Forests for Climate Change Mitigation. Sci-ence 320, 1456-1457

Christiansen, E., Waring, R.H., Berryman, A.A. (1987). Resistance of conifers to bark beetle attack: Searching for general relationships. For. Ecol. Manage. 22, 89-106

Danjon, F., Fourcaud, T., Bert, D. (2005). Root architecture and wind-firmness of mature Pinus pinaster. New Phytologist 168, 387-400

Fekedulegn, B.D., Colbert, J.J., Hicks Jr., R.R., Schuckers, M.E. (2002). Coping with Multicollinearity: An Example on Application of Principle Component Regression in Dendroecology. USDA Forest Service, 1-42

Forest Europe (2011). Oslo Ministerial Decision: European Forests 2020. Ministerial Confer-ence on the Protection of Forests in Europe. Oslo, June 14-16 2011

Führer , E., Nopp, U. (2001). Ursachen, Vorbeugung und Sanierung von Waldschäden. Facultas, Vienna, Austria.

Fürst, J., Nachtnebel, H.P. (2007): Hydrological Atlas of Austria (HAÖ). Institute for Water Management, Hydrology and Hydraulic Engineering - University of Natural Resources and Life Science, Vienna

Gardiner, B., Byrne, K., Hale, S., Kaminura, K., Mitchell, S.J. et al. (2008). A review of mech-anistic modelling of wind damage risk to forests. Forestry 81, 447–463

Gardiner, B., Blennow, K., Carnus, J.M., Fleischer, P., Ingemarson, F. et al. (2010) Destruc-tive Storms in European Forests: Past and Forthcoming Impacts. Final report to Eu-ropean Commission–DG Environment. EFIATLANTIC, European Forest Institute. 138 pp

Glynn, C., Herms, D.A., Orians, C.M., Hansen, R.C., Larsson, S. (2007). Testing the growth-differentiation balance hypothesis: dynamic responses of willows to nutrient availabil-ity. New Phytologist 176, 623-634

Grace, J.B. (2006). Structural Equation Modeling and Natural Systems. Cambridge Univ. Press, Cambridge, UK.

Hanewinkel, M., Breidenbach, J., Neeff, T., Kublin, E. (2008). Seventy-seven years of natural disturbances in mountain forest area - the influence of storm, snow and insect damage analysed with a long-term time series. Ca. J. For. Res. 38, 2249-2261

Hannah, P., Palutikof, J.P., Quine, C.P. (1995). Predicting windspeeds for forest areas in complex terrain. In: Coutts, M.P., Grace, J. (eds.) Wind and Trees. University of Edin-burgh. pp. 113-130

Hasenauer, H. (2011). The Carbon balance of Forest ecosystems. Austr. J. For. Sci. 128, 33-52

Hedderich, J., Sachs, L. (2011). Angewandte Statistik – Methodensammlung mit R. Springer, Berlin-Heidelberg. ISBN 978-3-642-24400-1, p. 702f

Hedgren, O.P., Schroeder, M.L., Weslien, J. (2003). Tree killing by Ips typographus (Coleoptera: Scolytidae) at stand edges with and without colonized felled spruce trees. Agricultural and Forest Entomology 5, 67-74

Hlasny, T., Kristek, S., Holusa, J., Trombik, J., Urbancova (2011). Snow disturbance in sec-ondary Norway spruce forests in Central Europe: Regression modeling and its impli-cations for forest management. Forest Ecology and Management 262, 2151-2161

Holling, C.S., Gunderson, L.H. (2002) Resilience and adaptive cycles. edited in Gunderson LH, Holling CS (eds) Panarchy: understanding transformations in human and natural systems. Island Press, Washington DC, pp 25-62

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solmon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M, Miller, H.L. (eds.). Cambridge University Press, Cambridge, United King-dom and New York, USA, 996 pp

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M., Midgley, P.M. (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 594pp

Jactel, H., Nicoll, B.C., Branco, M., Gonzalez-Olabarria, J.R., Grodzki, W., et al. (2009). The influences of forest stand management on biotic and abiotic risks of damage. Ann. For. Sci. 66, 1–18

Jolliffe, I.T. (2002). Principle Component Analysis, Second Edition. Springer, 173-177

Kantor, P., Karl, Z., Sach, F., Cernohous, V. (2009). Analysis of snow accumulation and snow melting in a young mountain spruce and beech stand on the Orlické hory Mts., Czech Republic. Journal of Forest Science 55, 437-451

Kautz, M., Dworschak, K., Gruppe, A., Schopf, R. (2011). Quantifying spatio-temporal dis-persion of bark beetle infestations in epidemic and non-epidemic conditions. Forest Ecology and Management 262, 598-608

Kilpeläinen, A., Gregow, H., Strandman, H., Kellomäki, S., Venäläinen, A., Peltola, H. (2010). Impacts of climate change on the risk of snow-induced forest damage in Finland. Cli-matic Change 99, 193-209

Kostal, V., Dolezal, P., Rozsypal, J., Moravcova, M., Zahradnickova, H., Simek, P. (2011). Physiological and biochemical analysis of overwintering and cold tolerance in two Central European populations of the spruce bark beetle, Ips typographus. Journal of Insect Physiology 57, 1136-1146

Kurz, W.A., Dymond, C.C., Stinson, G., Rampley, G.J., Neilson, E.T., et al. (2008). Mountain pine beetle and forest carbon feedback to climate change. Nature 452, 987-990

Lexer MJ (1995) Beziehungen zwischen der Anfälligkeit von Fichtenbeständen (Picea abies (L.) Karst.) für Borkenkäferschäden und Standorts- und Bestandesmerkmalen unter besonderer Berücksichtigung der Wasserversorgung. Dissertation, University of Natu-ral Resource Management and Applied Life Sciences (BOKU) Vienna, pp 210

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., et al. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manage. 259, 698–709

Littell, J.S., McKenzie, D., Peterson, D.L., Westerling, A.L. (2009). Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecol. Appl. 19, 1003-1021

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C. et al. (2007). Complexity of Coupled Human and Natural Systems. Science 317, 1513-1516.

MacQuarrie, C.J.K., Cooke, B.J. (2011). Density-dependent population dynamics of moun-tain pine beetle in thinned and unthinned stands. Can. J. For. Res. 41, 1031-1046

Manion, P.D. (1981). Tree disease concepts. Prentice-Hall, New Jersey

Marini, L., Ayres, M.P., Battisti, A., Faccoli, M. (2012). Climate affects severity and altitudinal distribution of outbreaks in an eruptive bark beetle. Clim. Change DOI 10.1007/s10584-012-0463-z

Mayer, H., Ott, E. (1991). Gebirgswaldbau - Schutzwaldpflege- Fischer, Stuttgart.

McCallum, D.J., Mason, E.G., Whitley, B. (2007). Influence of exposure and elevation on radiate pine branch size, log velocity, sweep, taper and value. NZ Journal of forestry Nov. 2007, 10-16

Metsämäki, S., Anttila, S. (2005). Snow Covered Area Algorithm in Boreal Forest. EnviSnow EVC1-CT-2001-00052, 1-38

Millar, C.I., Stephenson, N.L., Stephens, S.L., (2007). Climate change and forests of the fu-ture: Managing in the face of uncertainty. Ecol. Appl. 17, 2145-2151

Missbach, K. (1985). Beeinträchtigung der Biege- und Knickfestigkeit durch Wildschäden. edited in Beurteilung und Bewertung der Stabilität von Fichtenökosystemen. F/E-Bericht TU Dresden, Sekt. Forstw. Tharandt

Morzuch, B.J., Ruark, G.A. (1991). Principle Components Regression to Mitigate the Effects of Multicollinearity. Forest Science, Vol. 37, No. 1, 191-199

Netherer, S., Nopp-Mayr, U., (2005). Predisposition assessment systems (PAS) as supportive tools in forest management—rating of site and stand-related hazards of bark beetle infestation in the High Tatra Mountains as an example for system application and verification. For. Ecol. Manage. 207, 99–107

Netherer, S., Schopf, A., (2010). Potential effects of climate change on insect herbivores in European forests—general aspects and the pine processionary moth as specific ex-ample. For. Ecol. Manage. 259, 831–838

Nykänen, M-L., Peltola, H., Quine, C.P., Kellomäki, S., Broadgate, M. (1997). Factors Affect-ing Snow Damage of Trees with Particular Reference to European Conditions. Silva Fennica 31 (2), 1-21

ÖFJ (2009). Österreichisches Forstjahrbuch. Österreichischer Agrarverlag, Wien

Økland, B., Bjørnstad, O.N., (2006). A resource-depletion model of forest insect outbreaks. Ecology 87, 283-290

Overbeck, M., Schmidt, M. (2012). Modelling infestation risk of Norway spruce by Ips typographus (L.) in the Lower Saxon Mountains (Germany). Forest Ecology and Management 266, 115-125

Peltola, H. (1996). Model computations on wind flow and turning moment by wind for Scots pines along the margins of clear-cut areas. Forest Ecology and Management 83, 203-215

Peltola, H., Kellomäki, S., Väisänen, H. (1999). Model computations of the impact of climatic change on the windthrow risk of trees. Clim Change 41, 17 – 36

Schelhaas, M.J., Nabuurs, G.-J., Schuck, A., (2003). Natural disturbances in the European forests in the 19th and 20th centuries. Glob. Change Biol. 9, 1620–1633

Schelhaas, M.J., Hengeveld, G., Moriondo, M., Reinds, G.J., Kundzewicz, Z.W., et al. (2010). Assessing risk and adaptation options to fires and windstorms in European forestry. Mitig. Adapt. Strateg. Glob. Change 15, 681-701

Schmidt-Vogt, H. (1997). Wachstum und Schneebruchresistenz von Fichtenherkünften des Bayerischen Alpenvorlandes, der Bayerischen Alpen und des Bayerischen Waldes Forstwissenschaftliches Centralblatt Volume 91. Verlag Paul Parey, Hamburg und Berlin, p. 339

Schröter, D., Cramer, W., Leemans, R., Prentice, I.C., Araújo, M.B., et al. 2005. Ecosystem service supply and vulnerability to global change in Europe. Science 310, 1333–1337.

Schütz, J.P., Götz, M., Schmid, W., Mandallaz, D. (2006). Vulnerability of spruce (Picea abies) and beech (Fagus sylvatica) forest stands to storms and consequences for sil-viculture. Eur. J. Forest Res. 125, 291–302

Seidl, R., Rammer, W., Jäger, D., Lexer, M.J. (2008). Impact of bark beetle (Ips typographus L.) disturbance on timber production and carbon sequestration in different manage-ment strategies under climate change. For. Ecol. Manage. 256, 209-220

Seidl, R., Schelhaas, M.J., Lindner, M., Lexer, M.J., (2009). Modelling bark beetle disturb-ances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. Reg. Environ. Chang. 9, 101–119

Seidl, R., Rammer, W., Lexer, M.J. (2011a). Climate change vulnerability of sustainable for-est management in the Eastern Alps. Clim. Change 106, 225-254

Seidl, R., Schelhaas, M.J., Lexer, M.J. (2011b). Unraveling the drivers of intensifying forest disturbance regimes in Europe. Glob. Change Biol. 17, 2842-2852

Seidl, R., Fernandes, P.M., Fonseca, T.F., Gillet, F., Jönsson, A.M., et al. (2011c). Modelling natural disturbances in forest ecosystems: a review. Ecol. Model. 222, 903-924

Seidl, R., Rammer, W., Scheller, R.M., Spies, T.A. (2012). An individual-based process model to simulate landscape-scale forest ecosystem dynamics. Ecol. Model. 231, 87-100

Skogsstyrelsen. (2006). Stormen 2005 – en skoglig analys. Meddelande 1-2006, Skogsstyrelsens förlag, Jönköping, Sweden. ISSN 1100-0295

Starlinger, F. in Lexer, M.J., Hönninger, K., Scheifinger, H., Matulla, Ch., Groll, N. et al. (2001): The Sensitivity of the Austrian forests to Scenarios of Climatic Change. A Large-scale Risk Assessment (Sensitivität des österreichischen Waldes unter Klima-änderungsszenarien - Deutsche Zusammenfassung).. Umweltbundesamt Monographien, Band 132 (M-132), Umweltbundesamt Wien. ISBN 3-85457-556-1

Swanson, M.E., Franklin, J.F., Beschta, R.L., Crisafulli C.M., DellaSala, D.A., et al. (2011). The forgotten stage of forest succession: early-successional ecosystems on forest sites. Front. Ecol. Environ. 9, 117–125

Tomiczek, C., Cech, T.L., Fürst, A., Hoyer-Tomiczek, U., Krehan, H. et al. (2009). Waldschutzsituation 2008 in Österreich. AFZ-Der Wald 2009, 373-376

Tomiczek, C., Cech, T.L., Fürst, A., Hoyer-Tomiczek, U., Krehan, H. et al. (2011). Wald-schutzsituation 2010 in Österreich. Forstschutz aktuell 52, 3-9

Tomiczek, C., Schweiger, C. (2012). Gelbe Karte für das Forstschutz-Grundrisiko. Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW). available online http://bfw.ac.at/db/bfwcms.web?dok=9204 (accessed 04/09/2012)

Turner, M.G. (2010). Disturbance and landscape dynamics in a changing world. Ecology 91, 2833-2849

Urban, D.L., O'Neill, R.V., Shugart, H.H. (1987) Landscape ecology: A hierarchical perspec-tive can help scientists understand spatial patterns. BioScience 37:119-127

Usbeck, T., Wohlgemuth, T., Dobbertin, M., Pfister, C., Bürgi, A., et al. (2010). Increasing storm damage to forests in Switzerland from 1858 to 2007. Agric. For. Met. 150, 47–55

Vacik, H., Lexer, M.J. (2001). Application of a spatial decision support system in managing the protection forests of Vienna for sustained yield of water resources. For. Ecol. Manage. 143, 65-76

Wermelinger, B., Seifert, M. (1998). Analysis of the temperature dependent development of the spruce bark beetle Ips typographus (L.) (Col., Scolitidae). Journal of Applied En-tomology 122, 185-191

Wermelinger, B. (2004). Ecology and management of the spruce bark beetle Ips typograhus – a review of recent research. Forest Ecology and Management 202, 67-82

Wermelinger, B., Rigling, A., Schneider Mathis, D., Dobbertin, M. (2008). Assessing the role of bark- and wood-boring insects in the decline of Scots pine (Pinus sylvestris) in the Swiss Rhone valley. Ecological Entomology 33, 239-249

Wiens, J.A. (1989) Spatial scaling in ecology. Funct Ecol 3:385-397.

With, K.A. (2002). The landscape ecology of invasive spread. Cons. Biol. 16, 1192–1203

ZAMG (2012a). Wind risk and wind energy potential. Central Institute for Meteorology and Geodynamics. available online http://wms1.zamg.ac.at/beauvort/index.php (accessed 10/08/2012)

ZAMG (2012b). Climate data Austria between 1971 – 2000. Central Institute for Meteorology and Geodynamics. available online http://www.zamg.ac.at/fix/klima/oe71-00/klima2000/klimadaten_oesterreich_1971_frame1.htm

ZAMG (2012c). Surface synoptic observations. Central Institute for Meteorology and Geody-namics.

ZAMG (2012d). Extreme weather report. Central Institute for Meteorology and Geodynamics. available online http://www.zamg.at/klima/klima_monat/unwetterbericht (accessed 10/08/2012)

Zemek, F., Cudlin, P., Bohac, J., Moravec, I., Herman, M. (2003). Semi-natural Forested Landscape under a Bark Beetle Outbreak: a case study of the Bohemian Forest (Czech Republic). Landscape Research, Vol. 28, No. 3, 279-292

StartClim2011.C

Beikircher, B., Ameglio, T., Cochard, H., Mayr, S., 2010. Limitation of the Cavitron technique by conifer pit aspiration. Journal of Experimental Botany, 61(12): 3385-3393.

Beikircher, B., Mayr, S., 2009. Intraspecific differences in drought tolerance and acclimation in hydraulics of *Ligustrum vulgare* and *Viburnum lantana*. Tree Physiology, 29(6): 765-775.

Berry, J.A., Beerling, D.J., Franks, P.J., 2010. Stomata: key players in the earth system, past and present. Current Opinion in Plant Biology, 13(3): 232-239.

Bréda, N., Huc, R., Granier, A., Dreyer, E., 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. Annals of Forest Science, 63(6): 625-644.

Brilli, F. et al., 2011. Leaf and ecosystem response to soil water availability in mountain grasslands. Agricultural and Forest Meteorology, 151(12): 1731-1740.

Brunetti, M. et al., 2006. Precipitation variability and changes in the greater Alpine region over the 1800-2003 period. Journal of Geophysical Research, 111(D11): D11107.

Ciais, P. et al., 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature, 437(7058): 529-533.

Cochard, H., 2002. A technique for measuring xylem hydraulic conductance under high negative pressures. Plant, Cell & Environment, 25(6): 815-819.

Cochard, H., Bréda, N., Granier, A., Aussenac, G., 1992. Vulnerability to air embolism of three European oak species (*Quercus petraea* (Matt) Liebl, *Q pubescens* Willd, *Q robur* L). Annals of Forest Science, 49(3): 225-233.

Cochard, H., Lemoine, D., Dreyer, E., 1999. The effects of acclimation to sunlight on the xylem vulnerability to embolism in Fagus sylvatica L. Plant, Cell & Environment, 22(1): 101-108.

Gartner, K., Nadezhdina, N., Englisch, M., Čermak, J., Leitgeb, E., 2009. Sap flow of birch and Norway spruce during the European heat and drought in summer 2003. Forest Ecology and Management, 258(5): 590-599.

Granier, A. et al., 2007. Evidence for soil water control on carbon and water dynamics in European forests during the extremely dry year: 2003. Agricultural and Forest Meteorology, 143(1–2): 123-145.

Larcher, W., 2001. Ökophysiologie der Pflanzen. Ulmer-Verlag Stuttgart.

Nardini, A., Salleo, S., 2000. Limitation of stomatal conductance by hydraulic traits: sensing or preventing xylem cavitation? Trees - Structure and Function, 15(1): 14-24.

Pammenter, N.W., Van der Willigen, C., 1998. A mathematical and statistical analysis of the curves illustrating vulnerability of xylem to cavitation. Tree Physiology, 18(8-9): 589-593.

Rotach, M.W. et al., 1997. Nested regional simulation of climate change over the Alps for the scenario of a doubled greenhouse forcing. Theoretical and Applied Climatology, 57(3): 209-227.

Smiatek, G., Kunstmann, H., Knoche, R., Marx, A., 2009. Precipitation and temperature statistics in high-resolution regional climate models: Evaluation for the European Alps. Journal of Geophysical Research, 114(D19): D19107.

Sperry, J.S., 2004. Coordinating stomatal and xylem functioning – an evolutionary perspective. New Phytologist, 162(3): 568-570.

Sperry, J.S., Donnelly, J.R., Tyree, M.T., 1988. A method for measuring hydraulic conductivity and embolism in xylem. Plant, Cell & Environment, 11(1): 35-40.

Teuling, A.J. et al., 2010. Contrasting response of European forest and grassland energy exchange to heatwaves. Nature Geoscience, 3(10): 722-727.

Tyree, M.T., Davis, S.D., Cochard, H., 1994. Biophysical perspectives of xylem evolution: Is there a tradeoff of hydraulic efficiency for vulnerability to dysfunction? International Association of Wood Anatomists Journal, 15: 25.

Tyree, M.T., Zimmermann, M.H., 2002. Xylem structure and the ascent of sap. Springer, Berlin.

Viviroli, D., Dürr, H.H., Messerli, B., Meybeck, M., Weingartner, R., 2007. Mountains of the world, water towers for humanity: Typology, mapping, and global significance. Water Resources Research, 43(7): W07447.

Wieser, G., Hammerle, A., Wohlfahrt, G., 2008. The Water Balance of Grassland Ecosystems in the Austrian Alps. Arctic, Antarctic, and Alpine Research, 40(2): 439-445.

StartClim2011.D

AICHINGER, E. 1967. *Pflanzen als Forstliche Standortszeiger,* Vienna, Österr. Agrarverlag.

ALLEN, C. D., MACALADY, A. K., CHENCHOUNI, H., BACHELET, D., MCDOWELL, N., VENNETIER, M., KITZBERGER, T., RIGLING, A., BRESHEARS, D. D., HOGG, E. H., GONZALEZ, P., FENSHAM, R., ZHANG, Z., CASTRO, J., DEMIDOVA, N., LIM, J.-H., ALLARD, G., RUNNING, S. W., SEMERCI, A. & COBB, N. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management,* 259**,** 660-684.

ARANDA, I., GIL, L. & PARDOS, J. A. 2005. Seasonal changes in apparent hydraulic conductance and their implications for water use of European beech (Fagus sylvatica L.) and sessile oak [Quercus petraea (Matt.) Liebl] in South Europe. *Plant Ecology,* 179**,** 155-167.

AUER, I., HIEBL, J., REISENHOFER, S., BÖHM, R. & SCHÖNER, W. 2010. ÖKLIM 1971–2000 Aktualisierung des digitalen Klimaatlas Österreichs 1961–1990. Vienna: Zentralanstalt für Meteorologie und Geodynamik (ZAMG).

BADALOTTI, A., ANFODILLO, T. & GRACE, J. 2000. Evidence of osmoregulation in Larix decidua at Alpine treeline and comparative responses to water availability of two co-occurring evergreen species. *Ann. For. Sci.,* 57**,** 623-633.

BODIN, P. & WIMAN, B. L. B. 2007. The usefulness of stability concepts in forest management when coping with increasing climate uncertainties. *Forest Ecology and Management,* 242**,** 541-552.

BOISVENUE, C. & RUNNING, S. W. 2006. Impacts of climate change on natural forest productivity - evidence since the middle of the 20th century. *Global Change Biology,* 12**,** 862-882.

BOLTE, A., AMMER, C., LÖF, M., NABUURS, G.-J., SCHALL, P. & SPATHELF, P. 2010. Adaptive Forest Management: A Prerequisite for Sustainable Forestry in the Face of Climate Change.

In: SPATHELF, P. (ed.) *Sustainable Forest Management in a Changing World: A European Perspective.* Springer Netherlands.

BRÉDA, N., HUC, R., GRANIER, A. & DREYER, E. 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. *Annals of Forest Science,* 63**,** 625-644.

BROADMEADOW, M. S. J., RAY, D. & SAMUEL, C. J. A. 2005. Climate change and the future for broadleaved tree species in Britain. *Forestry,* 78**,** 145-161.

CHARRA-VASKOU, K., CHARRIER, G., WORTEMANN, R., BEIKIRCHER, B., COCHARD, H., AMEGLIO, T. & MAYR, S. 2012. Drought and frost resistance of trees: a comparison of four species at different sites and altitudes. *Ann. Forest Science,* 69**,** 325-333.

CHRISTENSEN, J. H., HEWITSON, B., BUSUIOC, A., CHEN, A., GAO, X., HELD, I., JONES, R., KOLLI, R. K., KWON, W.-T., LAPRISE, V., MAGAÑA REUDA, V., MEARNS, L., MENÉDEZ, C. G. R., J. RINKE, A., SARR, A. & WHETTON, P. 2007. Regional Climate Projections. *In:* SOLOMON, S., QIN, D., MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K. B., TIGNOR, M. & MILLER, H. L. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, USA: Cambridge University Press.

COCHARD, H. 1992. Vulnerability of several conifers to air embolism. *Tree Physiol,* 11**,** 73-83.

COCHARD, H., BRÉDA, N. & GRANIER, A. 1996. Whole tree hydraulic conductance and water loss regulation in Quercus during drought: evidence for stomatal control of embolism? *Ann. For. Sci.,* 53**,** 197-206.

CREGG, B. M. & ZHANG, J. W. 2001. Physiology and morphology of Pinus sylvestris seedlings from diverse sources under cyclic drought stress. *Forest Ecology and Management,* 154**,** 131-139.

CRUIZIAT, P., COCHARD, H. & AMÉGLIO, T. 2002. Hydraulic architecture of trees: main concepts and results. *Ann. For. Sci.,* 59**,** 723-752.

DIEKMANN, M. 2003. Species indicator values as an important tool in applied plant ecology – a review. *Basic and Applied Ecology,* 4**,** 493-506.

DIXON, H. H. & JOLY, J. 1896. On the ascent of sap. *Royal Society (London) Philosphical Transactions,* B 186**,** 563-576.

DORREN, L. K. A., BERGER, F., IMESON, A. C., MAIER, B. & REY, F. 2004. Integrity, stability and management of protection forests in the European Alps. *Forest Ecology and Management,* 195**,** 165-176.

DREXLER, W. & WALENTOWSKI, H. 2011. Auswirkungen von sommerlichen Klimaextremen auf nemorale Laubwälder – Baumarten, Waldlebensgemeinschaften und Ökostem. unpubl. Research application.

ELLENBERG, H. 1979. Zeigerwerte der Gefäßpflanzen Mitteleuropas *Scripta Geobotanica,* 9**,** 1-122.

ELLENBERG, H., WEBER, H. E., DULL, R., WIRTH, V., WERNER, W. & PAULISEN, D. 1991. Zeigerwerte von Pflanzen in Mitteleuropa *Scripta Geobotanica,* 18**,** 1-248.

ENGELMARK, O., SJÖBERG, K., ANDERSSON, B., ROSVALL, O., ÅGREN, G. I., BAKER, W. L., BARKLUND, P., BJÖRKMAN, C., DESPAIN, D. G., ELFVING, B., ENNOS, R. A., KARLMAN, M., KNECHT, M. F., KNIGHT, D. H., LEDGARD, N. J., LINDELÖW, Å., NILSSON, C., PETERKEN, G. F., SÖRLIN, S. & SYKES, M. T. 2001. Ecological effects and management aspects of an exotic tree species: the case of lodgepole pine in Sweden. *Forest Ecology and Management,* 141**,** 3-13.

ENGLISCH, M. & KARRER, G. 2001. Zeigerwertsysteme in der Vegetationsanalyse - Anwendbarkeit, Nutzen und Probleme in Österreich. *Ber. d. R. Tüxen Ges.,* 13**,** 83-102.

ENGLISCH, M., KARRER, G. & WAGNER, H. 1991. Bericht über den Zustand des Waldbodens in Niederösterreich. FORSTL. BUNDESVERSUCHSANSTALT. Vienna.

ENGLISCH, M., KILIAN, W., GÄRTNER, M., HERZBERGER, E. & STARLINGER, F. 1998. Anleitung zur Forstlichen Standortskartierung in Österreich. *FBVA-Berichte.* Vienna, Austria: Forstliche Bundesversuchsanstalt.

FAO 2010. *Global Forest Resources Assessment 2010* Rome, Italy, Food and Agriculture Organization of the United Nations.

FAO 2011. *State of the World's Forests,* Rome, Italy, Food and Agriculture Organization of the United Nations.

FISCHLIN, A., MIDGLEY, G. F., PRICE, J. T., LEEMANS, R., GOPAL, B., TURLEY, C., ROUNSEVELL, M. D. A., DUBE, O. P., TARAZONA, J. & VELICHKO, A. A. 2007. Ecosystems, thier properties, goods and services. *In:* PARRY, M. L., CANZIANI, O. F., PALUTIKOF, J. P., VAN DER LINDEN, P. J. & HANSON, C. E. (eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, USA: Cambridge University Press.

GEßLER, A., KEITEL, C., KREUZWIESER, J., MATYSSEK, R., SEILER, W. & RENNENBERG, H. 2006. Potential risks for European beech (Fagus sylvatica L.) in a changing climate. *Trees,* 21**,** 1-11.

HAMRICK, J. L. 2004. Response of forest trees to global environmental changes. *Forest Ecology and Management,* 197**,** 323-335.

HASENAUER, H., NEMANI, R. R., SCHADAUER, K. & RUNNING, S. W. 1999. Forest growth response to changing climate between 1961 and 1990 in Austria. *Forest Ecology and Management,* 122**,** 209-219.

HAUK, E. 2011. Biodiversität in Österreichs Wald. *BFW Praxis Information,* 24**,** 17-21.

HERZBERGER, E. & KARRER, G. 1992. Test der internen Konsistenz ökologischer Zeigerwerte am Beispiel der Vegetationsaufnahmen der Österreichischen Waldboden-Zustandsinventur. *FBVA-Berichte.* Vienna, Austria: Forstliche Bundesversuchsanstalt.

IPCC 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, U.K. and New York, USA, Cambridge University Press.

IRVINE, J., PERKS, M. P., MAGNANI, F. & GRACE, J. 1998. The response of Pinus sylvestris to drought: stomatal control of transpiration and hydraulic conductance. *Tree Physiol,* 18**,** 393-402.

KAPELLER, S., LEXER, M. J., GEBUREK, T., HIEBL, J. & SCHUELER, S. 2012. Intraspecific variation in climate response of Norway spruce in the eastern Alpine range: Selecting appropriate provenances for future climate. *Forest Ecology and Management,* 271**,** 46-57.

KARRER, G. & KILIAN, W. 1990. Standorte und Waldgesellschaften im Leithagebirge Revier Sommerein. *Mitt. der Forstlichen Bundesversuchsanstalt.* Vienna, Austria.

KILIAN, W., MÜLLER, F. & STARLINGER, F. 1994. *Die forstlichen Wuchsgebiete Österreichs: Eine Naturraumgliederung nach waldökologische Gesichtspunkten. Bericht 82,* Vienna, Austria, Forstliche Bundesversuchsanstalt.

KIMMINS, J. P. 1987. *Forest Ecology: A Foundation for Sustainable Management,* New Jersey, USA, Prentice Hall, Inc.

KLEINSCHMIT, J. R. G., KOWNATZKI, D. & GREGORIUS, H.-R. 2004. Adaptational characteristics of autochthonous populations—consequences for provenance delineation. *Forest Ecology and Management,* 197**,** 213-224.

KOZLOWSKI, T. T. 1979. *Tree Growth and Environmental Stresses,* Washington, USA, University of Washington Press.

KOZLOWSKI, T. T., KRAMER, P. J. & PALLARDY, S. G. 1991. *The Physiological Ecology of Woody Plants,* California, USA and London, U.K., Academic Press, Inc.

LARCHER, W. 2003. *Physiological Plant Ecology: Ecophysiology and Stress Physiology of Functional Groups,* Berlin, Germany, Springer-Verlag.

LINDNER, M., MAROSCHEK, M., NETHERER, S., KREMER, A., BARBATI, A., GARCIA-GONZALO, J., SEIDL, R., DELZON, S., CORONA, P., KOLSTRÖM, M., LEXER, M. J. & MARCHETTI, M. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecol. Man.,* 259**,** 698-709.

MAGNANI, F. 2009. Phenotypic variability: underlying mechanisms and limits do matter. *New Phytologist,* 184**,** 277-279.

MAHERALI, H., POCKMAN, W. T. & JACKSON, R. B. 2004. Adaptive variation in the vulnerability of woody plants to xylem cavitation. *Ecology,* 85**,** 2184-2199.

MANDRE, M., KIVISTE, A. & KÖSTER, K. 2011. Environmental stress and forest ecosystem. *Forest Ecology and Management,* 262**,** 53-55.

MARTINEZ-VILALTA, J., COCHARD, H., MENCUCCINI, M., STERCK, F., HERRERO, A., KORHONEN, J. F., LLORENS, P., NIKINMAA, E., NOLE, A., POYATOS, R., RIPULLONE, F., SASS-KLAASSEN, U. & ZWEIFEL, R. 2009. Hydraulic adjustment of Scots pine across Europe. *New Phytol,* 184**,** 353-64.

MARTÍNEZ-VILALTA, J., SALA, A. & PIÑOL, J. 2004. The hydraulic architecture of Pinaceae – a review. *Plant Ecology,* 171**,** 3-13.

MCDOWELL, N., POCKMAN, W. T., ALLEN, C. D., BRESHEARS, D. D., COBB, N., KOLB, T., PLAUT, J., SPERRY, J., WEST, A., WILLIAMS, D. G. & YEPEZ, E. A. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? *New Phytologist,* 178**,** 719-739.

MEEHL, G. A., STOCKER, T. F., COLLINS, W. D., FRIEDLINGSTEIN, P., GAYE, A. T., GREGORY, J. M., KITOH, A., KNUTTI, R., MURPHY, J. M., NODA, A., PRAPER, S. C. B., WATTERSON, I. G., WEEVER, A. J. & ZHAO, Z.-C. 2007. Global Climate Projections. *In:* SOLOMON, S., QIN, D., MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K. B., TIGNOR, M. & MILLER, H. L. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, USA: Cambridge University Press.

MEINZER, F. C., CLEARWATER, M. J. & GOLDSTEIN, G. 2001. Water transport in trees: current perspectives, new insights and some controversies. *Environmental and Experimental Botany,* 45**,** 239-262.

MILLAR, C. I., STEPHENSON, N. L. & STEPHENS, S. P. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecol. Appl.,* 17**,** 2145-2151.

NIESE, G. 2011. Österreichs Schutzwälder sind total überaltert. *BFW Praxis Information,* 24**,** 29-31.

NIINEMETS, Ü. 2010. Responses of forest trees to single and multiple environmental stresses from seedlings to mature plants: Past stress history, stress interactions, tolerance and acclimation. *Forest Ecology and Management,* 260**,** 1623-1639.

NIINEMETS, Ü. & VALLADARES, F. 2006. Tolerance to shade, drought, and waterlogging of temperate northern hemisphere trees and shrubs. *Ecological Monographs,* 76**,** 521-547.

NIKLFELD, H. 1994. Der aktuelle Stand der Kartierung der Flora Mitteleuropas und angrenzender Gebiete. *Floristische Rundbriefe,* 28**,** 200-220.

O'BRIEN, E. K., MAZANEC, R. A. & KRAUSS, S. L. 2007. Provenance variation of ecologically important traits of forest trees: implications for restoration. *Journal of Applied Ecology,* 44**,** 583-593.

ÖWI. 2007/2009. *Die Österreichische Waldinventur* [Online]. Available: http://bfw.ac.at/rz/wi.home [Accessed 15 July 2012].

RAFTOYANNIS, Y. & RADOGLOU, K. 2002. Physiological Responses of Beech and Sessile Oak in a Natural Mixed Stand During a Dry Summer. *Ann. Bot.,* 89**,** 723-730.

RENNENBERG, H., LORETO, F., POLLE, A., BRILLI, F., FARES, S., BENIWAL, R. S. & GESSLER, A. 2006. Physiological responses of forest trees to heat and drought. *Plant Biol (Stuttg),* 8**,** 556-71.

RICHARDSON, D. M. 1998. Forestry Trees as Invasive Aliens. *Conservation Biology,* 12**,** 18-26.

RICHARDSON, D. M. & REJMÁNEK, M. 2011. Trees and shrubs as invasive alien species – a global review. *Diversity and Distributions,* 17**,** 788-809.

ROSE, L., LEUSCHNER, C., KÖCKEMANN, B. & BUSCHMANN, H. 2009. Are marginal beech (Fagus sylvatica L.) provenances a source for drought tolerant ecotypes? *European Journal of Forest Research,* 128**,** 335-343.

SCHULTZE, U. & RASCHKA, H.-D. 2002. Douglasienherkünfte für den "Sommerwarmen Osten" Österreichs. Ergebnisse aus Douglasien-Herkunftsversuchen des Insituts für Forstgenetik. Vienna: FBVA.

SEIDL, R., RAMMER, W., JÄGER, D., CURRIE, W. S. & LEXER, M. J. 2007. Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. *Forest Ecology and Management,* 248**,** 64-79.

SEKOT, W. 2007. European forest accounting: general concepts and Austrian experiences. *European Journal of Forest Research,* 126**,** 481-494.

SELYE, H. 1936. A syndrome produced by diverse nocuous agents. *Nature,* 138**,** 32.

SELYE, H. 1973. The evolution of the stress concept. *American Scientist,* 61**,** 693-699.

SPERRY, J. S. 2000. Hydraulic constraints on plant gas exchange. *Agricultural and Forest Meteorology,* 104**,** 13-23.

STEPPE, K. & LEMEUR, R. 2007. Effects of ring-porous and diffuse-porous stem wood anatomy on the hydraulic parameters used in a water flow and storage model. *Tree Physiol,* 27**,** 43-52.

STOCKER, O. 1947. Probleme der pflanzlichen Dürreresistenz. *Naturwissenschaften,* 34**,** 362-371.

TANEDA, H. & SPERRY, J. S. 2008. A case-study of water transport in co-occurring ring- versus diffuse-porous trees: contrasts in water-status, conducting capacity, cavitation and vessel refilling. *Tree Physiol,* 28**,** 1641-1651.

TYREE, M. T. & EWERS, F. W. 1991. The hydraulic architecture of trees and other woody plants. *New Phytologist,* 119**,** 345-360.

TYREE, M. T. & SPERRY, J. S. 1989. Vulnerability of Xylem to Cavitation and Embolism. *Annual Review of Plant Physiology and Plant Molecular Biology,* 40**,** 19-36.

WIEDERMANN, R. 1995. Pflanzensoziologisches Datenmanagement mittels PC-Programm HITAB5. *Carinthia II,* 53**,** 133-134.

WILLNER, W., BERG, C. & HEISELMAYER, P. 2012. *Austrian Vegetation Database* in Dengler J., Oldeland J., Jansen F., Chytrý M., Ewald J., Finckh M., Glöckler F., Lopez-Gonzalez G., Peet R.K. & Schaminée J.H.J. [Eds.]: Vegetation databases for the 21st century. – *Biodiversity & Ecology,* 4, 333

WILLNER, W. & GRABHERR, G. (eds.) 2007. *Die Wälder und Gebüsche Österreichs. Ein Bestimmungswerk mit Tabellen,* Heidelberg, Germany: Spektrum Akad. Verlag.

ZANG, C., PRETZSCH, H. & ROTHE, A. 2012. Size-dependent responses to summer drought in Scots pine, Norway spruce and common oak. *Trees - Structure and Function,* 26**,** 557-569.

ZIMMERMANN, M. H. 1983. *Xylem Structure and the Ascent of Sap,* Berlin, Germany, Springer-Verlag.

Table of Figures

Annex

All following reports can be found on the StartClim2010-CD-ROM and on the StartClim website (www.austoclim.at/startclim/)

Subprojects of StartClim2003

StartClim.1: Quality control and statistical characteristics of selected climate parameters on the basis of daily values in the face of extreme value analysis
Central Institute of Meteorology and Geodynamics
Wolfgang Schöner, Ingeborg Auer, Reinhard Böhm, Sabina Thaler

StartClim.2: Analysis of the representativeness of a data collected over a span of fifty years for the description of the variability of climatic extremes
Central Institute of Meteorology and Geodynamics
Ingeborg Auer, Reinhard Böhm, Eva Korus, Wolfgang Schöner

StartClim.3a: Extreme events: documentation of hazardous events in Austria such as rock avalanches, floods, debris flows, landslides, and avalanches
Institute of Forest and Mountain-Risk Engineering, BOKU
Dieter Rickenmann, Egon Ganahl

StartClim.3b: Documentation of the impact of extreme weather events on agricultural production ARC Seibersdorf research: Gerhard Soja, Anna-Maria Soja

StartClim.3c: Meteorological extreme event data information system for the eastern Alpine region - MEDEA
Federal Environment Agency, Martin König, Herbert Schentz, Johann Weigl
IIASA, Mathias Jonas, Tatiana Ermolieva

StartClim.4: Development of a method to predict the occurrence of extreme events from large-scale meteorological fields
Institute of Meteorology and Physics, BOKU Andreas Frank, Petra Seibert

StartClim.5: Testing statistical downscaling techniques for their applicability to extreme events in Austria
Institute of Meteorology and Physics, BOKU -
Herbert Formayer, Christoph Matulla, Patrick Haas
GKSS Forschungszentrum Geesthacht, Nikolaus Groll

StartClim.6: Adaptation strategies for economic sectors affected heavily by extreme weather events: economic evaluation and policy options
Austrian Humans Dimensions Programme (HDP-A)
Department of Economics, Karl-Franzens-Universität Graz
Karl Steininger, Christian Steinreiber, Constanze Binder, Erik Schaffer
Eva Tusini, Evelyne Wiesinger

StartClim.7: Changes in the social metabolism due to the 2002-flooding in Austria: case study of an affected community
Institute of Interdisciplinary Studies of Austrian Universities (IFF)
Willi Haas, Clemens Grünbühel, Brigitt Bodingbauer

StartClim.8: Risk-management and public prosperity in the face of extreme weather events: What is the optimal mix of private insurance, public risk pooling and alternative transfer mechanisms
Department of Economics, Karl-Franzens-Universität Graz
Walter Hyll, Nadja Vetters, Franz Prettenthaler

StartClim.9: Summer 2002 floods in Austria: damage account data pool
Centre of Natural Hazards and Risk Management (ZENAR),
BOKU - University of Natural Resources and Applied Life Sciences
Helmut Habersack, Helmut Fuchs

StartClim.10: Economic aspects of the 2002 floodings: data analysis, asset accounts and macroeconomic effects
Austrian Institute of Economic Research (WIFO)
Daniela Kletzan, Angela Köppl, Kurt Kratena

StartClim.11: Communication at the interface science - education
Institute of Meteorology and Physics,
BOKU - University of Natural Resources and Applied Life Sciences
Ingeborg Schwarzl
Institute of Interdisciplinary Studies of Austrian Universities (IFF)
Willi Haas

StartClim.12: Developing an innovative approach for the analysis of the August 2002 flood event in comparison with similar extreme events in recent years
Department of Meteorology and Geophysics, University of Vienna
Simon Tschannett, Barbara Chimani, Reinhold Steinacker

StartClim.13: High-resolution precipitation analysis
Department of Meteorology and Geophysics, University of Vienna
Stefan Schneider, Bodo Ahrens, Reinhold Steinacker, Alexander Beck

StartClim.14: Performance of meteorological forecast models during the August 2002 floods Central Institute of Meteorology and Geodynamics
Thomas Haiden, Alexander Kann

StartClim.C: Design of a long term climate/climate-impact research programme for Austria Institute of Meteorology and Physics, BOKU:
Helga Kromp-Kolb, Andreas Türk

StartClim. Reference database:
Implementation of a comprehensive literature database on climate and climate impact research as a generally accessible basis for future climate research activities
Institute of Meteorology and Physics,
University of Natural Resources and Applied Life Sciences
Patrick Haas

Subprojects of StartClim2004

StartClim2004.A: Analysis of heat and drought periods in Austria: extension of the daily StartClim data record by the element vapour pressure
Central Institute of Meteorology and Geodynamics
Ingeborg Auer, Eva Korus, Reinhard Böhm, Wolfgang Schöner

StartClim2004.B: Investigation of regional climate change scenarios with respect to heat waves and dry spells in Austria
Institute of Meteorology, BOKU: Herbert Formayer, Petra Seibert, Andreas Frank, Christoph Matulla, Patrick Haas

StartClim2004.C: Analysis of the impact of the drought in 2003 on agriculture in Austria – comparison of different methods
ARC Seibersdorf research: Gerhard Soja, Anna-Maria Soja
Institute of Meteorology, BOKU: Josef Eitzinger, Grzegorz Gruszczynski, Mirek Trnka, Gerhard Kubu, Herbert Formayer
Institute of Surveying, Remote Sensing and Land Information, BOKU
Werner Schneider, Franz Suppan, Tatjana Koukal

StartClim2004.F: Continuation and further development of the MEDEA event data base
Federal Environment Agency: Martin König, Herbert Schentz, Katharina Schleidt
IIASA: Matthias Jonas, Tatiana Ermolieva

StartClim2004.G: "Is there a relation between heat and productivity?" A project at the interface between science and education
Institute of Meteorology, BOKU
Ingeborg Schwarzl, Elisabeth Lang, Erich Mursch-Radlgruber

Subprojects of StartClim2005

StartClim2005.A1a: Impacts of temperature on mortality and morbidity in Vienna
Medical University of Vienna, Centre for Public Health, Institute of Environmental Hygiene
Hanns Moshammer, Hans-Peter Hutter
Institute of Meteorology, BOKU
Andreas Frank, Thomas Gerersdorfer
Austrian Federal Institute of Health Care
Anton Hlava, Günter Sprinzl
Statistics Austria, Barbara Leitner

StartClim2005.A1b: Nocturnal cooling under a changing climate
Institute of Meteorology, BOKU
Thomas Gerersdorfer, Andreas Frank, Herbert Formayer, Patrick Haas
Medical University of Vienna, Centre for Public Health, Institute of Environmental Hygiene
Hanns Moshammer
Statistics Austria, Barbara Leitner

StartClim2005.A4: Impacts of meteorological extreme events on safety of drinking water supply in Austria
Institute of Sanitary Engineering and Water Pollution Control, BOKU
Reinhard Perfler, Mario Unterwainig
Institute of Meteorology, BOKU
Herbert Formayer

StartClim2005.C2: Studies on the distribution of tularaemia under the aspect of climate change
Gesellschaft für Wildtier und Lebensraum – Greßmann & Deutz OEG
Armin Deutz
HBLFA Raumberg Gumpenstein, Agricultural Research and Education Centre
Thomas Guggenberger

StartClim2005.C3a: Impacts of climate change on agricultural pests and antagonists in organic farming in Eastern Austria
Bio Forschung Austria
Bernhard Kromp, Eva Maria Grünbacher, Patrick Hann
Institute of Meteorology, BOKU
Herbert Formayer,

StartClim2005.C3b: Risk analysis of the establishment of the western flower thrips (*Frankliniella occidentalis*) under outdoor conditions in Austria as a result of the climate change
The Austrian Agency für Health and Food Safety, AGES
Andreas Kahrer
Institute of Meteorology, BOKU
Herbert Formayer,

StartClim2005.C5: An allergenic neophyte and its potential spread in Austria – range dynamics of ragweed (*Ambrosia artemisiifolia*) under influence of climate change
VINCA, Vienna Institute for Nature Conservation & Analysis
Ingrid Kleinbauer, Stefan Dullinger
Federal Environment Agency
Franz Essl, Johannes Peterseil

StartClim2005.F: GIS-sustained simulation of diminishing habitats of snow grouse, black grouse, chamois and capricorn under conditions of global warming and heightening forest limits
Joanneum Research
Heinz Gallaun, Jakob Schaumberger, Mathias Schardt
HBLFA Raumberg-Gumpenstein
Thomas Guggenberger, Andreas Schaumberger, Johann Gasteiner
Gesellschaft für Wildtier und Lebensraum - Greßmann & Deutz OEG
Armin Deutz, Gunter Greßmann

Subprojects of StartClim2006

StartClim2006.A: Particulate matter and climate change – are there connections between them in north-eastern Austria?
Institute of Meteorology, BOKU: Bernd C. Krüger, Irene Schicker, Herbert Formayer
Medical University of Vienna, Centre for Public Health, Institute of Environmental Hygiene: Hanns Moshammer

StartClim2006.B: Risk Profile for the autochthonous occurrence of Leishmania infections in Austria
Medical University of Vienna: Horst Aspöck, Julia Walchnik
Institute of Meteorology, BOKU: Thomas Gerersdorfer, Herbert Formayer

StartClim2006.C: Effects of climate change on the dispersion of white grub damages in the Austrian grassland
Bio Forschung Austria
Eva Maria Grünbacher, Patrick Hann, Claus Trska, Bernhard Kromp
Institute of Meteorology, BOKU: Herbert Formayer

StartClim2006.D1: Sensitivity of Austrian summer tourism to climate change
Institut für touristische Raumplanung: Volker Fleischhacker
Institute of Meteorology, BOKU: Herbert Formayer

StartClim2006.D2: Effects of climate change on the climatic potential of tourism
Institute of Meteorology, University of Freiburg
Andreas Matzarakis, Christina Endler, Robert Neumcke
Central Institute of Meteorology and Geodynamics
Elisabeth Koch, Ernest Rudel

StartClim2006.D3: See-Vision: influence of climate change-induced fluctuation of water level in Lake Neusiedl on the perception and behaviour of visitors and locals
Institute of Landscape Development, Recreation and Conservation Planning, BOKU
Ulrike Pröbstl, Alexandra Jiricka, Thomas Schauppenlehner
Simon Fraser University, Burnaby, Canada
Wolfgang Haider

StartClim2006.F: Climate change impacts on energy use for space heating and cooling in Austria
Institute of Technology and Regional Policy, Joanneum Research (1);
Wegener Center for Climate and Global Change, University of Graz (2);
Institute for Geophysics, Astrophysics and Meteorology, University of Graz (3);
Institute for Meteorology and Geophysics, University of Vienna (4);
Institute of Energy Research, Joanneum Research (5)
Franz Prettenthaler[1,2], Andreas Gobiet[2,3], Clemens Habsburg-Lothringen[1], Reinhold Steinacker[4], Christoph Töglhofer[2], Andreas Türk [2,5]

Subprojects of StartClim2007

StartClim2007.A: Enlargement and completion of the StartClim dataset for the element daily snow depth. Update of the already existing StartClim datasets (air temperature, precipitation and vapour pressure) until April 2007
Central Institute of Meteorology and Geodynamics: Ingeborg Auer, Anita Jurković, Reinhard Böhm, Wolfgang Schöner, Wolfgang Lipa

StartClim2007.B: Health risks for the Austrian population due to the depletion of stratospheric ozone
Institute of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna: Stana Simic
Institute of Medical Physics and Biostatistics, University of Veterinary Medicine Vienna: Alois W. Schmalwieser
Medical University of Vienna, Centre for Public Health, Institute of Environmental Hygiene: Hanns Moshammer

StartClim2007.C: Adaptations of insect pests to climate change in crop production of eastern Austria: conception of a long-term monitoring system
Bio Forschung Austria: Eva-Maria Grünbacher, Patrick Hann, Bernhard Kromp
Institute of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna: Herbert Formayer

StartClim2007.D: Consequence of the climate-induced upwards shift of the timberline on the release of greenhouse gases - dynamics of soil organic matter
Federal Forest Office: Robert Jandl, Andreas Schindlbacher, Sophie Zechmeister-Boltenstern, Michael Pfeffer
Department of Forest and Soil Sciences, University of Natural Resources and Applied Life Sciences, Vienna:
Klaus Katzensteiner
Federal Environment Agency: Sabine Göttlicher
University of Vienna: Hannah Katzensteiner
Tiroler Landesforstdirektion: Dieter Stöhr

StartClim2007.E: Global change and its effect on runoff behaviour of glacierised basins with regard to reservoir power stations
Institute of Meteorology and Geophysics, University Innsbruck:
Michael Kuhn, Marc Olefs, Andrea Fischer

StartClim2007.F: ALSO WIKI – Alpine summer tourism in Austria and the potential effects of climate change
Austrian Institute for Regional Studies and Spatial Planning: Cornelia Krajasits, Gregori Stanzer, Adolf Anderl, Wolfgang Neugebauer, Iris Wach
Central Institute of Meteorology and Geodynamics
Christine Kroisleitner, Wolfgang Schöner

StartClim2007.G: Integrated modelling of the economy under climate change in application of the STERN report (STERN.AT)
Wegener Centre for Climate and Global Change, University of Graz: Olivia Koland, Karl Steininger, Andreas Gobiet, Georg Heinrich, Claudia Kettner, Alexandra Pack, Matthias Themeßl, Christoph Töglhofer, Andreas Türk, Thomas Trink
Joanneum Research, Institut für Technologie- und Regionalpolitik: Raimund Kurzmann
University of Natural Resources and Applied Life Sciences, Vienna: Erwin Schmid

Subprojects of StartClim2008

StartClim2008.A: Impacts of adaptation measures on the acute mortality risk due to extreme temperature in Vienna
Institute of Environmental Hygiene, Centre for Public Health, MUW: Hanns Moshammer, Hans-Peter Hutter
Institute of Meteorology, BOKU: Thomas Gerersdorfer

StartClim2008.B: Which adaptations of soil erosion protection measures can be recommended for expected climate change impacts?
Institute of Hydraulics and Rural Water Management, BOKU: Andreas Klik
Institute of Meteorology, BOKU: Josef Eitzinger
Institute of Agronomy and Plant Breeding, BOKU: Peter Liebhard

StartClim2008.C: Practical testing of the monitoring concept "Adaptations of insect pests to climate change in crop production of eastern Austria" by investigating the distribution of current cutworm (*Agrotis segetum, Schiff.; Fam. Noctuidae*) damage as a function of site-related and climatic factors
Bio Forschung Austria: Patrick Hann, Claus Trska, Eva Maria Frauenschuh, Bernhard Kromp

StartClim2008.D: Organic agriculture in the mountains of Tyrol—contributions to mitigating climate change and adaptation strategies
Division of Organic Farming, BOKU: Michael Dorninger, Bernhard Freyer

StartClim2008.E: Development and economic valuation of landscape structures to decrease evapotranspiration on agricultural acres with account taken of climate change and biomass production
Institute of Landscape Development, Recreation and Conservation Planning, BOKU: Christiane Brandenburg, Bernhard Ferner, Sonja Völler, Brigitte Allex
Institute of Meteorology, BOKU: Josef Eitzinger, Thomas Gerersdorfer
Division of Organic Farming, BOKU: Bernhard Freyer, Andreas Surböck, Agnes Schweinzer, Markus Heinzinger
Institute of Agricultural and Forestry Economics, BOKU: Enno Bahrs

StartClim2008.F: Perception and evaluation of natural hazards as a consequence of glacier retreat and permafrost degradation in tourism destinations—a case study in the Tux Valley (Zillertaler Alps, Austria)
Institute of Landscape Development, Recreation and Conservation Planning, BOKU: Ulrike Pröbstl
University of Regensburg, University Eichstätt-Ingolstadt: Bodo Damm

StartClim2008.G: Adaptation of forest soils to a changing climate
Federal Research and Training Centre for Forests, Natural Hazards and Landscape: Barbara Kitzler, Verena Stingl, Sophie Zechmeister-Boltenstern
Institute of Meteorology and Climate-Research – Atmospheric Environmental Research, Garmisch: Arjan De Brujin, Ralf Kiese, Klaus Butterbach-Bahl

Subprojects of StartClim2009

StartClim2009.A: Vegetation change according to different climate and management conditions in Austrian mountain grassland – a case study on Styrian mountain grasslands
Institute of Botany, BOKU: Gabriele Bassler, Gerhard Karrer,
Institute of Meteorology, BOKU: Herbert Formayer
LFZ-Raumberg-Gumpenstein: Andreas Schaumberger, Andreas Bohner, Walter Starz
Bio Ernte Steiermark: Wolfgang Angeringer

StartClim2009.B: Climate-growth response of Norway spruce provenances in the Alpine region – an opportunity for adaption of the Austrian forestry
Federal Research and Training Centre for Forests, Natural Hazards and Landscape: Silvio Schüler, Stefan Kapeller,
Central Institute of Meteorology and Geodynamics: Johann Hiebl

StartClim2009.C: Analysis of vulnerability and adaptation to climate change in the Wienerwald biosphere reserve
Institute of Silviculture, BOKU: Stefan Schörghuber, Werner Rammer, Rupert Seidl, Manfred J. Lexer

StartClim2009.D: Humus assays as a practical tool for farmers to support carbon sequestration in agriculture
Bio Forschung Austria: Wilfried Hartl, Eva Erhart

StartClim2009.E: Adapting office buildings to climate change: optimisation of thermal comfort
Danube University Krems: Tania Berger, Peter Pundy

StartClim2009.F: AlpinRiskGP - estimation of present and future risk potential for Alpine tourists and infrastructure caused by glacier retreat and permafrost changes in the Grossglockner-Pasterze glacier area (Hohe Tauern, Austria)
Geography and Regional Science, Karl-Franzens-University Graz: Gerhard Karl Lieb, Katharina Kern, Gernot Seier,
Andreas Kellerer-Pirklbauer-Eulenstein, Ulrich Strasser

Subprojects of StartClim2010

StartCim2010.A: Fields of action and responsible actors for climate change adaptation of public parks in cities
Institute of Landscape Development, Recreation and Conservation Planning (ILEN), BOKU: Stephanie Drlik, Andreas Muhar

StartClim2010.B: Recommendations for an adaptation of urban open and green spaces in Austrian cities and city regions
PlanSinn GmbH, Office for Planning and Communication: Erik Meinharter
Federal Environment Agency: Maria Balas

StartClim2010.C: The social costs of adaptation: approaches to an evaluation of adaptation options (SALDO)
Wegener Center for Climate and Global Change, University Graz: Birgit Bednar-Friedl, Olivia Koland, Janine Raab
Federal Environment Agency: Martin König

StartClim2010.D: Integrated precautionary and adaptation measures for the Marchfeld region
Institute for Sustainable Economic Development, BOKU: Christine Heumesser, Mathias Kirchner, Erwin Schmid, Franziska Strauss

StartClim2010.E: Ecological and silvicultural characteristics of European larch (Larix decidua Mill.) – consequences for forest management in Austria in consideration of climate change
Institute of Silviculture, BOKU: Eduard Hochbichler, Gabriele Wolfslehner, Roland Koeck, F. Arbeiter,
Federal Research and Training Centre for Forests, Natural Hazards and Landscape: Herfried Steiner, Georg Frank
Institute of Meteorology, BOKU: Herbert Formayer

Startclim2010.F: Hot town, summer in the city – effects of hot days on recreational and leisure behaviour and sightseeing programmes of city tourists as exemplified by the case of Vienna
Institute of Landscape Development, Recreation and Conservation Planning (ILEN), BOKU: Christiane Brandenburg, Brigitte Allex, Ursula Liebl, Christina Czachs
Institute of Meteorology, BOKU: Thomas Gerersdorfer

StartClim2010.G: Knowledge-based platform to optimise operations strategies in handling natural hazards
Austrian Red Cross: Jürgen Högl, Clemens Liehr, Gerry Foitik
Institute of Production and Logistics, BOKU: Manfred Gronalt, Magdalena Schweiger, Patrick Hirsch