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Preface

This publication is the outcome of the "Dendrosymposium 2002", a tree-ring conference held from April 11th – 13th 2002 at the University of Bonn (Institute of Geography) and the Research Centre Jülich (Institute of Sedimentary Systems, ICG V). The aims of the German-language symposium were (i) to present the state of the art as well as new research perspectives in the different fields of dendrochronology, (ii) to stimulate further investigations and closer collaboration between different research groups and (iii) to strengthen dendrochronological sciences in central European research. About 50 scientists from Germany, Switzerland, Austria and The Netherlands attended the meeting. In total, 20 talks and 19 posters covering the topics (1) Archaeology, (2) Long Records, (3) Climatology, (4) Isotopes and Climate, (5) Isotopes and Plant Physiology, (6) Dendroecology, (7) Forest Dynamics at the Timberline and (8) Geomorphology were presented. The contributions clearly documented the topical and methodological progress that has been achieved in dendrochronology during the last years, including new approaches such as stable isotope analysis, dendrogeomorphology or ecophysiological aspects.

The proceedings volume contains 21 extended abstracts. In order to give a comprehensive overview, shorter abstracts of participants, who did not submit a long version, are additionally included in their original language.

Another important goal of the conference was the first meeting of the "Gesellschaft für Jahrringforschung" GJF ("Association of Tree Ring Research" ATR) founded in September 2001 in Davos. Gerhard Schleser (Research Centre Jülich) and Esther Jansma (National Service for Archaeological Heritage/The Netherlands) have been elected for a period of two years as the president and vice president of the Association, respectively. Considering his outstanding scientific and educational merits Fritz Schweingruber was assigned as honorary president. Members of the advisory council are Achim Bräuning (Stuttgart), Jan Esper (Birmensdorf), Holger Gärtner (Birmensdorf), Karl-Uwe Heussner (Berlin), Hans-Peter Kahle (Freiburg), Klaus-Felix Kaiser (Birmensdorf), Kurt Nicolussi (Innsbruck), Constantin Sander (Heidelberg), Matthias Saurer (Villingen), Burkhard Schmidt (Köln), Uwe Treter (Erlangen) and Matthias Winiger (Bonn).

More detailed information is available on-line at the ATR-Homepage: ***www.tree-ring.org***

Finally, sincere thanks are given to all the participants of the meeting, who made it a lively forum with much exchange of ideas, including the authors of the submitted papers and last but not least to the organizing team of the symposium Burkhard Neuwirth (Bonn), Holger Gärtner (Birmensdorf), Kerstin Treydte (Jülich), Gerd Helle (Jülich) and Jan Esper (Birmensdorf).

Prof. Dr. Gerhard Schleser

Prof. Dr. Matthias Winiger

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SECTION 6 DENDROECOLOGY

A glance back, a glance ahead

F.H. Schweingruber and G. H. Schleser

32 lectures and posters were presented at the Symposium covering a rather broad spectrum of dendrochronological research themes. Among the topics discussed were archaeological studies, investigations on landscape development, vegetation history, vegetation dynamics, geomorphology, wood biology, dendrochronological statistics and analytical techniques. Last but not least problems related to the reconstruction of climate history were discussed. The temporal dimension bridged the gap between late glacial and today while the geographical areas explored covered regions from Siberia, Mongolia, South America and Central Europe, also allowing for altitudinal aspects ranging from sea level to high alpine locations. Contributions with regard to research in the realm of snow, wind and fire as well as plant pathology were, however, missing.

Looking back to the varying presentations given, a number of trends can be traced:

The compilation and combination of data in networks or transects

The annual sequence of any proxies derived from a single tree just mirrors the behaviour of an individual. If the sequences of several individuals are combined conclusions can be drawn with regard to the environmental conditions at a site. Large scale statements, however, can only be the result of a comparison with chronologies from different sites. In this respect networks of European and even hemispheric dimensions are needed to allow for climatological statements. Some first initiatives were presented which allow statements of climate development. In addition archaeological, ecological and geomorphological networks on local scales could be treated.

It is self-evident that chronologies in particular from prehistoric, historic and present day times, stored in computers of countless laboratories world wide, should be available to all dendrochronologists free of charge. The International Tree Ring Data Bank as well as the Institution at Birmensdorf, namely the WSL, provide the necessary means for the safe incorporation of such data.

Long sequences - the ultimate approach to assess the climate trend of our century

The major question of global change centres on the problem of whether or not human activities are possibly responsible for the climatic change of past decades. To answer this question reliably, several thousand year long chronologies are required; including chronologies originating from extreme sites as from the upper and northernmost timberline, from temperate zones of all continents and if possible, incorporating atypical areas such as deserts and the tropics. Some such chronologies have been presented, showing the potential inherent in them, however, much more is required and should be initiated.

Besides the potential inherent in tree rings by being able to provide many different proxies leading to a wealth of different information, they represent the best archives for precisely dating any events that can be traced by them.

Climatic and geomorphic extremes have an effect upon the development and composition of the vegetation

This statement is a truism, however, by including frost rings, density fluctuations, abrupt increment changes and many other intra-annually appearing symptoms - frequently only to be grasped microscopically - it is possible to extend our knowledge on the behaviour of plants and to contribute new elements to the present discussion on the environment. A number of presentations have clearly demonstrated the potential inherent in this approach. It has to be stressed that not only 'normally' growing trees supply valuable data but also ecologically dwarfed individuals, i. e. 'crippled trees'. However, much more effort has to be devoted to these subjects. In this respect discontinuous time series, heeding pointer years are as important as continuous time series allowing the set up of response functions.

How much carbon is stored in the vegetation cover?

Contrary to present day practise dendrochronologists will have to include in future projects roots and branches and not just limit themselves to trunks. In this respect all 'non-trees' are important. Millions of square kilometers of deserts, taiga and tundra are partly covered by shrubs or dwarf shrubs, plants we do hardly know anything about, especially with regard to their growth, their age and their biomass production. In many cases even less is known about the life cycle of herbs which often can be dated by annual rings. Dendrochronologists should broaden their activities in this respect because news from these objects might lead to much additional information.

The methodical development in the field of dendrochronology is far from concluded.

New studies and developments introduced lately have demonstrated that dendrochronology is a lively field of research with vast potentials still lying ahead. Especially the latest investigations in the application of stable isotopes, studies in wood anatomy, advances in analytical measuring devices and progress in statistics open a new understanding, yet more important new scientific dimensions.

Isotope studies on tree rings have lately expanded enormously. They may probably not only be able to trace temperatures or precipitation but may also give information on atmospheric circulation patterns etc. Various studies have shown their potential not only for setting up 'climate chronologies' but also for getting information on carbon fluxes or the distribution of particular storage materials. Plant physiological aspects are another possible field of research. Some such information was presented at the conference.

The basis for solving the real big questions remains to be the study of ecophysiological processes in wood.

Any study in this respect is valuable and will advance our knowledge especially in view of the possibility to open up new drawers from tree rings as an archive of past environmental information.

Every dendrochronologist has to raise the question in which larger scientific context he can place the results that have painstakingly been produced. Discussions in small groups in whatever language held, be it in Chinese or Russian, at small symposia as the ones of Bonn or Verona – in German or Italian – but also those of larger congresses as e. g. Eurodendro or in Montreal – in English – and the large-scale and generous exchange of data are an irrevocable necessity for the scientific progress.

The young, newly founded 'Association for Tree Ring Research' (Gesellschaft für Jahrringforschung) is a platform for exchange on all aspects that need to be tackled in the future.

SECTION 1

ARCHAEOLOGY

Dendroarchaeology from a palaeodendroecological perspective: the case of Bronze and Iron Age pile dwellings in Southwest Germany

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Since 1982 systematic timber and tree-ring investigation of Southwest German bog and lake-shore sites has been carried out by the Tree-Ring Laboratory of the Baden-Württemberg Office for the Protection of Ancient Monuments in Hemmenhofen. Within the scope of landscape and settlement archaeology, strong emphasis has been placed upon the interrelation between man, timber and woodland (Billamboz 1992, 1996). The analysis of archaeological data from a palaeodendroecologial perspective represents an extension of this approach. The first application developed here concerns Bronze and Iron Age wetland occupation during the course of the entire second millennium and the first half of the first millennium BC in Upper Swabia and the Bodensee area (i.e., Lake Constance). Parallel to the final publication of a large scale excavation, namely „Siedlung Forschner", Federsee (Billamboz, in Press), such palaeodendroecologial investigations were undertaken within the framework of the Project – „Wandel von Landschaft und Siedlungsweise im Übergang vom Subboral zum Subatlantikum im Bodenseeraum", a subproject of the main program of the Deutsche Forschungsgemeinschaft „Geo-Biosphäre der letzten 15 000 Jahre" (time slice III).

Particularly topical in current pile-dwelling research is the question of climatic influence on the evolution of wetland occupation and related settlement patterns. Supporters of this theory argue using correlations between archaeological evidence and phases of reduced radiocarbon production, presumably related to increased solar activity (Magny 1993, Groß-Klee, Maise 1997). Using this approach, only the dendrochronological felling dates are taken into consideration, not the tree-ring data itself. The following question is therefore raised: what can tree-ring analysis contribute to the question of the interrelation between man, climate and environment and more specifically to the question of a climatic stimulation of wetland occupation? The focus of this analysis was aimed at the time slice between 2000 and 500 BC, a period with sustained long term variations in radiocarbon production. On the basis of cross-dating different tree species from both zonal and azonal vegetation, an attempt was made to differentiate the local and global factors which concurrently influenced tree growth, site conditions and settlement possibilities in wetland areas.

Beneath the large sample series of the Siedlung Forschner, which consists of not less than 12 000 samples (7000 posts and 5000 horizontal woods) further reference material can be provided by other wood findings from excavation. The most important are cited here:

-At Bodensee- the early Bronze Age lake-shore sites of Bodman-Schachen I and Egg-Obere Güll I, the Late Bronze Age sites of Hagnau-Burg, Mainau-Nord and Unteruldingen-Stollenwiesen and the Late Bronze and Early Iron Age peninsular settlement of Uerschhausen-Horn at Nussbaumersee (Thurgovia, CH).

-At Federsee- the Middle Bronze Age track ways of Bad Buchau-Wuhrstraße, the Late Bronze Age bog settlement of the „Wasserburg“ Buchau, as well as the Early Iron Age fishing weirs of Oggelshausen-Bruckgraben.

Analysing the wood from Siedlung Forschner allowed a closer insight into the construction history of this bog settlement. This site exhibits a consistent defensive usage during the tree main phases of occupation (between 1767 and 1480 BC). Beyond the chronological aspects, further considerations such as the supply of timber and the first forms of woodland management, as well as the composition and development of woodland surroundings, could be derived from this approach. On the one hand, the well-defended settlement structure system gives the impression of stability. On the other hand, wood investigation exposes tangible changes in both timber supply and consequent adaptation of construction leading to a sharper perception of the changing environmental conditions of the settlement.

An approach to the interaction between evolution of climate, environmental change and settlement behaviors in wetland areas was made based on an evaluation of the timber documentation in conjunction with tree-ring information. In this way, long term settlement evolution, already deduced from other analysis methods, could be more precisely defined, specific to periods of wetland occupation. With the help of statistical representation of anatomical determination of tree-species and of dendrotypological analysis (a classification of timber according to the dendrological, dendrochronological and techno-morphological parameters), human influence on woodland development and crop dynamics could be highlighted.

Firstly, for the evaluation of tree-ring data, a growth trend analysis was made, with special emphasis on high and medium frequency variations. For this purpose, local series were built with regard to cambial age and the high frequency signals were removed using an 11yr low pass filter (Fritts 1976). Finally, the series were expressed as a departure from the mean, in units of standard deviation. The second method used concerns single year analysis (pith, pointer and cutting years). Chronological phasing could be derived from a synthetic presentation and subsequent evaluation of the results. Considering the numerous synchronous positions between negative depressions of growth and brief gaps in wetland occupation, there is some evidence to support a relation between wetland settlement development and short term regional fluctuations of climate with corresponding environmental changes on a local scale. This conclusion is supported by the comparison of our results with those of other centers of pile-dwelling research north of the Alps. The evolution of occupation, with short term flourishing or diminishing development, can be similarly identified in the Early and Late Bronze Age. Thus theories of climatic stability during the course of both periods become rather doubtful.

Finally, the comparison of these results with proxy data evaluated by other means (geobotany , geomorphology, glaciology and limnology) underlines the accuracy of dendrochronology in the approach to the above assessed evolution, which occurs at high and medium frequency, with a turnover of around 10 years. The methods presented here can now be transferred to forthcoming applications, in other regions and for other time periods.

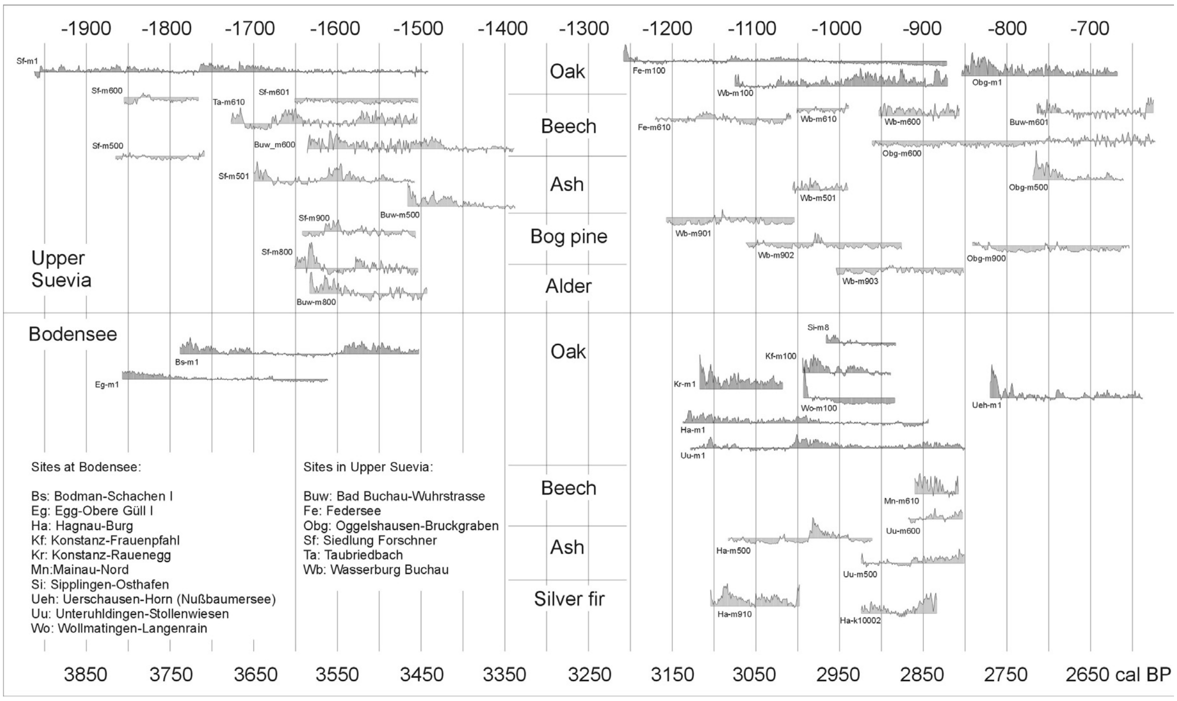

Figure 1: Local chronologies from Bronze and Iron Age bog and lake-shore sites in Southwest Germany with cross dating chart of different tree-species from the zonal and azonal vegetation between 2000 and 500 BC. The curves are low-pass filtered after Fritts, 1976, and the horizontal line corresponds to the 1mm-width.

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Population dynamics and long-term growth depressions in European bog oaks as indicators of climate changes in the Holocene

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Abstract

The dendrochronological data set of absolutely dated sub-fossil oak trunks from Irish, Dutch and German bogs consists of some 2600 series. They cover the period from 6000 BC to AD 1700. The distribution of the trees in time shows distinct changes in the frequency, germination and dying-off. One way to graphically represent germination and dying-off phases is to calculate the 'mean age' of all trees at every calendar year. Where trees are uniformly ageing the mean age chronology rises; recruitment of juvenile trees and dying-off of old trees causes the chronology to drop. The GDO-events (sudden drop) coincide with growth depressions in the regional ring-width chronologies. Regional mean-age chronologies of the bog oaks contain similar elements, sometimes over long periods. This observation indicates common large-scale climate forcing.

Introduction

From 1970 onwards, European tree-ring laboratories have studied oak trunks preserved in bogs, river gravels and marine/brackish sediments. Tree-ring series of these trees have been used to compile ultra-long absolutely dated tree-ring chronologies which extend back to 8400 BC (Pilcher et al. 1984 Leuschner 1992; Jansma 1996; Spurk et al. 1998). This paper considers the 'bog oaks' that grew under marginal ecological conditions on the surface and margins of the peat. Fluctuations of the generally high ground-water table – partly triggered by climate - are assumed to have a major impact on population dynamics and tree growth on these sites. However, by looking at the diversity of bog sites it is not clear to which extent changes in oak vitality have to be considered as local or regional. Leuschner et al. (1987) studied bog oaks from ten different sites in North Germany and found simultaneous phases of dying-off that were related to an increasing wetness of the climate. More evidence for wet climatic conditions as triggering factor is the temporal coincidence that was found between phases of dying-off and germination (=GDO) and periods of long-term growth depressions in

German bog oaks from different sites (Leuschner 1992). However, this picture became blurred when bog oaks from more sites were included.

Yet, we assume that at least major large-scale regional changes in climate towards wetter conditions are reflected in the population dynamics and the tree-ring pattern of oaks from different bog sites in Europe. Therefore comparisons are undertaken on a bigger scale; hence the comparisons between German, Dutch and Irish bog oaks. The new parameter 'mean age' is introduced, that describes variation in tree age through time and is used to detect common abrupt changes in population dynamics (germination and dying-off) of bog oaks from different European regions. Regional tree-ring chronologies are used to detect (contemporary) changes in growth activity. This paper provides a general outline of the results; a detailed description can be found in Leuschner et al. 2002.

Material and Methods

This study is based on 2.600 tree-ring series from North European bog-oak sites in Germany, the Netherlands and Ireland.

Compilation of regional bog-oak chronologies

We compiled four regional tree-ring chronologies for (1) North Germany, (2) The Netherlands, (3) Ireland, and (4) a so-called 'continental' chronology, as a combination of all German and Dutch bog-oak series. The chronologies span the interval from 6000 BC to AD 1000 and were calculated as the arithmetic mean of the single filtered tree-ring series from each area. We applied the following approach in order to remove the age trends and to maximise the common long-term variation: (1) logarithmical transformation of the series, (2) use of a weighted moving average as a high pass filter. The length of the moving average varies according to the variance of the ring width series. On average the filter-width was defined as 140 years (variable Kern-Filter, Riemer, 1994). A (parabolical) weighted running mean of 15 years (Riemer 1994) was applied to the chronologies to enable visualisation of the long-term variability of the average annual growth rates.

Assessment of population dynamics

Mean-age (MA) chronologies were compiled for the three regions (Germany, the Netherlands, Ireland) by calculating the arithmetic mean of the age of all single trees in each given year. The course of the MA chronology reflects phases of germination- and dying-off as well as the duration of undisturbed tree growth. An abrupt decrease in a MA chronology reflects a major GDO-phase while an increase of the curve points to relatively undisturbed growth. Minor wiggles and changes in slope reflect small-scale or local population dynamics. The height of the maxima in the MA chronology is related to the duration of undisturbed phases and the number of dominating old trees within a given population of trees. To detect major changes in population dynamics and to compare population dynamics with long term changes in tree-ring width we calculated the first differences of the smoothed (15-year parabolically weighted running mean) MA chronologies. Negative peaks in the first differences reflect abrupt drops in the mean-age chronologies and mark major GDO-phases in the bog oaks.

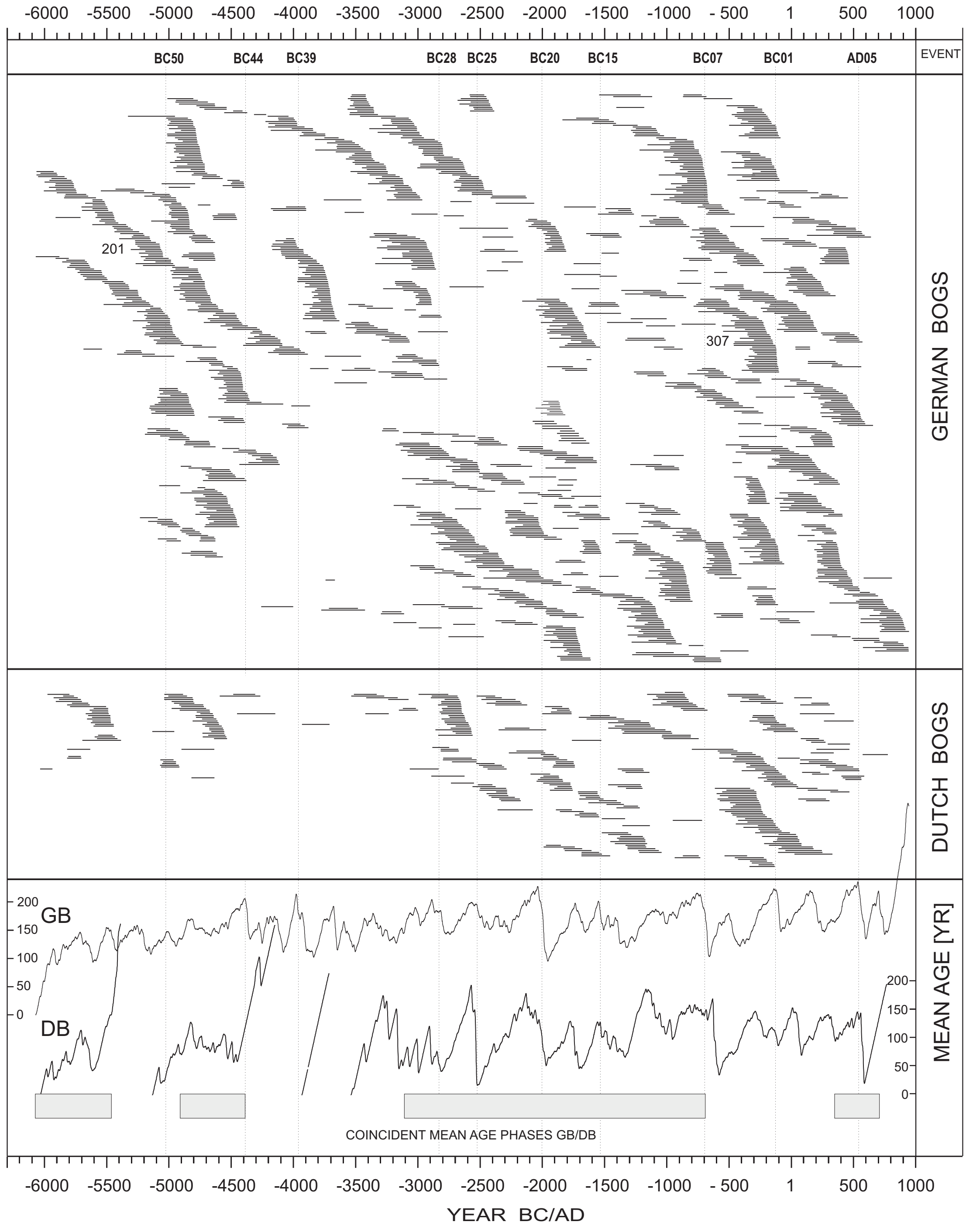

Figure 1: The life spans of bog oaks from Germany (GB, n = 1561, 101 sites) and the Netherlands (DB, n = 301, 43 sites) clustered according to their site provenance. The lower curves represent the mean ages of the trees in the two regions through time. For reference, decreases in the mean age (determined optically) are marked by dotted lines and labelled in two digits according to their date (e.g., B50 = 5000 BC; A05 = AD 500). Episodes of notable similarity are marked with bars.

Results and Discussions

The temporal distribution of the life spans of the North German and Dutch bog oaks is shown in figure 1. It is obvious that germination as well as dying-off phases on bog oak sites occur gradual instead of abrupt from one year to the other. That makes it difficult to define clear dying-off and germination (GDO) phases in the two data sets. However, the MA chronolgies of the two regional data sets clearly mirror common changes in population dynamics at the different sites of one region. Even less distinct GDO phases mostly fit to the steep part of a dropping MA curve. Striking changes in population dynamics, reflected by a sudden drop of the mean-age values in both the German and Dutch mean-age chronologies occurred around 5040 BC, 4350 BC, 3970 BC, 2820 BC, 2550 BC, 2000 BC, 1550 BC, 150 BC and AD 540

A large scale comparison is undertaken in Figure 2 by comparing the MA chronologies of the continental (German and Dutch) and the Irish bog oaks. Despite a distance of about 800 km between the sources of material we observe a remarkable agreement especially in the period from c.5500 BC to c.2000 BC. After 2000 BC, and especially between 2000 and 1000 BC there are only episodic periods of agreement which may be no more than random. This lack in agreement may be either notable climate change or increased human influence.

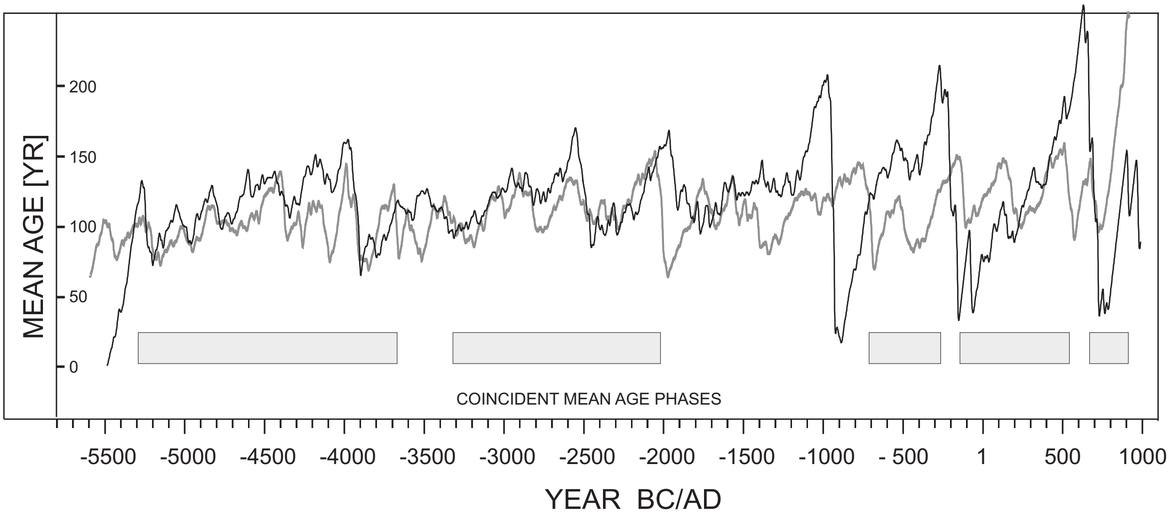

Figure 2: Comparison of macro-scale mean-age chronologies in common periods between continental (all German and Dutch) (grey) and Irish bog oaks. Phases of good agreement are marked by grey boxes.

Major common changes in population dynamics between the continental and the Irish oaks can be found between 4000 and 3900 BC around 2500 BC, and at 2000 BC. A good agreement can also be seen in much of the fine detail information of the two mean-age chronologies. We assume that phases of low mean age are the result of wetter than normal growth conditions (Baillie 1995), which may lead to the death of older trees and subsequently favor the germination of a new oak generation. Intervals of increasing mean age point to relatively dry conditions on bog sites allowing the oaks to get older; germination will eventually be reduced due to a lack of light.

Common abrupt changes in population dynamics on bog oak sites all through Europe in c. 4000 BC and 2500 BC and 2000 BC point to major changes in European climate around these periods. In this context it is interesting that there is a widespread interest in climate change in the later third millennium BC (Dalfes et al. 1997).

The question arises if significant changes in population dynamics as indicated by the first differences of the mean-age chronology correspond with contemporary changes in tree-ring width.

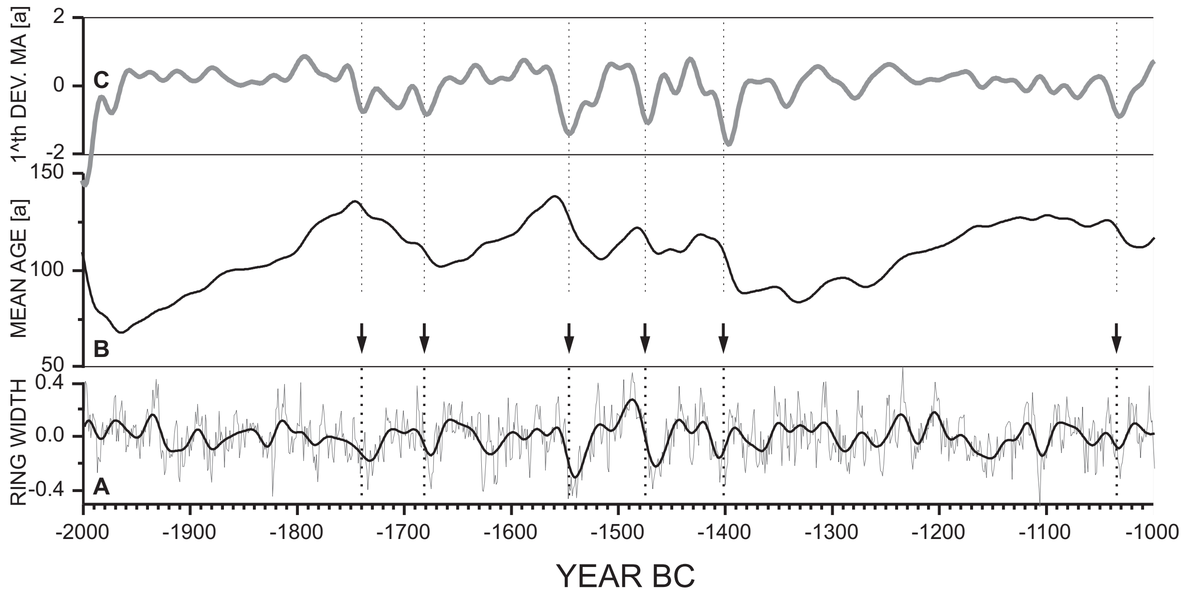

Figure 3: Example period (2000-1000 BC) for the continental (combined German and Dutch material) oaks showing comparison between the smoothed tree-ring chronology, the mean-age chronology and the chronology of first differences derived from the mean-age chronology.

A: tree-ring chronology with 15-year running mean superimposed, B: mean-age chronology, 15-year running mean C: chronology of first differences of "B". Arrows mark depression phases in the tree-ring chronology, which coincide with abrupt changes in the slope in the mean-age chronology, expressed by minimum peaks in the chronology of first differences.

Figure 3 shows a comparison of the two independent chronologies. There is clear evidence for the coincidence of the majority of GDO events with long-term ring width depressions in the Continental and the Irish data set (fig. 4) The comparison between the continental and the Irish tree-ring chronologies proves a high agreement and suggests a common forcing by climate. In this way tree-ring widths chronologies and mean-age chronologies may complement each other very well.

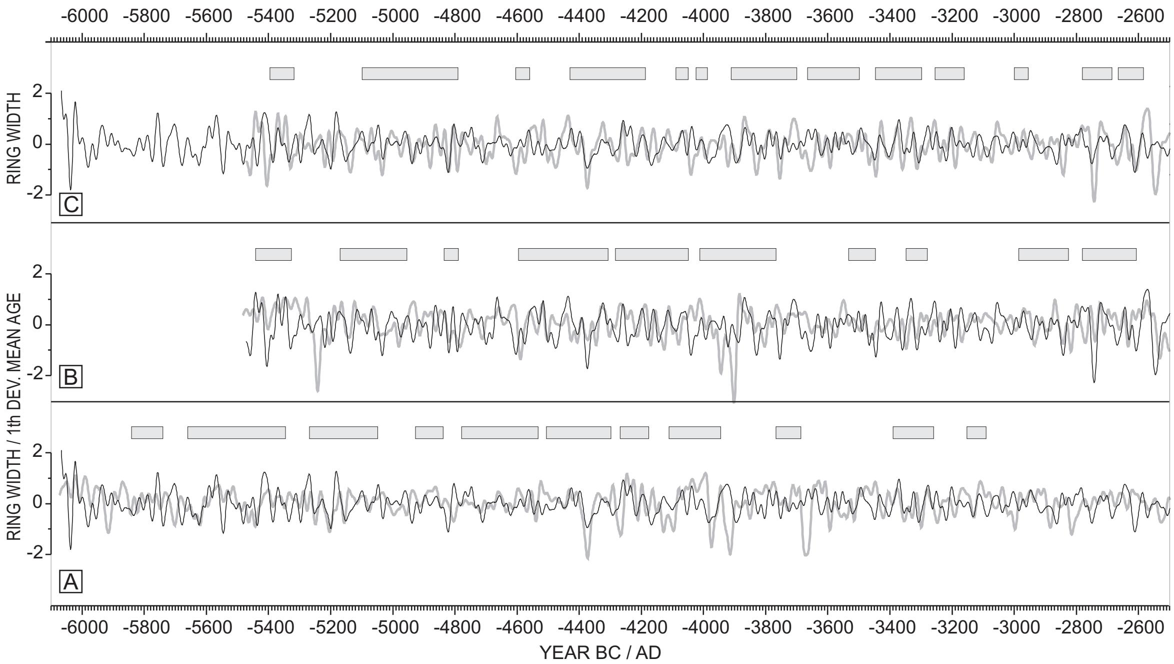

Figure 4: Comparison of regional and macro-scale population dynamics (derived from mean age curves) and changes in the tree-ring chronology in the period from 6100 BC to 2500 BC.

A: Running mean of the continental (German and Dutch) bog oak tree-ring chronology in comparison to the chronology of first differences of the mean-age chronology (15-year running mean). B: Running mean of the Irish bog oak tree-ring chronology in comparison to the chronology of first differences of the mean-age chronology (15-year running mean). C: Running mean of the continental and the Irish tree-ring chronologies. Phases of good agreement are marked by grey boxes at the top. The tree-ring chronologies were derived from the raw tree-ring measurements after logarithmic transformation and by applying a 141-year high-pass filter.

Conclusions

The analysis of large dendrochronological data sets in terms of mean age produces clear data about changes in population dynamics on bog sites in Europe. Abrupt changes in population dynamics indicate climatic change in regions of varying size. Given the scale of these events in the extended period 5400 BC to 2000 BC and – less clear – 2000 BC to 1000 AD, it is highly unlikely that they resulted from human intervention. Instead this must have been the result of a strong forcing by macro-scale environmental influence probably expressed as hydrological changes.

Acknowledgements

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High-medieval urban development between the middle Elbe River and the lower Oder based on dendrochronological data

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The present study is based on the analyses of 31.630 wood samples collected by the laboratory of the Eurasia Department of the German Archaeological Institute (Deutsches Archäologisches Institut). Beside the evaluation of the state of the art of dendrochronology in the study area, the aim was to reconstruct the chronological sequence of medieval urban development as it is represented in the archaeological source type of „wooden materials". Only dated wood samples with the highest possible explanatory power, i.e. with preserved waney edge or at least with heartwood-sapwood-boundary, were examined. In total, 5002 samples from wooden constructions of 87 towns were analysed, with ages ranging from the 9th to the 14th century. The samples originate from sources between the middle Elbe River and the lower Oder (federal states of Mecklenburg-Vorpommern, Berlin and Brandenburg). Dendrochonological data from the various towns were compared with evidence from written sources and archaeological examinations. Since it was not possible to study all aspects of town development we focused on the most prominent issue: These are mainly possible discrepancies between the earliest settlement activities in the towns dated dendrochronologically and the earliest mention as settlement and/or town including municipal righths in written sources. The space of time between the beginning of the continuous settlement and the typical medieval dense building structure was equally examined. Additionally, we were interested in the chronological and spatial settlement succession within the town limits. Furthermore, we attempted to obtain data on the development of urban settlement in the whole study area.

For a series of towns we were able to evaluate very precise data regarding their initial settlement and their development during the Middle Ages. For this purpose, even a small number of appropriate wood samples proved to be sufficient. The dendrochronological data indicate earliest settlement activities of 100, occasionally even 200 years before the first written sources. In some cases (e.g., Lübz and Cottbus), a time difference of even 250 years was found. For most settlements the discrepancy between the first dendrochronological date and the first written texts averages about 40 years for the mention of a place and 50 to 60 years for the mention as town, respectively.

The development of a whole medieval town can not be reconstructed reliably if less than about 100 wood samples are available. In this case, only vague periods of settlement activity can be specified. However, if the number of wood samples exceeds 200, a general trend of town development can be outlined with decent precision. If several hundreds of wood samples are available, even details of the history of individual parts of towns can be reconstructed. The spatial development of the urban structure can be mapped with acceptable accuracy on the medieval town map if more than 20 sites can be analysed (e.g., Greifswald, Rostock, Stralsund).

It became apparent that the medieval expansion of towns usually spanned only several decades. In the study area, the peak activity of urban development was reached during the second and third quarter of the 13th century (Fig. 1).

Figure 1: Phases of the peak extension of medieval towns in the study area based on dendrochronological data.

For the majority of the coastal towns along the southern shore of the Baltic Sea this peak was reached during the last decades of the 13th century and was mainly connected with the emerging hanseatic long-distance trade.

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SECTION 2

LONG TREE-RING CHRONOLOGIES

Dendrochronologie im Spätglazial, Schmelzwasserschübe, Dansgaard-Oeschger Zyklen und Heinrich-Ereignisse

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Der letzte einer Serie von Dansgaard-Oeschger Zyklen bringt die Temperaturen zu Beginn des Bölling (ca. 14'500 cal BP) bis auf 1°C an das holozäne Niveau heran. Mindestens zwei solche Zyklen, also mit Älterer Dryas und Gerzenseeschwankung Klimaeinbrüche und entsprechenden -erholungen folgen darauf. Schliesslich bereitet der Temperatursturz des vorläufig letzten Heinrich-Ereignisses - die Jüngere Dryas - dem Bölling/Alleröd Interstadial ein jähes Ende. Diese auf dem Ozeanboden und im Grönlandeis nachgewiesenen Schwankungen werden überlagert von zwei Schmelzwasserschüben, die mit etwa 500 Jahren Verzögerung um 14'000 cal BP und ca. 11'500 cal BP folgen. Fossile Wälder in Mitteleuropa und Nordamerika widerspiegeln mit ihrer Ausbreitung die Erwärmung, mit ihrem Absterben die klimatischen Rückschläge. Sie bilden ein hochauflösendes Archiv für die Wärmephasen, welches die globalen Verhältnisse widerspiegelt. Komplementärfunde erlauben es, die dendrochronologisch noch nicht vollständig überbrückten Abschnitte dennoch in den globalen Zusammenhang einzuordnen.

Eine ultra-lange Hochlagen-Chronologie für die zentralen Ostalpen: Möglichkeiten und Ergebnisse

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Bis vor kurzem fehlten im Alpenraum mehrtausendjährige Jahrringchronologien. Für den Aufbau einer Holozän-Chronologie wurden in den letzten Jahren in den zentralen Ostalpen ca. 700 Hölzer an 34 Lokalitäten beprobt. Die Untersuchungsorte befinden sich jeweils im Hochlagenbereich, zwischen ca. 1900 und 2500 m SH. Das Probenmaterial wird dominiert von Pinus cembra (über 90%), die übrigen Proben entfallen auf Larix decidua bzw. Picea abies. Bisher gelang der Aufbau einer ca. 7000 Jahre langen, bis ins Jahr 5125 v.Chr. zurückreichenden Chronologie. Für das frühe Holozän liegen mehrere schwimmende Chronologien vor. Dieses Chronologie-Projekt erbrachte neue Ergebnisse zu Fragen der alpinen Umwelt- und Klimageschichte.

SECTION 3

CLIMATE

A detailed view on instrumental temperature data from northern Eurasia

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Motivation

Briffa *et al*. (1998) describe a reduced sensitivity of recent tree growth to temperature at Northern Hemisphere (NH) high latitudes. Their study shows a divergence starting about 1950 between increasing mean summer temperature and decreasing tree-ring density and ring width for North America and several regions of northern Eurasia. This phenomenon is significant, because it questions the validity of ring-width and density records as being a proxy for mid-to-low frequency temperature variability. We believe that a detailed view of the instrumental records of northern Eurasia will improve our insight in this matter.

Here we analyze the sparse set of meteorological records available for northern Eurasia by subdividing the area North of 65°N into four study regions: North Europe, West Siberia, Central Siberia, and East Siberia. For these regions, we analyzed the raw instrumental data and the adjustments made to these measurements by the Global Historical Climatology Network (GHCN). In particular, we investigated what urban adjustments should be made after the completion of all other station corrections and adjustments. Corrections done for urban warming were of particular interest to us, because rising temperature trends can in part be forced by warming effects of urbanized territories. Our assumption was that the discrepancy between the instrumental and tree-ring data might be caused by corrections that do not adequately or fully remove the urban warming effect.

Introduction

The large number of tree-ring sites in the NH, especially in the boreal zone near the northern timberline, provides a valuable network for the reconstruction of paleoclimate (Schweingruber 2002). Tree-ring chronologies can be used as a proxy for past summer temperature, because both the density of the wood formed during the late summer as well as ring width correlate well with local temperatures during the growing season, especially with temperatures in June, July and August (Briffa et al. 1998). Tree-ring chronologies therefore can provide a detailed history of changing temperatures throughout the last millennium, on local, regional and even hemispheric scales. However, the reconstruction of paleoclimate by using proxy data such as tree-rings is closely tied to temperature observations, because the proxy must be calibrated against climate data in order to estimate the magnitude of past temperature changes.

Briffa *et al.* (1998) describe a reduced sensitivity of recent tree growth to temperature, showing decadally smoothed maximum-latewood density and ring-width series together with mean summer temperatures recorded by a sparse instrumental meteorological network. They show that around 1950 a divergence started between the tree-ring data and temperature, expressed by a slightly increasing mean summer air temperature and decreasing tree-ring density and ring-width values. They scaled all data series over the period 1881-1940 to have zero mean and uniform variance, except for East Siberia where the interval 1932-1975 was used due to a lack of older instrumental records.

Raw measurements on meteorological phenomena (e.g. temperature, precipitation) must be individually adjusted in order to account for problems such as shifts in station locations, changes in instrumentation and urban heating influencing the station's environment. Such corrections are made by the GHCN (Peterson et al. 1998, 1999). In this paper, we analyze the adjustments made to the raw instrumental data from Northern Eurasia used by Briffa *et al.,* in order to come to a better understanding of the signal in these time series caused by urbanization effects (Jones et al. 1990). One hypothesis is that some of the divergence in the low-frequency relationship between the tree-ring and meteorological records as seen in Briffa et al. (1998), is caused by the fact that effects of urban warming were not properly or fully removed from the instrumental measurements.

Material and Methods

In order to get a detailed view on instrumental meteorological stations in the large region of northern Eurasia between 65°-75°N, we downloaded both raw and adjusted version 2 GHCN monthly weather station temperature data from the IRI/LDEO Climate Data Library website. Version 2 of the Global Historical Climatology Network is a data set of 7300 monthly mean temperature stations and 5100 monthly mean maximum and minimum temperature stations, gathered from 30 data sources (Peterson et al. 1998). In order to be consistent and clear, we only used the homogeneous raw and adjusted data series that were marked with „ver.0" and did not mix different sources.

After downloading the data from all 23 stations in our study area that had data for at least the period 1950-1980, we classified them by the length of their records and by their surrounding population (Figure 1). Seven stations supplied records that start before 1900, five of which are located in Northern Europe and West Siberia, and only two of which are situated in the vast expanse of Central and East Siberia. Following GISS (Goddard Institute for Space Studies) conventions, the 23 instrumental meteorological stations were classified as urban (pop. > 50,000), suburban (pop. > 10,000) and rural (pop. < 10,000) (Hansen et al. 1999, 2001).

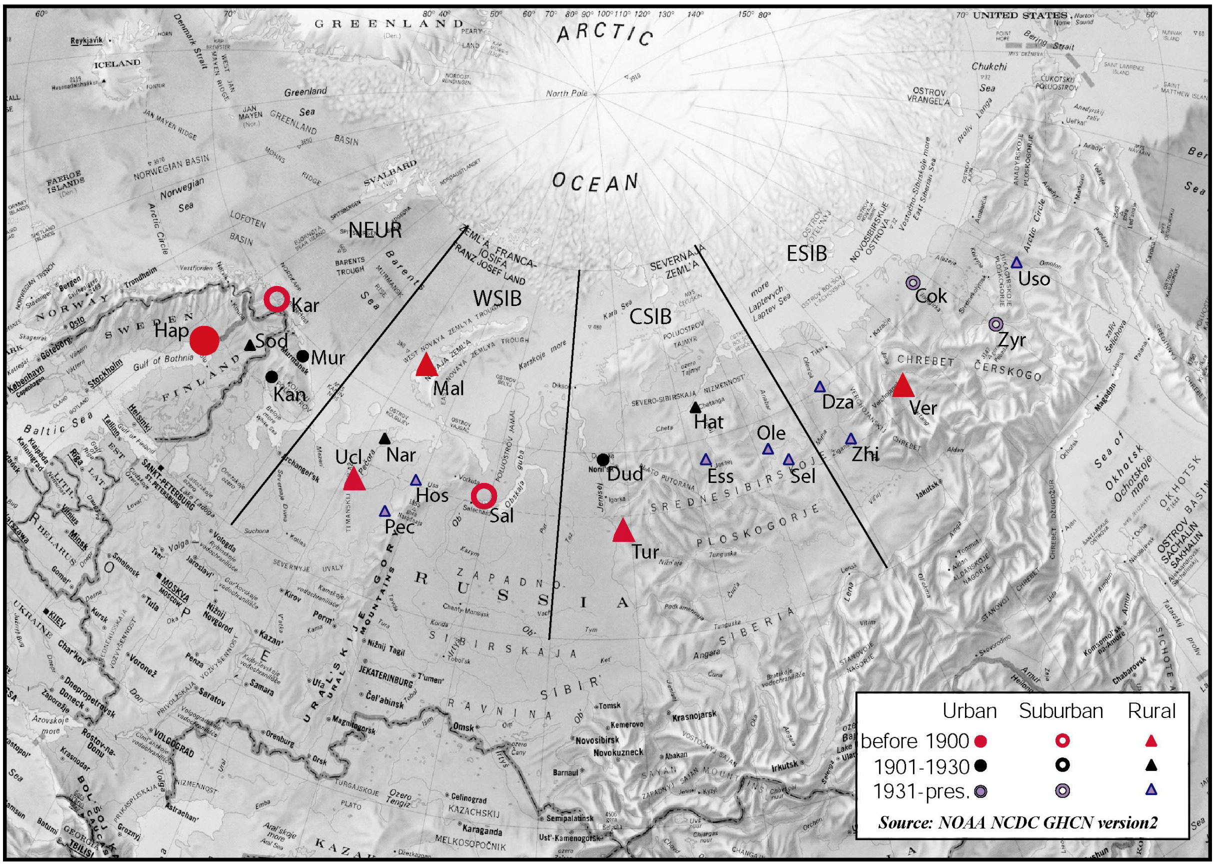

Figure 1: Locations of the 23 meteorological stations used in our study. These stations were classified according to the length of record and population setting. The four sub-regions are also shown: NEUR=Northern Europe; WSIB=Western Siberia; CSIB=Central Siberia; ESIB=Eastern Siberia.

The large size of the study area near the northern timberline prevents us from handling it as a single region. Based on station correlation matrices for the raw and adjusted data series, the 23 stations were subdivided into 4 geographical regions: northern Europe; West Siberia; Central Siberia and East Siberia. These four regions are similar to the division of Eurasia by Briffa *et al.* (1998). For northern Europe, in addition to the records from Russian meteorological stations, we also obtained records from Sweden – Haparanda, the longest record measuring since 1875 – Norway, Karasjok – and Finland, Sodankyla.

Figure 2 shows the raw and adjusted normalized June, July and August temperature trends of the individual stations, as well as the regional average trend curves, for each of the 4 regions (Figure 2). All data were normalized over the period 1951 – 1980, because all meteorological series cover this 30-year interval. The normalization was done to avoid the dominance of a single month when averaging monthly temperature records. We also normalized various stations over their entire individual length. In these cases, we obtained similar temperature trends and relationships between the raw and adjusted series. This implies that most likely no bias was introduced by using an interval of 30 years only.

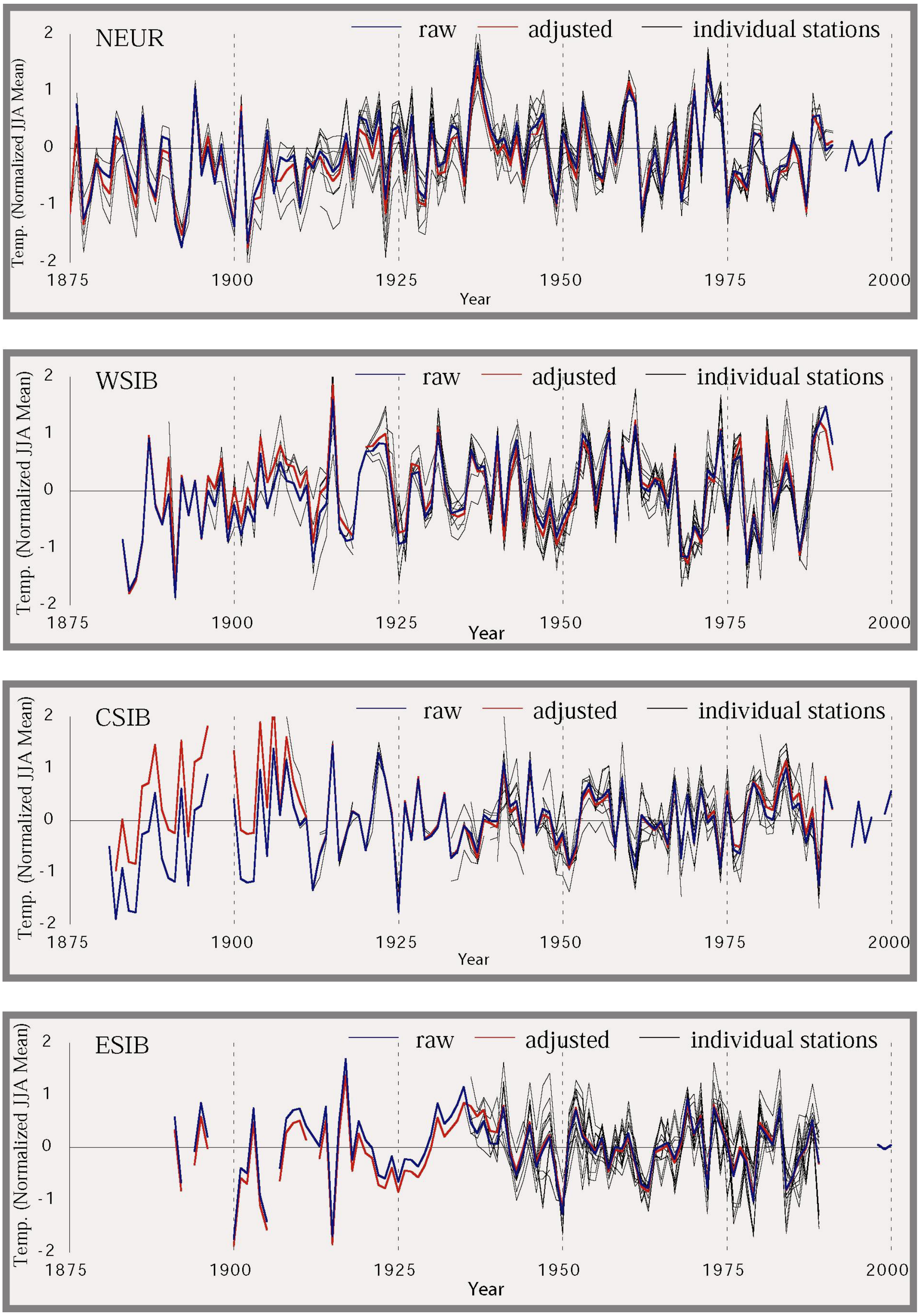

Figure 2: Plots of raw and adjusted normalized JJA mean temperatures for the four subregions. NEUR=Northern Europe; WSIB=Western Siberia; CSIB=Central Siberia; ESIB=Eastern Siberia. Individual station records (thin black lines), and regional means for both the raw (thick blue lines) and adjusted (thick red lines) are shown.

For each station record, we calculated the difference between the adjusted and raw summer temperature, in order to reach a more precise understanding of the way the GHCN adjusts raw data. We did not use the normalized data to show real adjustments in C°. Figure 3 shows the adjusted minus raw data for the four stations classified as urban in our study area.

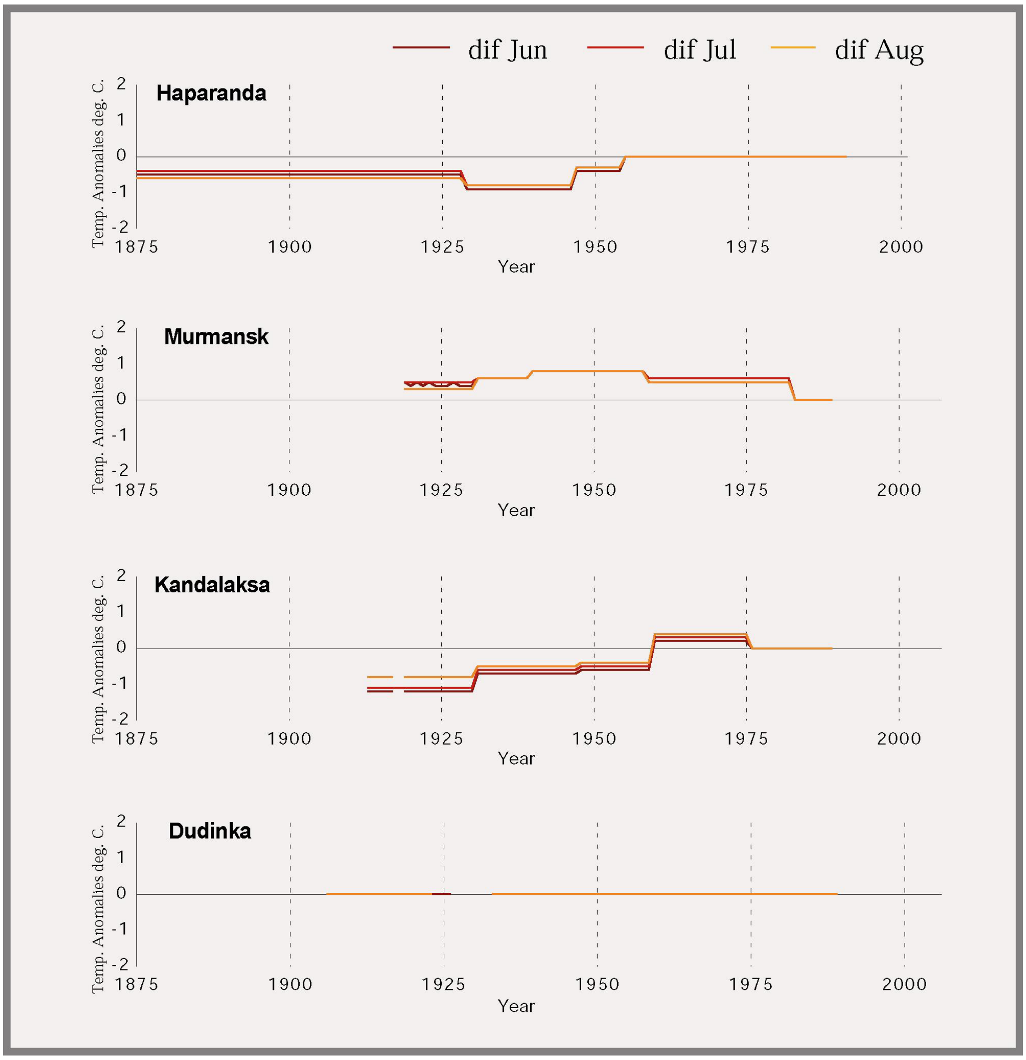

Figure 3: Adjusted minus raw values for the months of June, July and August for each of the four urban stations in the study area. In the absence of other factors, adjustments for urban warming would result in lines of negative slope when differences are calculated in this way. No adjustments were made to the summer Dudinka record.

Discussion

Gridded meteorological data represent weighted averages of varying numbers of station records. When analyzing gridded temperature data in data-sparse regions, one single station can have a huge impact on a large area. Figure 1 shows that in the high northern latitudes of Eurasia both the length of the meteorological records as well as the density of the spatial distribution of the meteorological stations decrease from West to East (only three

meteorological stations in the region of 65° - 75°N reach back to 1881). This implies that the findings based on these data have to be viewed with some caution.
Plots of the normalized individual raw and adjusted series, and their means (Figure 2) for the four regions, do not reveal a consistent or clear relationship between raw and adjusted series. The means of the adjusted and raw series are fairly similar, except towards the earlier parts of the instrumental record, where significant differences occur. The earlier intervals are covered by fewer data series, which makes their average series sensitive to adjustments made to individual stations. This early portion of the record is critical for the understanding of the lower-frequency trends in the instrumental records during the late 19^{th} and 20^{th} centuries. It also further illustrates the limited nature of the available instrumental data.
Similarly, differences between raw and adjusted series for the four urban stations do not reveal consistent results (Figure 3). If the series had been adjusted to correct for urban warming, we would expect to see a negative slope for the adjusted minus raw data. However, trend lines for the Haparanda and Kandalaksa stations yield positive slopes. No adjustments were made to the Dudinka station summer temperatures. Only the Murmansk station indicates a general downward correction. These results either suggest a dominance of other corrections that mask those done for urban warming, or they may simply indicate the ommission of adequate corrections accounting for urban warming. Similar graphs for all stations (not shown) also do not reflect corrections for urban warming independent of their surrounding population. We could not detect any uniform adjustment pattern based on the three population classifications (Urban, Suburban and Rural) that is related to the individual size of the settlement where the meteorological station is located.
In summary, when focusing on the way the GHCN adjusts raw instrumental data, no intuitive adjustments were found that might relate to the elimination of urban-warming effects. We conclude that the current view of the 'true' climate of northern Eurasia to some extent is uncertain, due to (a) the sparse distribution of meteorological stations between 65°N and 75°N, (b) the general and rigid classification (urban, suburban, and rural), and (c) the manner in which adjustments to the meteorological data were performed or ommitted. Potentially, some of the low-frequency divergence between tree ring and instrumental data can be explained by inadequate or missing corrections. We plan to further analyze the discrepancy between the tree-ring and instrumental records in the northern Eurasian sector.

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Dendrochronological network analyses of Central European chronologies: a conceptional approach of a new project

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Introduction

The reconstruction of past climate conditions is an important goal of dendroclimatological investigations. Normally such reconstructions are based on tree-ring data of one or more species that grow in a spatially limited area. In order to be able to use tree-ring series as proxies for climate reconstruction, the non-climatic environmental signal(s) should be removed from the series. Dendroclimatological studies have shown that the signals in tree-ring series may differ widely. Supplementary and sometimes even dissimilar climatic signals may occur in the growth patterns of trees from the same site (e.g. Bräker 1981). The reason is that different species of trees have different ecological demands (Ellenberg 1996, Schütt *et al.* 1984, Ott *et al.* 1997), meaning that they show a species-dependent sensitivity to their environment (Schweingruber 1996). Therefore, similar climatic events can trigger dissimilar responses in tree growth (Desplanque 1997).

Based on these statements, we postulate that dendroclimatologists should: (a) sample more trees from different species; (b) select more sampling sites that cover the whole ecological spectrum; (c) study more tree-ring parameters; and (d) apply a wider variety of methods. In addition, raw tree-ring data used in dendroclimatological studies should to be prepared in a uniform way, using the same method(s) for all series.

At present, we are in the process of applying this approach to Central European tree-ring data, in order to answer questions such as:

- Can dendroclimatological results be transferred from one location to another?
- Is it possible to assess growth-limiting and growth-promoting factors over larger regions in relation to climate and site ecology?
- Do the climate signals contained in tree-ring series have a spatial and ecological range?
- What are the criteria and rules for defining this dendroclimatological range?

In this context, we are building a Central European network of tree-ring chronologies. Using tree-ring parameters such as ring width, maximum X-ray density, and relations of stable carbon isotopes, we intend to compute pointer years and interannual and decal growth variations. For the 20th century, we will analyze the patterns of these chronologies spatially in terms of known climate anomalies and with regard to various ecological site conditions and species-specific growth responses.

Our research will be focussed on:

1. The distribution of intra-regional and inter-regional pointer years;
2. Climate signals in tree rings at an interannual and decal level;
3. Environmental growth factors, differentiated by means of climatical and site-ecological criteria;
4. The spatial and ecological range of climate signals in tree rings;
5. The factors and rules that define this dendroclimatological range.

In this paper we present a description of the database and of the applied methods, and preliminary results based on pointer-year analysis.

Material

Our network consists of over 650 chronologies from Central Europe, which we define as the area between 5° to 17° E and 42° to 55° N. These chronologies represent nine different tree species: *Abies alba*, *Fagus sylvatica*, *Larix decidua*, *Picea abies*, *Pinus cembra*, *Pinus sylvestris*, *Pinus uncinata*, *Quercus petrea*, and *Quercus robur*. The latter two species, *Quercus robur* and *Quercus petrea*, are very similar in terms of wood structure and ecological demands, and therefore were condensed to a single class. As a result, in this study we differentiate between eight classes of tree species.

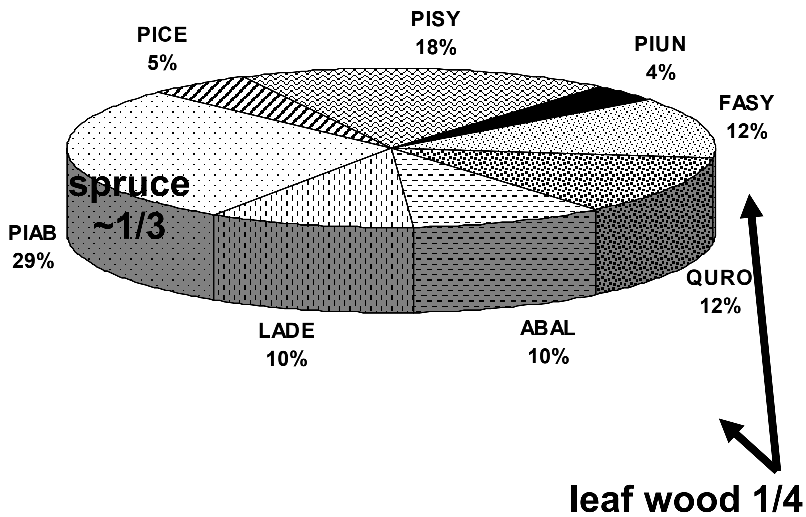

Fig. 1: The ratio of tree species in percentages.

Almost a third of the chronologies in our network are of spruce, whereas deciduous trees only make up one quarter of the collective (Fig. 1). Not shown here, but also important, is the fact that nearly 80% of all chronologies represent tree-ring width, about 20% are density chronologies and only 1,4% are isotope chronologies. Given this unequal distribution, additional chronologies will have to be collected in order to balance the data set.

Methods

The common signal in the raw tree-ring series underlying the chronologies was checked with NET (Esper *et al*. 2001). NET is a new parameter for estimating the signal strength of mean tree-ring chronologies that have an annual resolution. It combines the coefficient of variation, v, and the "Gleichläufigkeit", Gl., which are variables that are widely known from the statistical and dendrochronological literature respectively (e.g., Bahrenberg, Giese 1975; Eckstein, Bauch 1969). At a NET threshold value of 0.8, both the common variance and the value for Gl. indicate some common signal. As the strength of the common signal increases, the value for NET decreases towards a minimum value of 0.

In our study, chronologies with NET > 0.8 were removed from the data set. The raw ring-width series of the remaining chronologies were standardised after Cropper (1979), implying that for each tree-ring series and for each year a so-called z-value was calculated according to the formula:

$$z_i = \frac{x_i - mean[window]}{stdev[window]} * 1000$$

with window := $\{x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}\}$.

(see Meyer (1999) for a further explanation of this procedure). By averaging the annual z_i-values of the individual tree-ring series in each chronology, we produced mean series of so-called Cropper values. We transformed the Cropper series to a d-base format, and subsequently imported them into the geographical information system ARC VIEW 3.2. Using the digital terrain model (DGM) G-TOPO 30, we created a digital map of the research area, on which we plotted the geographical distribution of Cropper values. We choose the Inverse Distance Weighted (IDW) interpolation method with eight nearest neighbours, which is a standard interpolation procedure in ARC VIEW 3.2, to transform the point data into surface data. The IDW interpolator assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing cell more severely than those that are further away. To simplify the presentation, the annual Cropper values were classified according to their distance from the mean (< -3 to > +3 standard deviations (σ), 7 classes in total).

Preliminary results

The removal of chronologies with a NET value over 0.8 reduced the data set from 650 to 308 chronologies. The remaining chronologies cover the period AD 1880 to 1980. Figure 2 shows their average Cropper values for the years 1933 (a), 1948 (b), and 1975 (c), with blue colours representing negative deviations, and red colours representing positive deviations from the annual mean of radial growth. Various spatial patterns can be discerned. The years 1933 and 1975 seem to be very similar, showing a colour transition from red in the North, corresponding to positive growth anomalies, to blue in the South, corresponding to negative pointer years. 1948 on the other hand shows a decrease from the Southeast to the Northwest. We tentatively conclude that there exists no direct relationship in our material between radial tree growth and latitude. Further research is needed to ascertain the validity of this conclusion.

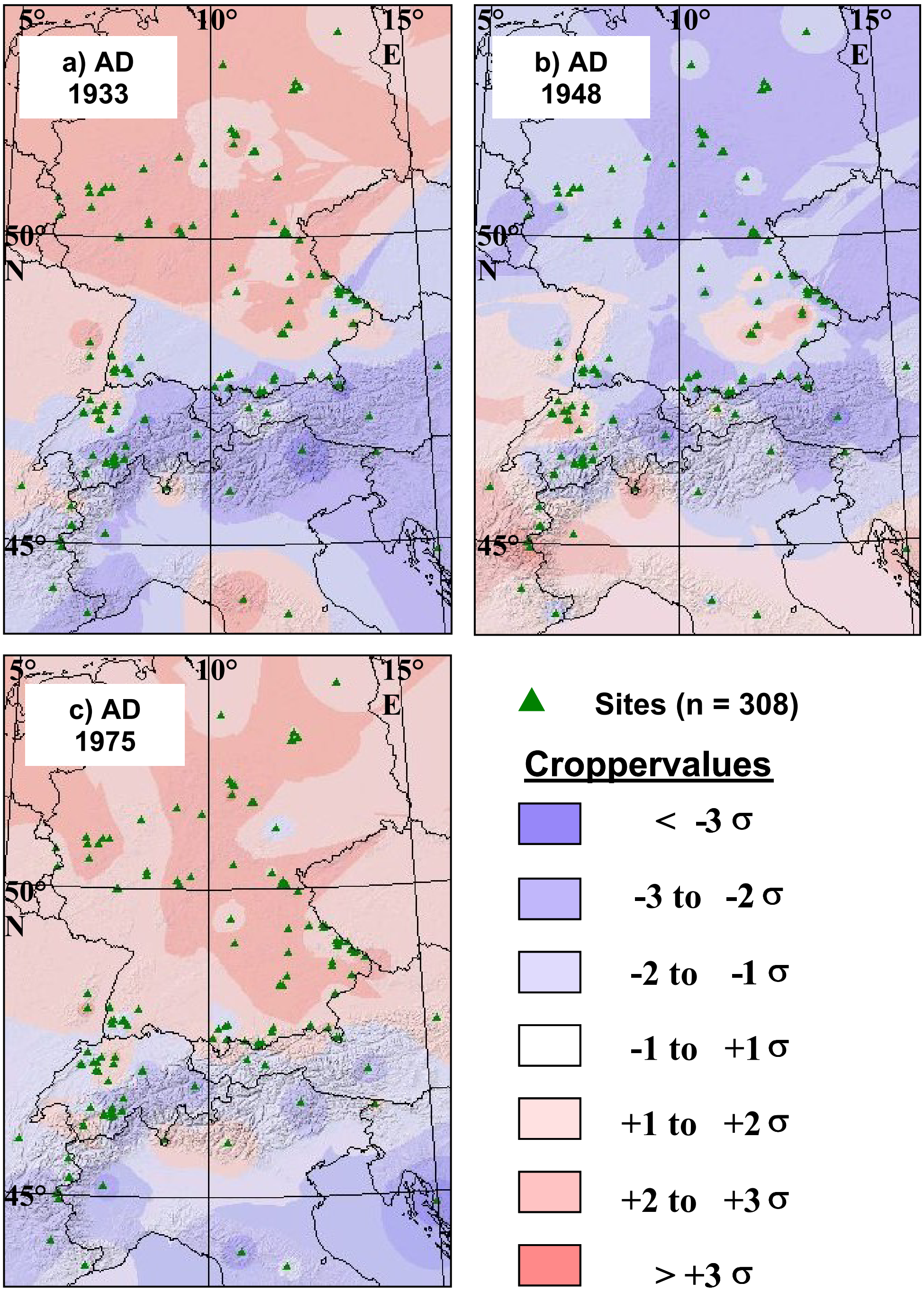

Fig. 2: Spatial patterns of pointer years in Central Europe presented as deviations from average Cropper values for AD 1933, 1948, and 1975.

Future perspectives

As stated above, we intend to determine (1) the distribution of intra-regional and inter-regional pointer years; (2) climate signals in tree rings at an interannual and decal level; (3) environmental growth factors, to be differentiated by means of climatical and site-ecological criteria; and (4) the spatial and ecological range of climate signals in tree rings. In order to achieve our goals, first of all we will compare the Cropper values with climatological data (for example the frequency of westerly "Großwetterlagen") and topographical data (elevation, exposition), using cluster analysis (part of the statistical software package SPSS). This should result in a classification of the data into groups with (a) similar data combinations, and (b) similar spatial growth patterns. The combination of tree-ring data with climatological and topographic data will help us to explain the various groups and, allowing for the various ecologically-determined site conditions and species-dependent responses, to determine which environmental growth factors determine the spatial distribution of the patterns.

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Subfossil pines from loamy slope sediments reflect Lateglacial climatic variations

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Introduction

During the last glacial maximum (c. 20 kyrs BP), Alpine glaciers formed numerous lateral drainage channels on the Swiss plateau. Adjacent to then existing nunataks (e.g., Uetliberg, plateaus of Brütten and Kyburg), drainage channels were formed such as the Daettnau valley, Rumstal near Winterthur, and the valleys of Sihl and Reppisch in the vicinity of Zurich. Mass movements, precipitation and meltwater filled the channels with predominantly loamy sediments. These developed to huge archives containing subfossil pines and other macro and micro remains. Greenland ice cores show that the Lateglacial (i.e., the beginning of the Bølling-Allerød interstadial around 14.500 cal BP) is characterized by an abrupt warming to ca. 1°C below the average Holocene level (Dansgaard et al. 1993, GRIP Members 1993). Until the end of the Allerød, at least 3 cycles of climatic cooling can be distinguished (Bond et al. 1999). These are the Older Dryas (OD), the Inner Allerød Cold Phase (IACP), and the Gerzensee deviation (GS). A significant warming followed each of these cooling events (Taylor et al. 1993). The Bølling-Allerød interstadial was terminated abruptly by the final event of the Younger Dryas (YD), the temperature dropping ca. 7°C relative to the early Bølling (Dansgaard et al. 1993, GRIP Members 1993).

At present, there is an abundance of known sites containing subfossil pine trunks that date back to the early Holocene (Preboreal) and the Lateglacial (Bølling, Allerød and Younger Dryas). Consequently, numerous Lateglacial floating chronologies have been constructed. The chronologies from the late Younger Dryas and early Preboreal have been dated absolutely against the Hohenheim pine/oak master chronology (Kaiser 1993, Friedrich *et al.* 1999, Friedrich *et al.* 2001, Spurk *et al.* 1998). The Hohenheim pine chronology from gravel beds of the Danube River dates back to 11919 cal BP [9969 BC]. The Swiss Preboreal pine chronology built parallel to the Hohemheim chronology extends the absolutely dated sequence backwards with 35 years, to 11954 cal BP [10004 BC] (B. Müller 2000). Subfossil pine trunks from the French Alps have been used to build several floating chronologies for the same period (Miramont 2000a/b).

Aims

The research objectives at the Gaenziloh site were:

1. The compilation of one or more independent chronologies;

2. The identification of phases of increased germination of the trees;
3. Crossdating the new chronologies against existing chronologies from Daettnau;
4. Assessing whether the new chronologies reflect Lateglacial climatic signals such as OD, IACP, GS and YD.

In this paper we present preliminary answers to question 1, 3, and 4, based on the Daettnau material (Kaiser 1993) and a subset of samples from Gaenziloh. More precise results will be presented when all pine trees from the Gaenziloh site have been included in the analysis.

Material and methods

In the summer of 2000, near Zurich the construction started of a tunnel through Uetliberg. In the glacial meltwater channels on both slopes of Uetliberg (i.e. Reppischtal and Sihltal), 120 fossil pine stumps were recovered from the construction sites of Gaenziloh and Landikon. During their lifetime, the pine trees were buried continuously beneath loamy alluvia washed down from the slopes. Hence the wood is well preserved. Our study focusses on the trees found at Gaenziloh in combination with those from Daettnau (Kaiser 1993) (Fig.1). The majority of the studied samples were dated by means of the radiocarbon method (Figs. 2 and 4).

Several disks were taken from each stump: a first one at the level where the roots spread, in order to obtain the germination date of the tree, and one or two more at a 30 to 40 cm higher level, in order to avoid growth disturbances caused by roots.

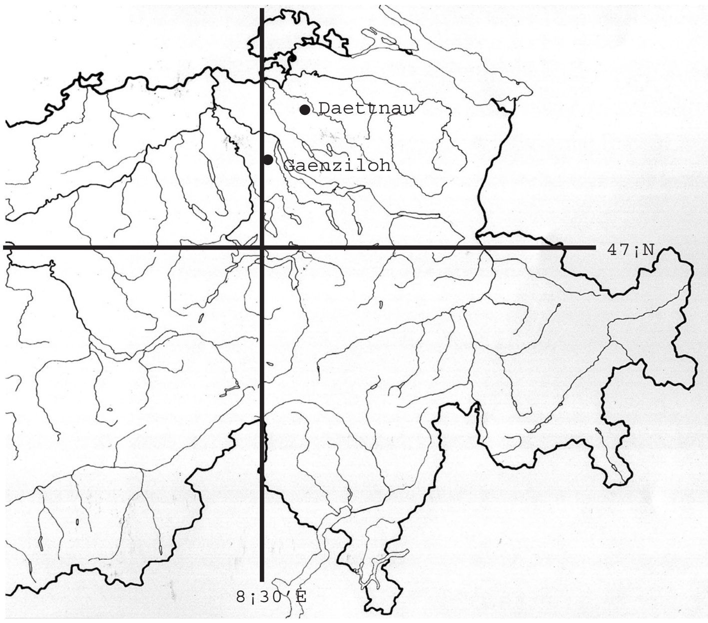

Figure 1: Location of the studied sites

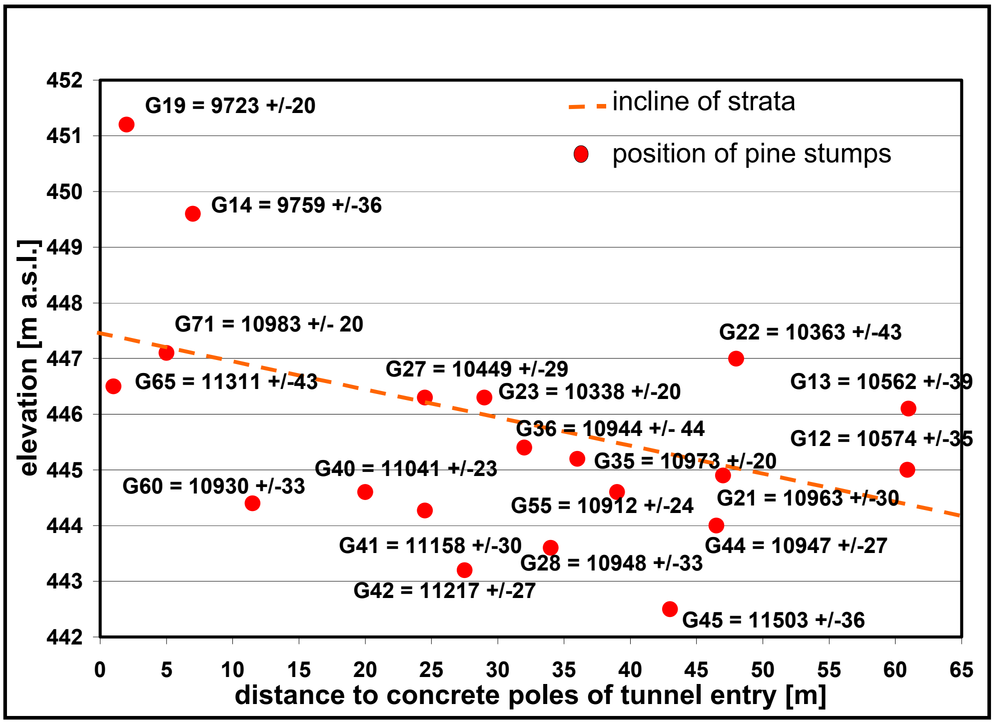

Figure 2: General position of the ^{14}C-dated pine stumps at Gaenziloh.

Results

Radiocarbon dating places the pines from Gaenziloh in the Allerød, with some scattered samples dating to the Younger Dryas (Fig. 2).

We first constructed a floating chronology, CHR65, from the ring-width series of five pines (Fig. 3). Since the replication of CHR65 is low, we relied in part on stratigraphy and radiocarbon dates when we placed the constituting time series on a relative time scale. Figure 4 shows that the available ^{14}C dates agree well with the dendrochonological results. CHR65 covers 830 years and may extend just into the Younger Dryas cold phase. Using CHR65, the gap between two floating chronologies from Daettnau (DAEALCH1 and DAEALCH2; Kaiser 1993) could be bridged (Fig. 3). Our results show that the latter chronologies do in fact overlap in time, but with an insufficient number of tree rings to allow for statistical certainty.

We then used the crossdated series from Gaenziloh and Daettnau to construct a combined chronology, which we termed CHR213 (Fig. 3). It covers an 1109-year interval, and agrees well with chronology Aller14 by Friedrich *et al.* (2001), the older part of which consists of chronology DAEBOCH from Daettnau (Kaiser 1993).

Minimum values in CHR213 seem to reflect climatic deteriorations of the Allerød such as IACP and GS (Siegenthaler et al. 1984). The distinct growth disturbance after relative growth year 1050 (see Fig. 3, x-axis) probably synchronizes with the Laachersee eruption (LSE) (Schminke *et al.* 1999, (Friedrich et al. 1999). However, these results are tentative, given the fact that they are based on a subset of the Gaenziloh material. Their validity will have to be assessed as soon as all samples have been evaluated.

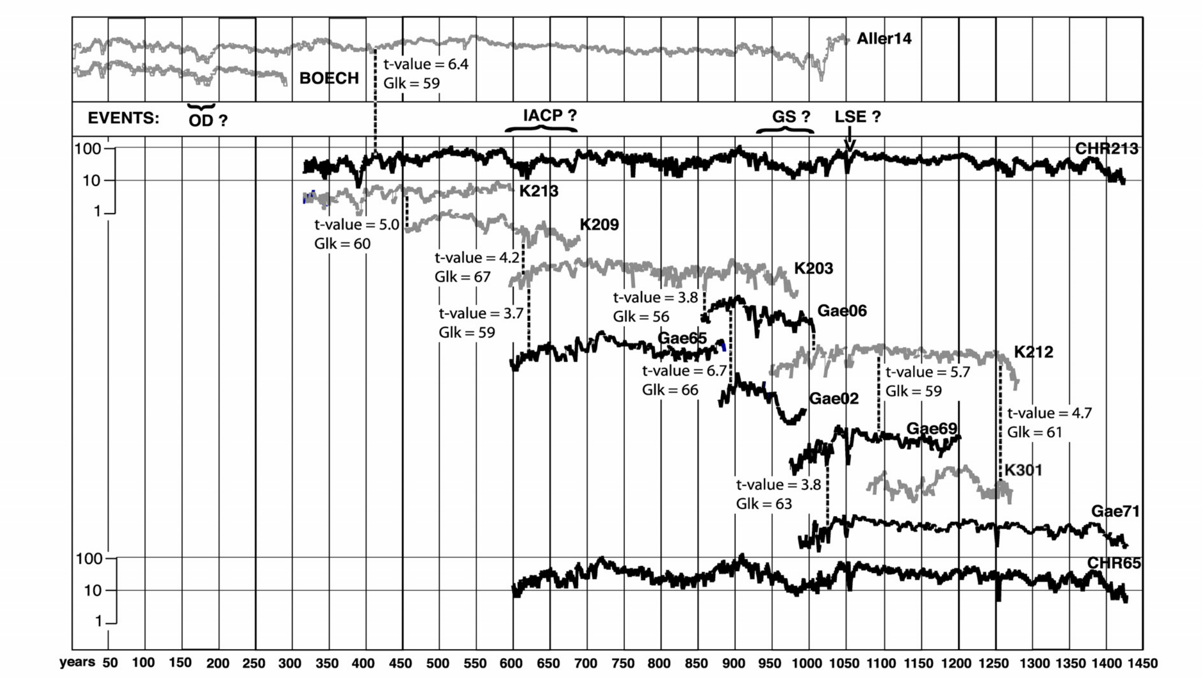

Figure 3: Lower part: The first chronology of Gaenziloh, entitled CHR65, was compiled from samples Gae65, Gae06, Gae02, Gae69, and Gae71. It covers 830 years and matches with important samples within the Daettnau chronologies DAEALCH1 (samples K213, K209, K203) and DAEALCH2 (samples K212, K301). The combined chronology, entitled CHR213, covers an interval of 1109 years. Intervals of below-average annual growth possibly reflect the Inner Allerød Cold Phase (IACP), the Gerzensee deviation (GS) and the Laachersee eruption (LSE).
Upper part: Chronology Aller14 (Friedrich et al. 2001) represents the average of Dättnau chronologies DAEBOCH and ALCH1 (Kaiser 1993). It matches well with CHR213 (t = 6.4; Glk = 59%).

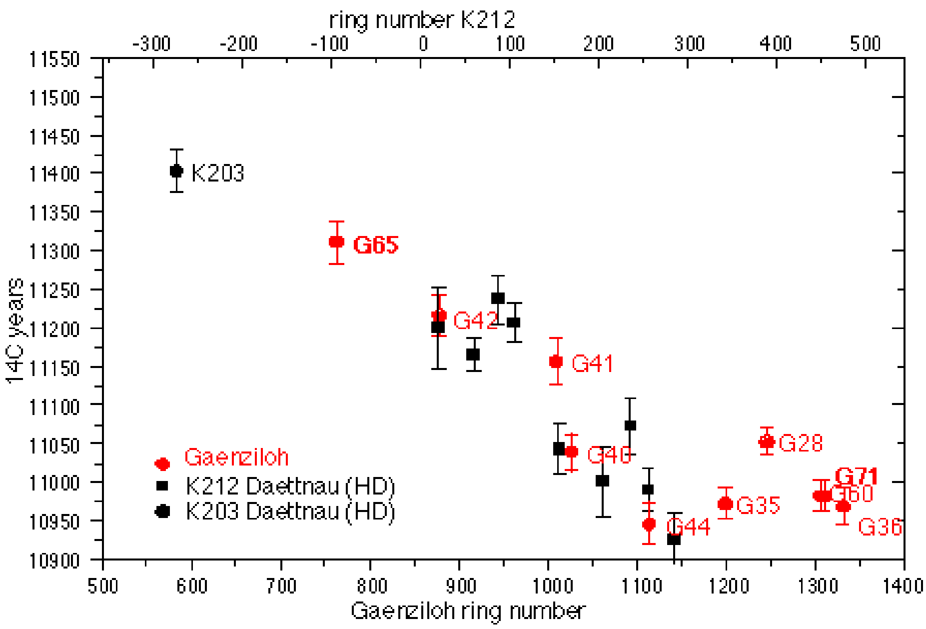

Fig. 4: The relationship between radiocarbon dates and relative tree-ring dates. Sample numbers appearing in bold typecast are also shown in Fig. 3.

Discussion

In our study, crossdating in some cases was impeded by (a) the occurrence of extreme growth disturbances in the series, and (b) insufficient overlap between the series. However, research in the area is still continuing, and the more samples we recover, the higher the chances are, that we will obtain samples that span chronological gaps. Due to the large number of trunks in the area, in addition we are able to restrict our sampling to those trees that are most useful for the development of long chronologies, i.e., trees whose growth patterns do not show extreme growth disturbances.

Growth disturbances mainly occur during the first 50 to 100 years of tree growth, when the tree is relatively young. By truncating the tree-ring series (i.e., by removing the first 50 to 100 annual values), the degree of crossdating should improve. This is the reason why we did not yet standardize the tree-ring sequences used in our study.

The fact that the studied tree-ring patterns show growth anomalies implies that rings may be missing. Undetected missing rings strongly affect the statistical results of crossdating efforts. We will have to solve this problem by analyzing more samples. In addition, we consider truncation of tree-ring curves prior to crossdating as a tool to determine missing rings.

Conclusions

Tree-ring chronologies have always been an extremly reliable high-resolution archive. Other annually resolved archives, such as Greenland ice (GRIP/GISP), marine varves and varves from freshwater lakes, rely on a few records only and therefore may have age-scale problems. Individual records from the same archive may differ considerably. Therefore, questions about the exact duration of (the cold phases within) the Bølling-Allerød interstadial, and of the Younger Dryas, can be answered best by analyzing tree-ring chronologies.

Events on a global or hemispheric scale, such as IACP, GS and LSE, cause distinct signals in all high-resolution archives, and therefore constitute important isochrones (Dansgaard et al. 1993, GRIP Members 1993, Taylor et al. 1993, Broecker 1994). These isochrones are an important tool for the calibration of varve, ice core and floating tree-ring records.

Summary

At the construction sites of the A4-highway tunnel through Uetliberg near Zurich, more than 100 buried subfossil pine stumps have been excavated. The trees were buried during their lifetime by loamy alluvia washed down from the upper part of the slopes. The stumps have remained well preserved for more than 13.000 years. The wood samples (cross sections of the trunks) were analyzed dendrochronologically. The radiocarbon method was used to determine their age. Five trees were used to build a new chronology, termed CHR65. CHR65 crossdates with two floating chronologies from Daettnau produced by Kaiser (1993), termed DAEALCH1 and DAEALCH2, and bridges the presumed gap between these chronologies.

CHR65, DAEALCH1 and DAEALCH2 were combined into chronology CHR213, which covers the main parts of the Allerød and ends at the transition to the Younger Dryas. Student's t-

values, percentages of parallel variation ('Gleichlaeufigkeit') and radiocarbon wiggle matching (^{14}C dates on a decadal scale) support the validity of the resulting chronology.
CHR213 contains climatic signals triggered by a series of cooling cycles such as the Inner Allerød Cold Phase (IACP), the Gerzensee deviation (GS), and perhaps the Laachersee eruption (LSE).

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A millennium-long temperature reconstruction for the Tien Shan Mountains, Kirghizia

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A millennium-long, low frequency juniper ring width chronology is presented for the Alai Range of the western Tien Shan in Kirghizia. The new chronology averages information from seven close-to-timberline sampling sites. Besides the centennial scale, a decadal scale Alai Range chronology is built, using standard dendrochronological techniques. We discuss some qualities of this record and point to the missing low frequency trends removed in the process of individual standardization. These are long-term negative trend in the first half of the past millennium and long-term positive trend since about AD 1800. The final centennial scale Alai Range reconstruction comprising these trends is an average of two differently standardized chronologies, both of which systematically biased, in their low frequency domains. It, nevertheless, represents a best estimate of long-term summer temperature variation, reflecting the Medieval Warm Period, the Little Ice Age, and a period of warming since about the middle of the 19th century.

Analyse der raumzeitlichen Variationen des Radialzuwachses von Fichten in Südwestdeutschland

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Während bei der Erforschung von Zuwachsvariationen von Waldbäumen und deren inneren und äußeren Ursachen bislang meist die Betrachtung der zeitlichen Variabilität im Vordergrund steht, erlaubt die zunehmende Verfügbarkeit von regionalisierten Daten und von neueren geostatistischen Methoden darüber hinaus auch eine Analyse der Variabilität in der räumlichen Dimension. Mit der kombinierten Auswertung räumlicher Variationsmuster und zeitlicher Entwicklungen der Wachstumsreaktionen von Fichten sowie relevanter Einflussfaktoren in einem multivariaten geostatistischen Ansatz wird das Ziel verfolgt, einen größtmöglichen Informationsgewinn aus der verfügbaren Datenbasis zu ziehen.

Für die hier vorgestellte Untersuchung werden Wachstumsdaten von Fichten (Picea abies L. Karst.) verwendet die im Rahmen der immissionsökologischen Waldzustandserfassung von der Forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg erhoben wurden. In die Auswertung fließen die Radialzuwachsdaten von mehr als 3.000 Untersuchungsbäumen ein, die in den Jahren 1983 und 1988 auf der Grundlage eines systematischen 4 km x 4 km Stichprobenrasters ausgewählt und stammanalytisch erfasst sowie ernährungskundlich untersucht wurden. Neben ernährungs- und standortkundlichen Informationen werden regionalisierte Daten zu Klima und Witterung (Deutscher Wetterdienst) sowie zu Stickstoffdepositionsraten in die Auswertungen einbezogen.Vor dem Hintergrund der verfügbaren Daten und der formulierten Forschungshypothesen wird ein kurzer Überblick über die in Frage kommenden geostatistischen Methoden gegeben und deren Potentiale und Limitierungen diskutiert. Anschließend werden erste Ergebnisse der Analyse der raumzeitlichen Variationen des Radialzuwachses von Fichten in Südwestdeutschland vorgestellt. Die Interpretation der Befunde wird durch eine kritische Diagnose und Validierung der entwickelten geostatistischen Modelle ergänzt.

Trendanalyse mit gemischten Modellen – Methodik, Software und Anwendung in der Dendroklimatologie

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Die Rekonstruktion von Umweltbedingungen in der Vergangenheit stützt sich u.a. auf lange Zeitreihen von Eichen-Jahrringbreiten. In der Dendroökologie werden die jährlichen Zuwächse je nach ehemaligem Standort der Bäume als Indikator für die damalige Temperatur, Feuchtigkeit, Insektenfraß und andere Ereignisse genutzt. Die Rekonstruktion wird vor allem dadurch erschwert, daß sich verschiedene Wachstumsfaktoren auf ähnliche Weise in den Jahrringen auswirken und sich die Wirkungen deshalb nicht ohne weiteres trennen lassen. Eine quantitative Analyse muss zunächst einmal bauminterne, physiologische Faktoren von baumübergreifenden Umweltfaktoren trennen, d.h. zwischen Zuwachsschwankungen unterscheiden, welche allein typisch sind für das Baumalter (dem „Alterstrend“) und solchen, die unabhängig vom Baumalter bei vielen Bäumen im gleichen Jahr auftreten, dem „Umweltsignal“. Mit herkömmlichen statistischen Modellen und Filtermethoden ist keine zufriedenstellende Schätzung des Umweltsignals möglich. Sie ist entweder durch die unzureichende Erfassung interner Faktoren verzerrt oder hat nach einer vollständigen Elimination baumindividueller Zuwachsschwankungen auch die langfristigen Komponenten des Umweltsignals verloren. Auch allgemeine lineare Modelle mit den Faktoren „Umwelteinfluss“ und „Alterstrend“ sind kaum geeignet, weil sie die Unterschiede zwischen den individuellen Trendverläufen nicht angemessen berücksichtigen können.

Deutlich bessere Ergebnisse versprechen Zeitreihenmodelle, welche beide Arten von Wirkungen simultan schätzen und dabei die stochastische Natur von Umweltsignal und Alterstrend berücksichtigen. Dabei werden das Signal als stochastischer Prozess und die Trends mit Hilfe gemischter Parameter (Konstanten und Zufallsvariablen) modelliert. Der Vortrag gab einen Überblick über die bislang eingesetzten Verfahren mit ihren Vor- und Nachteilen, stellte das neue Modell vor und zeigte, wie sich die unbekannten Variablen (Varianzen, Chronologie, Trendparameter u.a.) schätzen lassen. Weiterhin wurden Möglichkeiten und Grenzen verschiedener Software-Lösungen verglichen. Den Abschluss bildeten erste Ergebnisse für ein Datenbeispiel mit niedersächsischen Eichenreihen.

SECTION 4

ISOTOPES AND CLIMATE

Interrelations between climatic changes and northern and alpine Holocene pine-limit movements – deduced from stable-isotope signals of ^{14}C-dated subfossil pines (*Pinus sylvestris L.*) on the Kola Peninsula, northwestern Russia

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Introduction

This paper focusses on dendroclimatological investigations carried out in the tree-line region of the Kola Peninsula in northwestern Russia (Fig. 1). This region is located at the dividing line between northern Scandinavia[1] and the eastern European polar regions of Russia[2].

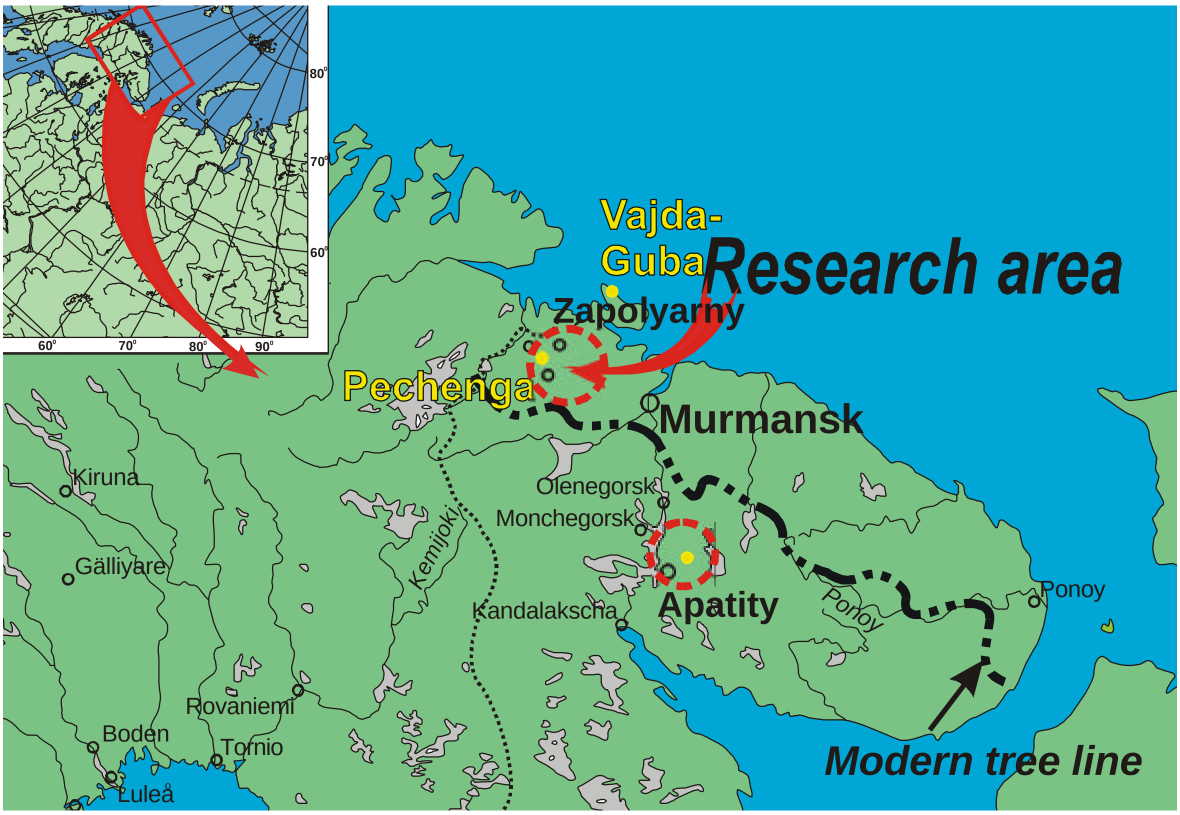

Figure 1: Map of northern Scandinavia showing the locations of the study areas (red) and the selected meteorological stations (yellow circles).

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[1] Northern Scandinavia has been the subject of both dendroclimatological and isotope-geochemical studies (e.g., Eronen 1979; Kullman 1995; Eronen *et al.* 1999 (dendroclimatology); Sonninen, Jungner, 1995; McCarrol, Pawellek, 2001 (isotopes)).
[2] This region so far has been only sporadically studied (e.g. MacDonald *et al.* 2000).

The area's climate is affected not only by the Gulf Stream and the North Atlantic, but also by the landmass of the Eurasian continent.

Study area

Our work took place in two areas of the Kola Peninsula (Fig. 1). The first area is located in the Khibiny low mountains in the central part of the Peninsula, ca. 400 kilometres South of Murmansk (ca. 67–68°N; c. 33–34°E). These mountains have a maximum height of about 1200 metres above sea level. The second area is located in the northern part of the Peninsula, near the border to Norway East of the town of Zapolyarny, in the tundra lowlands about 50 km beyond the modern occurrence of pines (> 69°N; approx. 31–32°E).

The climate on the Kola Peninsula is oceanic, with relatively mild winters and strong winds. The annual mean temperature is ca. –1°C, and rainfall up to 600 mm is characteristic for the area (Handbook for climate SSSR 1964; 1968). The strong influence of the sea is expressed in regional differences between the meteorological data. Near the coast of the Barents Sea, summer temperature is lower and winter temperature higher than in the interior of the peninsula. Thus the modern mean January temperatures at the Pechenga and Vaida-Guba meteorological stations are –10.9 and –5.5°C respectively, the mean July temperatures vary in the range of *c.* 12.8°C and 9.7°C, and annual precipitation is 575 and 690 mm respectively. The growing season is limited to the period between late May and late August.

Results and discussion

Khibiny low mountains. The data set of subfossil wood was collected at various sites in the eastern and western Khibiny mountains, in the area of the tundra zone located ca. 100–140 m above the modern pine tree line. At the current tree line, immediately below the sites of the subfossil finds, increment wood cores were taken from living Scots pines. Most of the subfossil wood that was studied consisted of pine species (Fig. 2, upper part).

The ^{14}C ages of the samples range from ca. 1400 to 300 years BP (Fig. 3). The majority of the subfossil pines date back to the period between 1000 and 800 years BP, corresponding to a calibrated age of about 1000–1300 AD. This period coincides with the Mediaeval Climatic Optimum, a warm phase of the Holocene that occurred in many parts of Europe. For this period, a tree line can be reconstructed that is at least 100–140 m higher than the current tree line. This phenomenon can be mainly attributed to the higher mean summer temperature between 1000 and 800 PB. Given the fact that we only found subfossil trunks of pine above the present-day pine forest, most likely the vegetation distribution in the Khibiny region has not changed since this optimum (Hiller et al., 2001).

Figure 2: Upper part: Subfossil pine log (c. 1000 ^{14}C years BP) at the site where it was found in the mountain tundra of Khibiny. The dead trees lying on the surface are gradually decomposing and will have disappeared within less than 2,000 years (Naurzbaev and Vaganov 2000). Lower part: This subfossil pine log (c. 5000 ^{14}C years BP) from the Zapolyarny region can easily be seen from the lake shore. We mostly found well-preserved logs and pine stumps in small, shallow lakes with a silty bottom.

The dendrochronological examination of the subfossil discs and the increment cores from living trees was carried out at the University of Hohenheim. It resulted in various modern tree-ring chronologies and one tree-ring chronology of about 600 years spanning the period AD 915–1508. The latter chronology could be synchronised with the pine tree-ring chronology from Finnish Lapland (Timonen, 1999). Results indicate that the ring widths of subfossil and modern pines closely resemble each other (r_{mean} >0.7), implying a climatic forcing of the signal.

Climatic parameters, which in part determine the characteristics of tree rings, were studied using $\delta^{13}C$ and $\delta^{18}O$ values of the latewood (LW) cellulose derived from five pine trees that were about 70 years old (Boettger et al., 2002). These values were compared to the temperature and precipitation data from the weather stations near the study area (Fig. 1). A significant correlation was found between the carbon-isotope values of cellulose of LW from living tree cores and the average temperatures for July and August, the end of the vegetation period ($r_{July/August} \approx 0.5$; n = 44). The carbon-isotope and oxygen-isotope values of individual tree rings from living and subfossil trees correlate well with each other ($r \approx 0.8$; n=93). According to Saurer (1997), in such a case the isotope ratios in the period of LW-formation probably are a function of moisture conditions. The short summer in Khibiny is a season with relatively little humidity. For the summer months, we found (a) a much less pronounced correlation between $\delta^{13}C$ values and precipitation amounts, and (b) a positive correlation between the carbon-isotope and oxygen-isotope values on the one hand and precipitation in the autumn and winter of the previous year (i.e., the time of snow accumulation) on the other hand. Although these studies are still underway, the climatic isotope signatures of the pines from these locations are already emerging.

The mean carbon-isotope content of the samples from the period of the Mediaeval Climatic Optimum was found to be significantly heavier than the mean content of living pines in the same region (Fig. 4). Distinct shifts in isotope values indicate higher temperatures and lower humidity, owing to reduced stomatal apertures and increasing evaporation fractionation in the source water. These results indicate a significantly warmer and probably also drier climate in mediaeval times than it is currently the case in the region of Khibiny or even in central Germany (by comparison, recent pines from the Leipzig region in central Germany have a mean $\delta^{13}C$ value of c. –25‰ vs. PDB).

The oxygen-isotope and hydrogen-isotope values of all subfossil and living samples from the Kola Peninsula fluctuate widely around their average values. This variability might be related to the air masses responsible for rainfall as they move across the region. If we assume that the source of the precipitation remained unchanged (i.e., the North Atlantic), marked differences must have occurred in its seasonal distribution during the 2nd millennium and even during the past few decades.

The results of the isotope studies together with the findings of the tree-line movements clearly and independently confirm that the Mediaeval Climatic Optimum (AD 1000-1300) was the most pronounced warm phase on the central Kola Peninsula in the last 1,500 years or so.

Northwestern section of the Kola Peninsula. A second collection of subfossil Scots pines was sampled in the northwestern part of the Kola Peninsula (> 69°N; approx. 31–32°E), in the small lakes in the modern tundra environment about 50 km North of the current forest border, East of the town of Zapolyarny (Fig. 2, lower part). Their dominant storage position – the crown part towards the lake shore and the root part embedded deeper in the lake gyttja – indicates that the trees were preserved *in situ*, and that the lake level at that time was lower than it is today. Sometimes we also found trunks embedded in the peat shore, about 1 m underneath the surface of the water, their crowns easily visible from the shore.

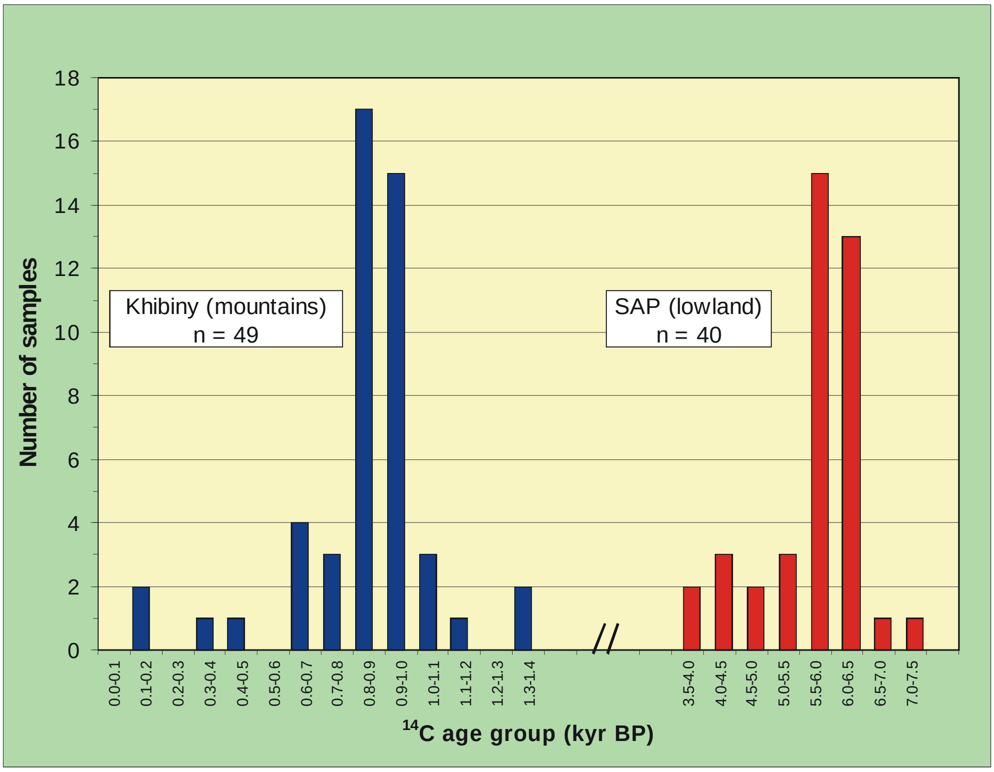

Figure 3: Age distribution of Khibiny and Zapolyarny subfossil pine woods.

Radiocarbon dating indicates that the trunks belonged to a pine forest that existed about 7,000 to 3,500 ^{14}C years ago (Fig. 3). The forest most likely reached its maximum size around 6,000 ^{14}C years ago. Based on comparisons with results from Finnish Lapland by Eronen (1979) and Eronen and Huttunen (1987), and on findings from the northeastern part of the Kola Peninsula published by MacDonald *et al.* (2000a), we conclude that the northern forest border first retreated in the East, during the Late Holocene temperature decline after ca, 4,000 ^{14}C years BP, and that it retreated later in the western part of the region. Nowadays this area is covered by tundra and characterized by a climate that gradually grows colder along the coast in an easterly direction.

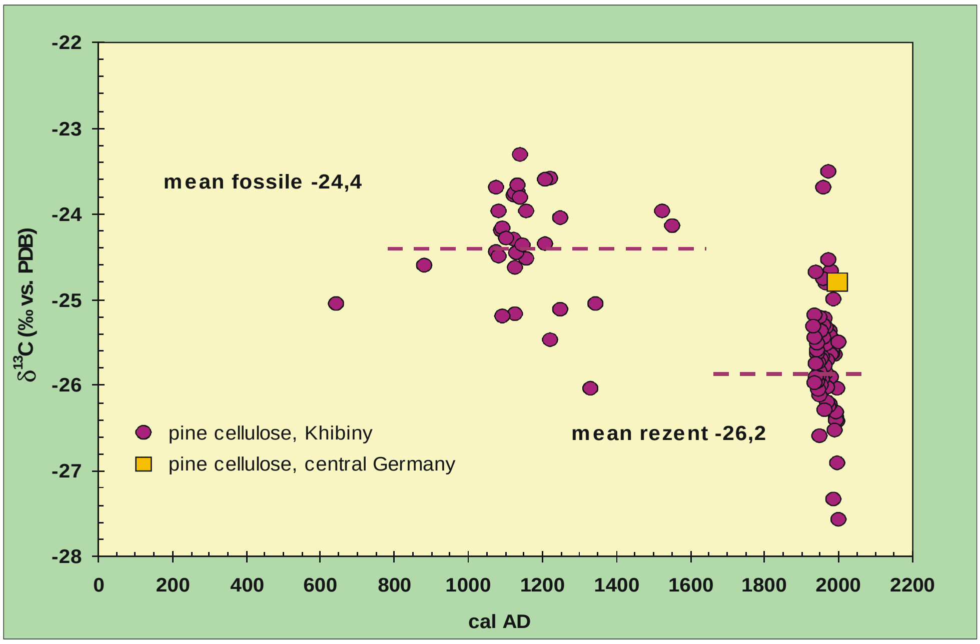

Figure 4: d[13]C values for cellulose from samples of living and dead Pinus sylvestris L. from the Khibiny low mountains in the central Kola Peninsula.

Our findings are supported by the results of the isotope studies on the material (Boettger *et al*., in press). On average, the mean δ^{13} C, δ^{18}O and δ^{2}H values of pine cellulose from the mid-Holocene are found to be ca. 1.1‰, 0.9‰ and 10‰ heavier than the values of living pines from the forest border in this region. This could well be explained by the higher temperatures and (simultaneously) reduced moisture supply at the studied sites during the mid-Holocene. Hence our results tally in suggesting that during the mid-Holocene, between ca. 7000 and 3500 ^{14}C years BP, the climate on the northwestern Kola Peninsula was warmer and drier than it is today. The mid-Holocene warm phase therefore must have been a general North-European climatic phenomenon, tied in with global climate.

Summary

1. The isotope signatures of pine cellulose in the studied areas of the Kola Peninsula are controlled by the climate.

2. a) The Mediaeval Climatic Optimum was the most pronounced warm phase on the Kola Peninsula in the last 1,500 years or so. During this interval, the alpine forest border in the Khibiny mountains was situated at least 100–140 metres higher than it is today. The vegetation distribution in the region has not essentially changed since this time.

b) During the mid-Holocene, the climate on the northwestern Kola Peninsula was warmer and drier than it is today.

c) These conclusions are unambiguously confirmed by the results of the isotope studies.

Hence the warm periods we found were not just a climatic phenomenon in central Europe, but also a general North-European climatic phenomenon, tied in with global climate.

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Oxygen isotopes in tree rings: do they really reflect temperature?

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Introduction

Because of isotopic fractionations in the hydrological cycle, there exists a relationship between temperature and the $\delta^{18}O$ of precipitation (Dansgaard 1964). The oxygen-isotope ratio $^{18}O/^{16}O$ therefore is a useful proxy parameter for climate. It is applied in particular in ice-core and sea-sediment studies. Because the isotope ratio in the cellulose of tree rings reflects that of precipitation (Burk & Stuiver 1981), it should also be well suited for tree-ring studies. Modern on-line pyrolysis systems enable the processing of a large number of samples (Werner *et al.* 1996), meaning that in the future this method may be used to build long oxygen-isotope chronologies for the purpose of reconstructing climate on the continents. However, it has to be kept in mind that the isotope ratio in precipitation and tree rings is determined by a large variety of factors and that as a consequence its climatic interpretation is not straightforward.

In this context, two main questions have to be addressed:

(1) What is the exact relationship between the isotope ratios of rainwater and temperature?

(2) What are the isotope fractionations during the trees' uptake and incorporation of the water?

Regarding the first question, one has to consider that the temporal oxygen-isotope variations in meteoric water are not simply determined by temperature, but also by the evaporative conditions over the oceans where the precipitation originated, as well as by the flow path of the moisture to a particular location on the continent. Therefore, changes in the oxygen-isotope ratio of precipitation may be caused by changes in the atmospheric circulation pattern.

Regarding the second question, one has to consider the transfer function between (a) the isotope ratio in the water taken up by the roots, and (b) the isotope ratio in the cellulose of the tree rings. The isotope ratio is modified in particular in the leaf, due to transpiration, and in biochemical steps during cellulose synthesis. Only part of these processes has been quantified, rendering it difficult to use isotope ratios for quantitative climate reconstructions. In addition, isotope-fractionation processes may be dependent on species and site conditions, meaning that calibration studies cannot be generalized, but have to be verified for different ecological situations.

In this paper, we present some results from research on this subject carried out at the Paul Scherrer Institute (Villigen, CH), and discuss the potential of oxygen-isotope analysis for temperature reconstruction.

Results and Discussion

We analysed tree-ring cellulose from three beech trees (*Fagus sylvatica*) growing at a relatively dry site in Switzerland (Saurer *et al.* 1997). The measurement series show a very synchronous signal, implying a small error of the mean curve (see the width of the band in Fig. 1, upper curve). There exists a significant correlation between the isotope variations and the average temperature of the months April,

May and June ($r=0.70$, $p<0.01$), especially between the lower-frequency variations (on a decadal scale; Fig. 1). The temperature coefficient for the correlation between δ^{18}O in tree rings and temperature is 0.33‰/°C, which is clearly lower than the coefficient for the correlation between δ^{18}O in precipitation and temperature (0.6‰/°C; Dansgaard 1964).

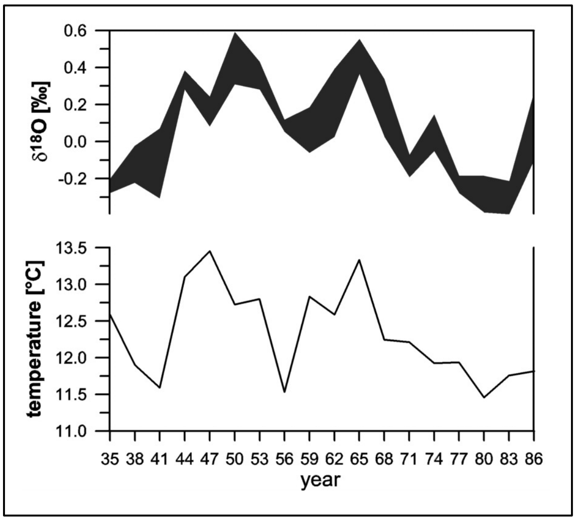

Figure 1: Upper curve: Mean d^{18}O-curve of cellulose of beech trees from a dry site in Switzerland for the period 1935 to 1986 (anomalies with standard deviation).
Lower curve: Mean temperature of the months April/May/June at the weather station Bern.

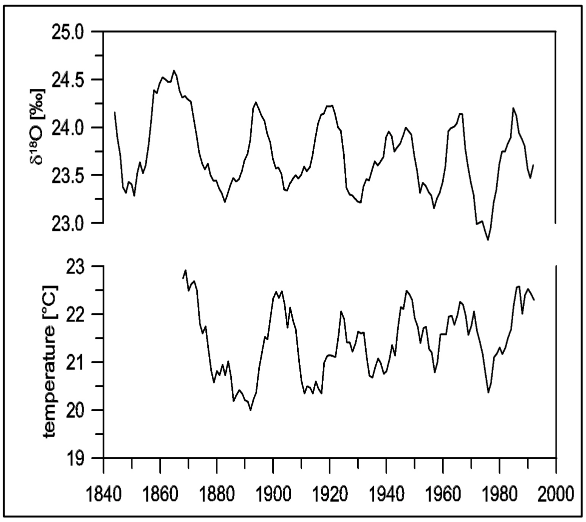

Figure 2: Upper curve: Late wood d^{18}O-chronology for Abies alba (10-yr running mean). Lower curve: July temperature at the weather station Bern (10-yr running mean).

This indicates that some of the variability in the isotope signal of precipitation was lost while the oxygen was incorporated in the wood.

In the study presented here, we did not separate earlywood (EW) and latewood (LW), but measured entire rings. This may explain why in this case δ^{18}O correlates best with temperature during a relatively early period of the growing season (May to June).

When LW would be analysed separately, however, one would expect the summer climate to be reflected in the isotope signal. This was confirmed by a second study in Switzerland, on silver fir (*Abies alba*, Saurer *et al.* 2000). Here, isotopes were found to correlate best with July temperature, although the correlation coefficient is rather low ($r=0.31$). This weak correlation appears to be at odds with the strong correlation that we found between summer precipitation and δ^{18}O in the tree rings of the same trees ($r=0.72$). However, the latter may simply mean that the isotope signal in precipitation was well recorded in the tree rings, but cannot solely be explained by temperature.

We estimated the lower-frequency variations using a 10-year running mean. In this manner, a quasi-periodic variation became apparent, characterized by a period of ca. 24 years (Fig. 2). This signal is related to temperature and to variations in precipitation and relative humidity. Given the fact that we found a significant correlation between the yearly NAO (North Atlantic Oscillation) index and the $\delta^{18}O$ in tree-ring series, this phenomenon may be explained by fluctuations in the large-scale atmospheric circulation over Europe and the North Atlantic.

A third study also suggests that oxygen-isotope variations can be explained by changing precipitation patterns (Saurer *et al.* 2002). In this study, focussed on Northern Eurasia and including sites from Norway to Siberia, we analysed $\delta^{18}O$ for the species *Picea*, *Pinus* and *Larix*. In the interior of the continent, the period 1961-90 shows lower tree-ring isotope values than the period 1861-90. This decreasing ^{18}O content over time is in contrast with the temperature increase observed at meteorological stations. The reason might be that during the last century winter precipitation increased in this area. Winter snowfall has a strongly negative isotope signature, which would have added to a more negative average $\delta^{18}O$ of the ground water that the trees were using. Based on simple mass-balance calculations, in this case we showed that changes in the seasonality of precipitation may indeed have affected the isotope values in the studied tree rings.

In conclusion, we have found strong evidence that tree rings faithfully record the isotopic composition of precipitation, and that this holds true relatively independent of tree species and site conditions. On the other hand, it has become clear that the isotope signal is not simply a function of summer temperature, but that changes in precipitation patterns, for instance regarding the flow path of the moisture or the seasonality of the precipitation amount, may be responsible for the observed isotope variations.

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d[13]C, d[18]O and tree ring widths as climate proxies in the Karakorum (Pakistan)

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Presently, millenia-legnth climate reconstructions with annual resolution are mostly based on tree ring width and density. There exist no studies on decadal and centennial climatic signals of stable isotopes in tree rings despite of many promising high frequency calibration results.
The aim of the project is the finding of recent and the reconstruction of past climate variations by using $\delta^{13}C$ and $\delta^{18}O$ of *juniperus spec*. in the Karakorum Mountains/Pakistan. The region is climatically situated at the interface between monsoon circulation and westerlies.
At four sites along horizontal and vertical gradients of temperature and precipitation relationships between $\delta^{13}C$, $\delta^{18}O$ (cellulose) and tree ring width as well as inter site correlations of the three parameters are investigated for the period AD 1900-1998. Site comparisons show a dependency of ring width records on ecological conditions. This correlation is reduced for the carbon records, and disappears for the oxygen records, i.e. the latter are highly similar regardless of site conditions. That points to the influence of an overregional external factor, which masks site dependent and plant physiological influences. First calibration results show high correlations of the oxygen records with winter precipitation.
At one cold and dry upper timberline site, millennia-length isotope records have been prepared. They show no individual age-trends, as they are known from tree ring width records. Therefore low frequency variations preserved in the raw measurements of our isotope records are more directly interpretable in relation to climate variability, especially when focussing on periods like the Mediaeval Warm Period and the transition to the Little Ice Age. On the other hand, atmospheric CO_2 changes due to anthropogenic influences starting at the beginning of the 19th century and masking low frequency climatic signals, hamper calibration calculations. Further investigations aim to combine the three tree ring parameters with their specific advantages to a detailed climate reconstruction including temperature *and* precipitation.

SECTION 5

ISOTOPES AND PLANT PHYSIOLOGY

Seasonal variations of stable carbon isotopes from tree-rings of *Quercus petraea*

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Introduction

Climate change is frequently accompanied by changes in seasonality, seasonal hazards and increased inter- and intra-annual variations. The ability to identify the causes of these alterations especially in the context of past regional climatic changes will help in the detection of future environmental developments. In addition the identification of characteristic patterns or cycles will assist modelers in assessing their predictions.

Many high-resolution climate proxy data are derived from tree rings (ring density, ring width, and isotopic composition of wood). However, based on our current understanding of tree-ring formation we are unable to deduce annual or season specific climate variables in order to provide comprehensive climate data for reconstructions at regional scales (Jones *et al.* 2001). A better understanding of tree-ring response to seasonal changes and, thus, to climate forcing is important for understanding the causes on past tree growth. Therefore, more work is currently required to better interpret the gained proxies (Briffa *et al.* 1998; Briffa & Osborn 1999).

In this respect, high resolution intra-annual isotope studies can help to elucidate the seasonal signal transfer in trees. These studies should greatly help in the construction of novel plant/climate/isotope models.

Recent intra-annual studies have revealed significant seasonal changes in the carbon and oxygen isotope composition (Schleser *et al.* 1999, Helle & Schleser in prep.).

Environmentally influenced stomatal activity, in combination with changes of enzymatic turnover, provokes fractionation shifts that are currently assumed to show up similarily in the corresponding tree-rings.

Provided the above reasoning is correct, a high intra-annual resolution should screen the weather conditions along the season experienced by the corresponding tree. Highest $\delta^{13}C$-values of the year should appear in wood formed during summer, when high temperatures, low air humidity and a high ground-water deficit lead to narrow stomatal apertures of the leaves. Whithin each ring, the earlywood (EW) and the end of the latewood (LW) should be characterized by the lowest $\delta^{13}C$-values.

Results and Discussion

Previously published data from investigations dealing with radial subsections of treerings in part reveal rather contradictory results (e.g. Wilson & Grinsted, 1977; Leavitt & Long, 1982, 1986, 1991; Kitagawa & Wada, 1993; Ogle & Mc Cormac, 1994; Loader *et al.* 1995).

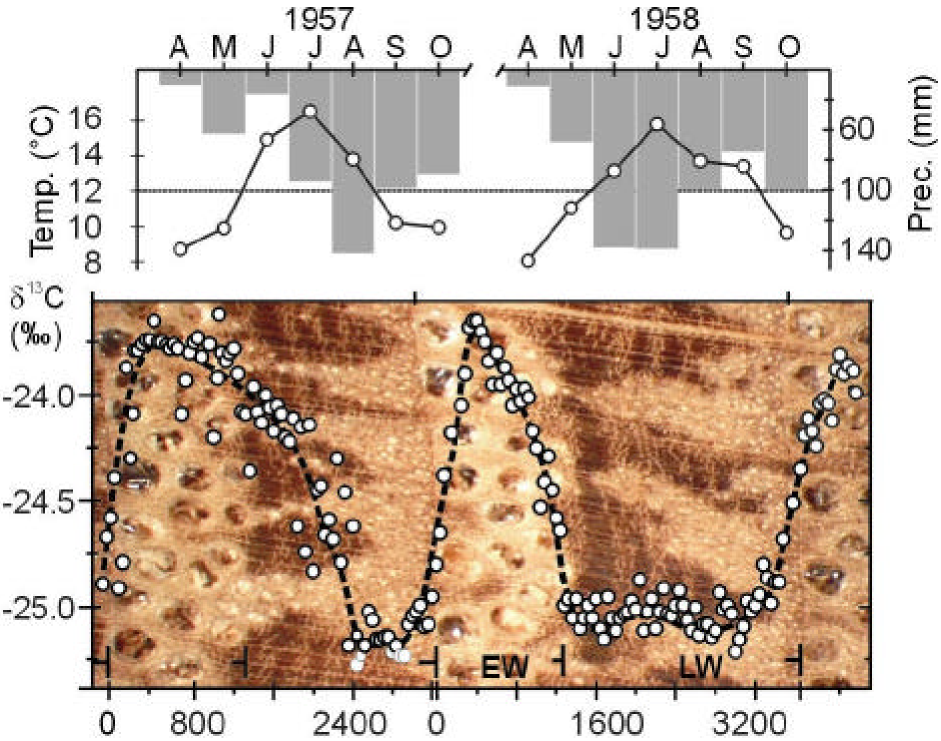

Fig. 1: Lower part: typical example of the seasonal tree-ring d13C pattern in two tree rings of oak (Quercus petraea) from N-Ireland. The tree rings were divided into slices of 40µm. Upper part: the corresponding monthly mean values of temperature (lines) and precipitation (bars).

However, many of these authors found systematic differences between EW and LW.

Detailed investigations of the intra-annual carbon isotope composition (Schleser *et al.* 1999, Helle & Schleser in prep.) revealed an overall pattern which is similar for all broad leaf species.

For this study, two tree rings of oak (Quercus petraea (Matt.) Liebl.) from Northern Ireland were subdivided into slices of 40µm thickness. Oak belongs to the group of deciduous trees with ring porous wood. Their EW formation starts before bud burst. It is completed before the leaves have fully expanded, i.e. before they become net exporters of assimilates (e.g. Pilcher 1995). Consequently EW has to incorporate carbon from previous years, accumulated as starch during summer and stored during winter. In contrast, coniferous tree species like e.g. *Pinus resinosa* or *P. banksiana* are known to produce almost the entire EW from current photosynthates (Dickmann & Kozlowski 1970, Glerum 1980)..

The results of our analysis, shown in Figure 1, constitute a typical example of the seasonal $\delta^{13}C$ pattern in the growth rings of broad-leaved trees. During the development of EW, $\delta^{13}C$ data rise to a maximum and subsequently fall to a minimum, which is reached in the LW section of a tree ring. At the end of LW formation $\delta^{13}C$ values start rising again. In contrast to the model predictions of carbon isotope fractionation during CO_2 fixation, highest $\delta^{13}C$ values always show up in the EW section and lowest $\delta^{13}C$ values are always found in the LW section.

The reasons for the observed $\delta^{13}C$ pattern in oak tree rings are quite complex, not only because tree-ring material partly originates from the previous years. In addition carbohydrates undergo a number of post-photosynthetic chemical modifications, which involve isotope fractionations.

In general, shifts of the stable carbon isotopes can occur due to carbon partitioning at metabolic branching points. The extent to which the carbon isotope composition shifts, depends on pool size and flux rates into the different metabolic directions.

In this respect, it is important to note that previous years starch material is not necessarily isotopically labelled by the climate signal of its formation period. It rather exhibits a general enrichment of ^{13}C as compared to far less polymerised sugars (Gleixner *et al.* 1993). Consequently, the incorporation of starch-derived ^{13}C-enriched carbon can result in the observed isotopically heavier EW.

The rising ^{13}C enrichment of EW in the period of fast growth at the beginning of the vegetation period might also be a consequence of the decreasing amount of available sugar reserves in conjunction with a ^{13}C enrichment of these reserves. Isotopically "lighter" molecules are turned over faster and removed from the sugar pool by formation of EW and CO_2 respiration, leading to an enrichment of the remaining sugars.

Bud burst and EW formation are accompanied by the highest respiration rates of the year in order to meet the energy requirements of the tree during this period of fast growth.

The intense carbon-isotope partitioning between anabolic and catabolic metabolism can lead to a further ^{13}C enrichment of EW, since "heavier" sugar molecules are preferentially used for polymerization of cellulose, whereas "lighter" molecules are preferred in secondary metabolism, leading to ^{13}C-depleted stem-respired CO_2, and secondary plant products (e.g. lignin) (Schmidt & Gleixner 1998).

The $\delta^{13}C$ decline of late EW and early LW results from the increasing incorporation of currently produced assimilates. As soon as the leaves become net exporters of photosynthates, the sugar pool in the stem will be replenished. Simultaneously the sugar pool will be isotopically diluted by assimilates with $\delta^{13}C$ signals from recent leaf-isotope fractionation processes, driven by the ambient environmental conditions.

Along with the increasing accumulation of starch during the summer months, changes in carbon-isotope partitioning take place between growth and storage. This probably leads to ^{13}C-enriched starch and therefore ^{13}C-depleted wood.

Effects from CO_2 respiration might play a minor role, since much of the CO_2 released is re-fixed by photosynthesis.

The increase in $\delta^{13}C$ of late LW can be assigned to changes in the carbohydrate metabolism going along with leaf senescence in autumn.

Therefore, not only the isotope composition of EW but also that of LW is influenced by non-climatic, post-photosynthetic tree-internal processes, all of which have to be considered.

In addition, annual ring growth is a nonlinear process, which makes it difficult to assign intra-annual $\delta^{13}C$ values to specific dates or weather events. The ability of a tree-ring to integrate environmental information depends on the longevity of its cells, which is, among other factors, species dependent.

Nevertheless, the $\delta^{13}C$ pattern in tree rings of oak exhibits different peculiarities, which can be attributed to certain weather situations along the vegetation period. In Figure1, the radial carbon-isotope distribution of the years 1957 and 1958 is compared to monthly means of temperature and the amount of precipitation.

The months of June and July of 1957 were particularly dry and warm. Following the model constraints for carbon-isotope fractionation during photosynthesis, the tree responded with narrow stomatal apertures and, therefore, the produced assimilates show a relatively high ^{13}C content. This also caused a fairly slow decline of $\delta^{13}C$ across the latewood. I The $\delta^{13}C$ values for 1958 fall immediately to a minimum at the beginning of latewood development, showing no significant ^{13}C variations further on. Indeed, the weather conditions during the summer months of the year 1958 varied little, especially precipitation, obviously causing no isotopic variations. Presumably water supply and temperature conditions just varied within the optimum range of tree growth, inducing no stress to the tree.

Conclusions

Carbon-isotope signals in tree rings are not direct proxies for changing meteorological variables encountered in the vicinity of trees. The present knowledge about carbohydrate partitioning during the transfer of photosynthates into tree rings is poor. In addition the fractionations involved in the seasonal interplay of major tree-physiological processes, such as accumulation and remobilization of storage material, varying stem respiration and build-up of tree-rings, are not known in detail. Therefore, their quantification is difficult to accomplish. The complexity of these processes presently prevents the establishment of a clear linkage of weather events to associated intra-annual isotope signals.

Only through a more complete knowledge of the factors controlling plant-physiological processes (e.g., respiration vs. photosynthesis, transitory storage, re-mobilization, length of dormancy), we may be able to better understand seasonal control and signal preservation.

The greater operating expenses of isotope work as compared to the costs of ring-width and ring-density investigations could well pay off in the future, because isotope studies bear the potential of improving the knowledge about tree-physiological processes. They could help to improve the understanding of growth in relation to climate. So far dendroclimatologists have treated the system as a “black box”, applying statistical methods that, although effective, mostly disregard direct plant-physiological processes. In future, a combination of plant-physiological and dendroclimatological methods could open up new opportunities for a more realistic approach. The tree-ring climate archive may then provide unique information on local to regional scales about the impacts of global change in regions that are sensitive to this change.

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The influence of temperature and relative humidity on d^{13}C values of C_3 plants in growth chamber experiments

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Experimental setting and methods

Three different C_3 plant species (*Vicia faba* var. *minor* cv. Fribo, *Eucalyptus globulus* and *Brassica oleracea* var. *medullosa* cv. Grüner Ring) were cultivated under controlled conditions in four growth chambers at the phytotron facility at the GSF (Research Centre for Environment and Health) in Neuherberg (for description of the chambers see Payer et al. 1993). The experimental setting consisted of seven climatic conditions that differed in relative humidity and/ or temperature. The experiments were carried out in two series including the repetition of one climatic condition. Other climatic parameters than relative humidity and temperature (e.g. irrigation and radiation) were kept identical in all chambers.

CO_2 concentrations in each chamber were regularly controlled and air samples were taken for δ^{13}C-analyses. Both CO_2 concentration and δ^{13}C values of the air did not differ significantly between any of the chambers.

The plants were set to the growth chambers immediately after germination and further cultivated there for 56 days. After that period the plant material was harvested for isotopic analyses of dry organic matter (δ^{13}C), cellulose nitrate (δ^{13}C, δ^{2}H) and plant water (δ^{18}O, δ^{2}H). Here only results from δ^{13}C analyses of cellulose nitrate are discussed. Cellulose nitrate was prepared from dried stem material using standard methods (Epstein et al. 1976). Cellulose nitrate was combusted in vacuo in glass tubes in the presence of copper and copper oxide and the resulting gases were separated cryogenically in a preparation line (Stichler et al. 1982). The purified CO_2 was trapped in an ampoule and isotope ratios were determined with an IR-mass spectrometer (Delta-S, Finnigan MAT, Germany). The analytical error including the preparation of cellulose nitrate was 0.1‰ (one standard deviation).

Results and discussion

The δ^{13}C values of cellulose nitrate extracted from the stems differed by up to 4.7‰ (*Brassica*) between plants grown under different climatic conditions. The experiment clearly demonstrated that both temperature and relative humidity had an influence on the stable carbon isotope ratios of the C_3 plants. All examined species showed a similar δ^{13}C response: the most negative isotope values were observed within the plants cultivated under high relative humidity and high temperature (climate conditions 3 and 2 in Table 1), the most positive δ^{13}C values within those grown under cold and dry conditions (conditions 6, 5 and 4/8).

Table 1. The d13C values of cellulose nitrate extracted from stems of the species cultivated in the experiments under the given climate conditions.

"Climate condition"	Temperature in °C	Rel. humidity in %	$\delta^{13}C$ *Brassica* in ‰	$\delta^{13}C$ *Eucalyptus* in ‰	$\delta^{13}C$ *Vicia* in ‰	
1	24	49	-30.04 ± 0.51	-29,50 ± 0,36	-28,12	±
2	24	68	-31.64 ± 0.73	-30,78 ± 0,24	-28,43	±
3	30	48	-32.30 ± 0.27	-30,35 ± 0,36	-29,83	±
4	18	32	-28.38 ± 0.52	-28,86 ± 0,48	-25,13	±
5	24	21	-27.95 ± 1.24	-28,11 ± 0,61	-25,62	±
6	14	24	-26.93 ± 1.13	-28,45 ± 0,10	-26,11	±
7	14	50	-28.37 ± 0.43	-28,80 ± 0,41	-26,86	±
8	18	32	-27.87 ± 0.72	-27,91 ± 0,38	-25,68	±

Three climatic conditions had identical temperature (24°C) but differing relative humidity (climate conditions 1,2,5), three other conditions had almost the same relative humidity (~50%) but different temperatures (climate conditions 1,3,7). The $\delta^{13}C$ values were approximately linearly correlated with temperature as well as with relative humidity (see Fig. 1 and 2). Both increasing temperature and increasing relative humidity resulted in decreasing $\delta^{13}C$ values. The negative correlation coefficients between $\delta^{13}C$ values and temperature found in the experiment are in contrast to a variety of field studies, in which positive correlations with temperature were observed, but are in agreement with various experimental results (see e.g. review of Schleser et al. 1999). The discrepancy with field studies may be explained by the intercorrelations of climate parameters under natural conditions. The $\delta^{13}C$ signal in plant material is a composite signal that reflects humidity and temperature conditions as well as water availability and radiation status

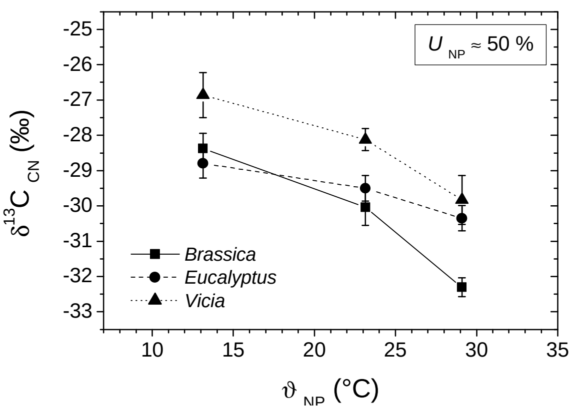

Fig. 1: d13C values of stem cellulose nitrate of plants cultivated under the same relative humidity (~50%) but with different temperature (mean values of five individuals and standard deviation of the mean for each data point).

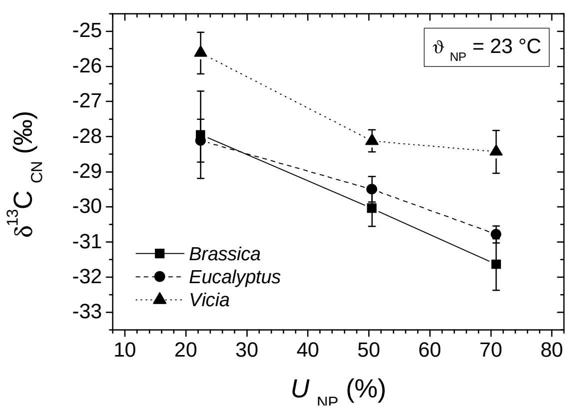

Fig. 2. d13C values of stem cellulose nitrate of plants cultivated under the same temperature (23°C) but with different relative humidity (mean values of five individuals and standard deviation for each data point).

The climate mode and the "$\delta^{13}C$ sensitivity" to each of these parameters should determine the $\delta^{13}C$ value in the end. An example of the effect of water availability on the $\delta^{13}C$ values of plants is provided by an experiment with *Vicia faba* carried out by Lipp et al. (1997). The plants were cultivated under two different irrigation levels with other climatic parameters being identical. In that experiment the plants with drought stress had 1.5 to 3.0‰ more positive $\delta^{13}C$ values than those supplied with high irrigation (Mayr et al. in press).

Relative humidity and temperature are generally negatively correlated with each other in Middle European summer climate. Provided that full-grown trees have similar $\delta^{13}C$ responses to relative humidity and temperature as the plants used in the experiment, both parameters should weaken or even cancel each other out in their influence on $\delta^{13}C$ values. This may explain, why $\delta^{13}C$ values of tree rings are often best correlated with another climate parameter, namely with summer precipitation sum, especially at relatively dry Mid-European sites (Saurer et al. 1995, Mayr et al. in press).

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SECTION 6

DENDROECOLOGY

Dendroecological investigations on mountain bog pine (*Pinus rotundata* Link) in a peat bog in southwestern Germany

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Abstract

Increment cores of 200 mountain bog pines (*Pinus rotundata* Link) were collected in five sample plots along a hydrological gradient in a peat bog in Upper Swabia, Southwest Germany. The aim of the study is a dendroecological characterization of mountain bog pine growing on sites showing different qualities to provide a better understanding of environmental signals enclosed in fossil wood of bog pines excavated in archaeological sites. Beside ring width, wood anatomical features like traumatic tissue, intraannual density fluctuations, compression wood and the occurrence of tangential resin ducts were registered. Traumatic tissue more frequently occurs at the moistest site which carries an open stand of bog pine, while other wood anatomical features do not reveal any pronounced differences among the sites. Cumulated growth rates calculated from ring-width measurements are smallest at the moistest site and largest at the driest site, but do not differ markedly at the three intermediate sites. A combination of signal-to-noise ratio (SNR), mean sensitivity (MS) and mean correlation (MCor) also reveals a clear separation of the trees growing at the driest and moistest sites, respectively. Future studies will search for a climatological interpretation of wood anatomical anomalies and pointer years derived from ring-width chronologies.

Introduction

In the course of intensive archaeological explorations in peat bogs in southwestern Germany (Federseeried close to Bad Buchau, Upper Swabia), huge numbers of subfossil logs of mountain bog pine (*Pinus rotundata* Link) dating from middle and late bronze age times were excavated (Huber and Holdheide 1942; Billamboz 1992, 1996, 2002). Between 1570 and 1510 B.C., the tree-ring chronologies of mountain bog pine and other tree species from moist sites show synchronously occurring periodic growth reductions. These growth reductions mark a phase between two settlement periods of the so called „Siedlung Forschner" and were interpreted as a climatic period of a rising peat bog water level (Billamboz 2002). Since today, however, only few dendroecological studies have been carried out on mountain bog pine (Freléchoux *et al.* 2000) which might partly be caused by the fact that the species and its natural habitats are under nature conservation.

Growth habitats of mountain bog pine (*Pinus rotundata* Link) in southwestern Germany are confined to marginal areas of acidic, oligotrophic ombrogeneous peat bogs. The species is a weak light competitor (Schmid *et al.* 1995) and is superseded by spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) or birch (*Betula pubescens*) under less extremely wet or oligotrophic conditions. Within peat bogs, *Pinus rotundata* occurs in several plant sociological units which differ in respect of their hydrological conditions (Wagner and Wagner 1996).

The present study investigates changes in growth reactions of mountain bog pine in dependency of a hydrological gradient from the drier margins to the very moist centre of a peat bog. On the other hand it shall be tested, if indications for different ecological site qualities can be derived from anatomical or dendroecological characteristics in the wood of *Pinus rotundata*. The results aim to provide a data basis for a better ecological and palaeoclimatological interpretation of the abundant subfossil material.

Study site and material

The study site „Pfrunger Ried“ is located northwest of the town of Wilhelmsdorf (Upper Swabia) at 47°54'15''N/ 9°20'00''E in 610m a.s.l. Five sampling plots (A to E) were established along a hydrological gradient which can be reproduced with the help of the species composition of the understory. Within the plots, all trees were levelled precisely and two tree-ring samples per tree were collected by the use of an increment corer. The size of the sampling plots and the respective number of collected trees are given in Table 1.

Table 1: Characterization of the sampling plots

sampling plot	**A**	**B**	**C**	**D**	**E**
size in m^2	490	250	220	270	186
number of trees sampled: *Pinus rotundata* *Pinus sylvestris*	 24 12	 52	 40	 39	 45
No. of undatable samples	0	6	3	6	3

Plot A is located close to the edge of a former peat cutting area and represents the relatively driest site of the transect. Beside *Pinus rotundata*, *Pinus sylvestris* occurs and points to the dominance of competing species if conditions would get even drier. The understory is dominated by dwarf shrubs like *Vaccinium myrtillus* and *Vaccinium uliginosum*. In plots B to E, mountain bog pine is the only tree species. By means of plant sociology, plot B can be classified as Vaccinio uliginosi-Pinetum rotundatae rich in dwarf shrubs, plots C and D belong to a variant of the Pino mugo-Sphagnetum rich in *Eriophorum vaginatum* and plot E to the variant of the Pino mugo-Sphagnetum with *Sphagnum spp*. dominating (after Wagner and Wagner 1996). Whereas *Pinus rotundata* predominantly forms upright stems in plots A to C, growth forms in plots D and E become more stunted associated with a decreasing stocking rate.

Methods

All increment cores were cut with razor blades and contrasted with chalk. Ring width was measured with a precision of 0.01 mm using the measurement system LINTAB II. During measurement, the occurrence of wood anatomical peculiarities like traumatic tissue, density fluctuations, tangential resin ducts, and compression wood, was registered. The cumulated increment for the tree population of each plot was calculated by averaging all raw measurement curves when dated to a common pith date of 1. In case of the pith was not hit by the borer, the number of missing rings to the pith was estimated by the average ring width and the curvature of the innermost rings of the core. For an ecological characterization of the local chronologies of plots A to F, the signal-to-noise ratio (Wigley et al. 1984) and the mean correlation among the individual curves of each plot were calculated as a measure of the homogeneity of the growth signal. The mean sensitivity of the local chronologies is used here as an indicator of the average variability of the chronologies, not as a measure of their quality or their dendroclimatological potential. Variance was calculated as an alternative parameter, but basically produced the same results. Before these calculations were carried out, the biological age trend was removed from the ring width curves using the software ARSTAN. Wherever applicable, a linear age trend was removed from the raw measurements, otherwise a cubic smoothing spline with a length of 67% of the individual ring-width series length was chosen.

Results

Figure 1 summarizes the occurrence of anatomical anomalies in the wood of *Pinus rotundata* along the five sampling plots. Time series of the detected anomalies and their possible climatological triggering factors will be discussed more extensively elsewhere. The trees in plot A, showing slender and upright growth forms and growing under increased competition pressure, show the least percentage of compression wood and traumatic growth rings, which are predominantly interpreted as a consequence of severe frost events.

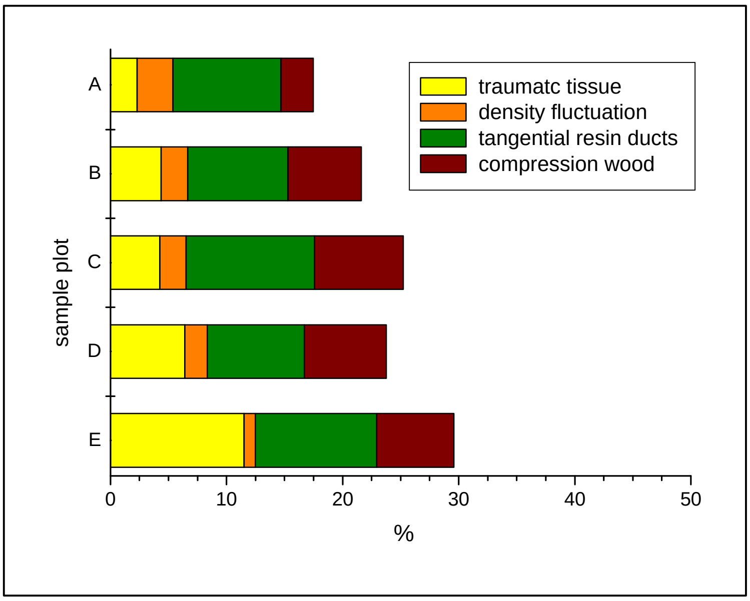

Figure 1: Percentage of wood anatomical anomalies in tree-ring samples on plots A to E

In contrast, a slightly increased occurrence of density fluctuations was found on plot A, whereas the lowest number of density fluctuations was registered at the moistest site E. At drought-sensitive sites, a close correlation was found between density fluctuations in different pine species and early summer drought (Villalba and Veblen 1996; Bräuning 1999; Wimmer et al. 2000). In spruce, however, Schweingruber (1980) found a close relationship between the formation of intraannual density fluctuations and low temperatures during the summer months, which seems to be a more plausible explanation for the site under consideration. The highest percentage of traumatic tissue in tree rings was found at site E, which might point to an increased endangerment to frost damage in the open tree stand without the equalising microclimate of a closed canopy. The occurrence of tangential resin ducts and compression wood does not exhibit significant differences among the sampling plots.

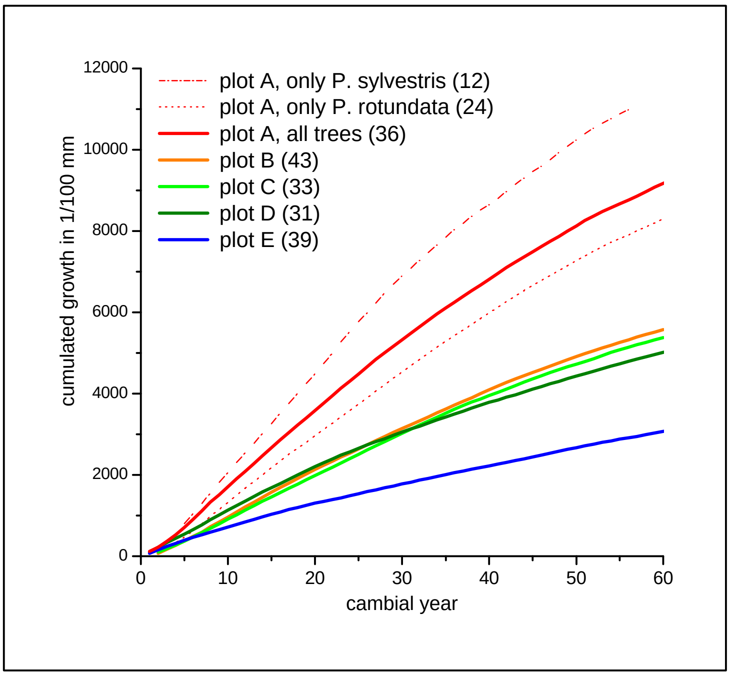

Figure 2: Cumulated growth on sample plots A to E. Numbers in parenthesis give the number of investigated trees per plot.

In figure 2, the cumulated growth curves for all plots are shown. For plot A, the growth curves for mountain bog pine and Scots pine are also presented separately. At all sites, a biological age trend is only weakly developed. At the drier sites, however, there is a slightly more pronounced decrease in growth rates with increasing tree age. The driest (A) and moistest plot (E) experience above and below average growth rates. Plots B, C and D, however, do not show any difference in growth rates. At plot A, growth rates of *Pinus sylvestris* are markedly higher than that of *Pinus rotundata*, which points to a beginning displacement of mountain bog pine by more vigorous competitors. Increasing growth rates of mountain bog pine related to falling ground water levels paralleled by an increase in interspecific competition was also found in peat bogs in the southern Black Forest (Schmid *et al.* 1995).

Several statistical parameters were tested for their usefulness for an ecological differentiation between the sampling plots. A combination of signal-to-noise ratio (SNR); mean sensitivity (MS) and mean correlation (MCor) turned out to be appropriate to reveal differences in growth behaviour. Although the values of SNR and MS are influenced by the sample depth (Briffa and Jones 1990), replication during the common interval of calculation seems sufficiently high at all sites to allow a comparison of the results.

The two extreme sites A and E clearly contrast with the other sampling plots (Fig. 3). Whereas the relatively dry site A is characterized by a low SNR and a slightly higher MS, the moistest site E depicts high SNR and MCor and a low MS, respectively. The three less extreme sites B to D can not be distinguished clearly by means of statistical parameters.

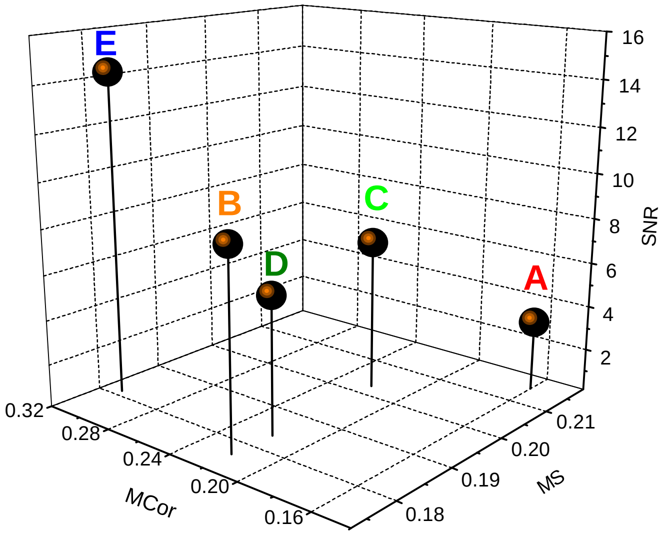

Figure 3: Combination of different statistical tree-ring parameters for an ecological characterization of the local chronologies A to E. In plot A, only Pinus rotundata is considered. SNR = signal-to-noise ratio; MS = mean sensitivity; MCor = mean correlation of all trees within a sampling plot.

Discussion

For a dendroecological characterization of *Pinus rotundata* on sampling plots along a hydrological gradient the frequency of tree rings showing traumatic tissue, the cumulated growth rate and a combination of the parameters SNR, MS and MCor turned out to be useful. However, only the extremely wet and dry sites differ significantly, less extreme sites can not be differentiated by the use of the parameters mentioned. Further studies shall be carried out to depict the relationship between pointer years in the ring width chronologies (Schweingruber *et al.* 1990; Cropper 1979), the occurrence of certain wood anatomical anomalies, like traumatic tissue and intraannual density fluctuations and the triggering climatic factors. After doing so, a more far-reaching dendroecological classification of sites B to D and a climatological verification of the findings for the extreme sites A and E can hopefully be carried out.

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How did 'bog oaks' grow?
First answers from the excavation of a mire woodland in Ypenburg, The Netherlands

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Background

Sub-fossil 'bog' oaks that grew in former mire woodlands are the main source of datable prehistoric tree-ring patterns (Leuschner 1992). They may serve as an archive to reconstruct natural variations in past climate (Baillie 1996, Leuschner *et al.*, in press). Until now the exact environmental conditions in which the oaks grew (species composition, succession, tree density, the response to hydrology and climate) is largely unknown. The detailed excavation of prehistoric woodland sites will provide information about the development, structure, and dynamics of oak supporting mire woodlands.

Research strategy

The following disciplines are involved:

- Dendrochronology: The absolute dating of (bog) oak stems provides knowledge about the period when oaks were part of the mire woodland;
- Wood anatomy: Determination of wooden species in different peat layers enables the reconstruction of forest succession;
- Palynology: Pollen analysis provides information about changes in species composition (forest succession) at the spot and in the surrounding area;
- Micromorphology: Chemical and physical soil characteristics are analysed to trace peat development, phases of decomposition (dry conditions) and inundation.

Site history

Ypenburg is located in the western part of the Netherlands only a few miles away from the current coastline. Approximately 6000 years ago the area consisted of floodplains with occasional sand dunes, where early settlers found excellent living conditions (Koot 2001). Research on waste pits shows a varied diet consisting of birds, cattle, fish and aquatic mammals. Between approx. 3800 BC and 2750 BC sand deposits cut off the floodplain from the sea and peat formation started (Beets *et al.* 1994; Clevinga 2000). At that time the human occupants abandoned the area.

Excavation of a mire woodland

In four excavation trenches, which slightly differ in height a.s.l., all wooden remains have been registered *in situ* for the purpose of enabling the reconstruction of the former position of the trees (fig. 1). Wood samples were taken for species determination and dendrochronological analysis. Peat samples were taken for pollen analysis, C^{14}-dating, micromorphology and to look for botanical macro remains (leaves, seeds).

Fig. 1: Excavation trench

Results

C^{14}-analysis and Palynology

C^{14} analysis showed that peat formation started between 3350 and 2900 BC. It turned into a raised bog after 2150 to 1750 BC. The development of the vegetation (especially trees) at the beginning of the peat formation until the switch to a raised bog is studied by pollen analysis (palynology). At first, primarily reed marshlands developed. Willow (*Salix spp.)* and buckthorn (*Rhamnus frangula*) were the first tree species that entered the reed vegetation. When alder (*Alnus spp.*), oak (*Quercus spp.*), ash (*Fraxinus spp.*) and birch (*Betula spp*.) appeared, the formation of an open mire woodland started, which later turned into a dense woodland dominated by alder. Pollen and seed records indicate that the last phase of the woodland can be characterised as an open birch forest. Subsequently a raised bog developed with heather (*Ericales*) and myrtle (*Myrica gale*) (Kooistra *et al.*, in prep.).

Determination of wood species

In total nearly 500 samples were determined. As expected, willow, alder, birch, and oak are the most frequent species. Interesting differences in species composition occur between the four trenches (fig. 2): trench 32, the lowest (a.s.l.) and thus wettest location, shows a high percentage of willow. The higher the trenches are situated, the more the share of oak increases.

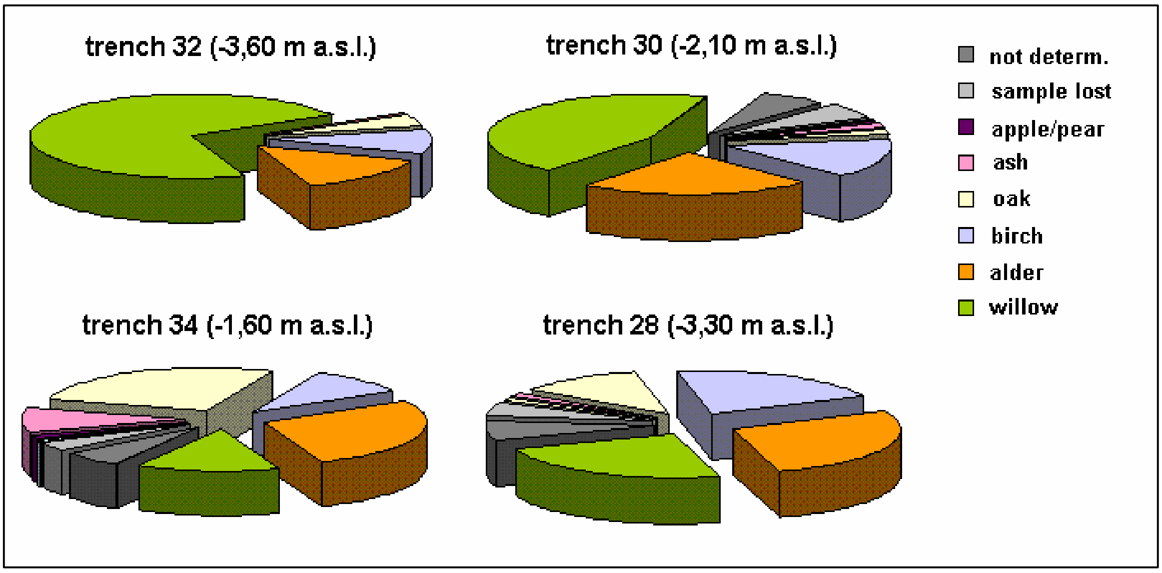

Figure 2: Species distribution in the four excavation trenches

Dendrochronological results

Suitable species for dendrochronological dating are oak (*Quercus spp.*) and ash (*Fraxinus spp.*); attempts with willow (*Salix spp.*), birch (*Betula spp.*) and alder (*Alnus spp.*) failed. Finally, twelve oaks from the excavation trenches were dated. Additional dates are achieved from 51 oaks that were collected outside the trenches (fig.3).

The results show that the oaks reached a mean age of 155 years; the oldest tree got 303 years old. A mean tree-ring width of 1.44 mm indicates that the oaks were not growing as slow as it is known for bog oaks from other locations. Moreover they lack the typical bog-oak pattern showing long-lasting growth depressions. The oaks grew (and were preserved!) in the period between 3030 BC and 2533 BC. The temporal distribution of the dated oak stems indicates no obvious periods of tree germination or die back.

Conclusions

In the prehistoric woodland of Ypenburg we found oaks growing along with other species which can normally be found in mire woodlands, i.e., willow, alder, ash, and birch. The oaks were preferably growing on somewhat higher and dryer locations. However, the oaks do not show any indication that they suffered from (temporarily) high or low ground-water levels. There are no distinct changes in their population dynamics (germination/die back) that may point to sudden changes in for instance site hydrology.

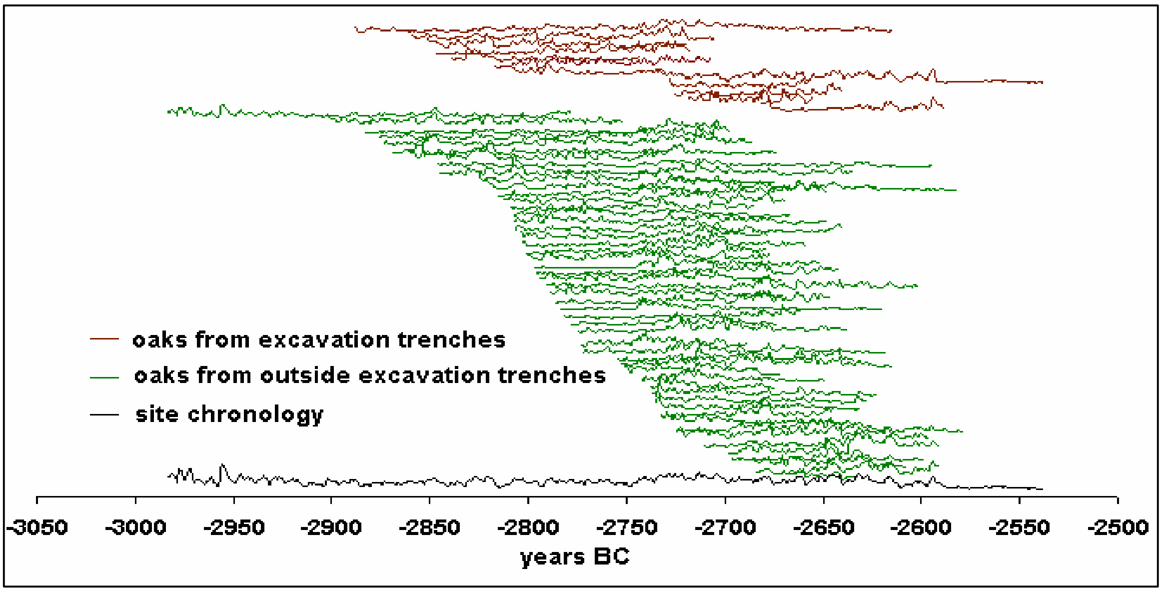

Figure 3: Tree-ring series from 12 oaks excavated from trenches 34 and 8, with site chronology. The tree-ring series lack the typical bog-oak pattern with long-lasting depressions

Future perspectives

The dendrochronological and wood-anatomical results will be supplemented with data from micromorphology. Combined with results from another excavation realised in Zwolle, Overijssel, it will be possible to evaluate hydrology as a growth-limiting factor for oaks in mire woodlands and to identify the ecological conditions that determine the development and conservation of oak supporting mire woodlands.

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Fluctuations in subalpine tree-ring records from sites located along a dendroecological transect in Northern Patagonia

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Introduction

Due to their great altitudinal range mountain systems display climatic regimes similar to those of widely separated latitudinal belts within short horizontal distances. Along such pronounced environmental gradients, the subalpine altitudinal belt, including tree- and timberline, inheres a key position in high mountain ecosystems by forming the highly climate-sensitive transition zone between the closed mountain forest and the periglacial (subnival) and nival belts. Thus, trees growing in these environments comprise excellent palaeoenvironmental records. The first studies on these topic were realized in the northern hemisphere, whereas the southern hemisphere has lagged greatly behind (Boninsegna and Villalba 1996). A substantial increase in the number of tree-ring chronologies from South America took place in the 1990s. More than 90 chronologies were recently developed from collections of *Nothofagus pumilio*, the dominant subalpine tree in the Andes of Chile and Argentina (c. 35°35' to 55°S) (Villalba et al. 2001). Nevertheless, fluctuations in radial growth in a dendroecological context, i.e. considering the entire ecological range of the distribution of the species from dry to moist environments have not been analysed yet. The present study is a first attempt to do so.

Material & methods

In the Northern Patagonian Andes, *Nothofagus pumilio* (lenga), is the dominant subalpine species, ranging from its lower distribution limit at elevations around 1100m asl up to the upper treeline in about 1800m asl.

In order to assess fluctuations in the radial growth along the steep precipitation gradient from the steppe in the east towards the Valdivian Rainforest in the west of the Andes, fourteen *N. pumilio* tree-ring chronologies have been developed (Figure 1), applying a strict sampling strategy across the northern Patagonian Andes at 41°S. It systematically followed

a) an E-W transect from dry to moist environments and
b) altitudinal gradients located along this transect.

The dendroecological network resulting from intensive sampling using increment borers encompasses fourteen sites located along five altitudinal gradients between the lower, xeric timber line in the east and the upper, humid tree line in the west. All samples were dried, mounted and surfaced. In a following step the tree rings were counted, crossdated and measured

Chronologies were built using standard methods commonly used in dendrochronology: COFECHA (Holmes 1983) and 'Gleichläufigkeit' (Huber 1952) provided quality control of crossdating, while ARSTAN (Cook 1985) was used for chronology construction. For frequency analysis of the dendroecological network, the power spectrum analysis PSA (Blackman & Tukey 1958) was applied to each site-chronology.

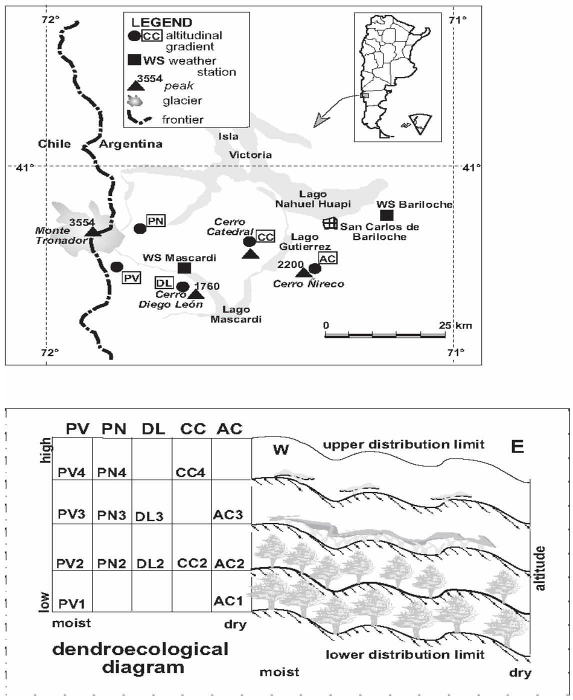

Figure 1: Location map and characteristics of N. pumilio sites sampled over a transect from the dry east to the moist west along five altitudinal gradients limited by the upper and lower distribution boundaries of this species. Sites are arranged in the dendro-ecological diagram according to their ecological characteristics.

Results

Analysis of the fluctuations in radial growth of *N. pumilio* along the entire ecological range of the species revealed the peaks of the Blackman-Tukey spectrum shown Table 1:

*Table 1: Significant peaks of the Blackman-Tukey spectrum for all sites of the transect. * significant at the 95%-level, ** at the 99%-level.*

site	period > 7yr	period < 7yr (high frequency)	altitudinal gradient
AC1	30.7* 11.4*	5.1* 3.0* 2.44** 2.40** 2.1*	
AC2	11.8* 10.6*	3.6** 3.5** 2.9*	dry
AC3	22.06*		
CC2	11.8*	3.5*	↓
CC4	29.6*	4.0* 3.7**	
DL2	24.9* 11.2*	5.7** 3.8* 3.7** 3.3* 2.4* 2.3**	
DL3		3.2*	
PN2	10.2*	2.7* 2.63** 2.58** 2.03* 2.0*	
PN3		3.1* 2.9* 2.0**	
PN4		3.4** 3.1** 2.5* 2.4*	
PV1	10.0* 7.7*		
PV2	10.1* 8.7* 8.1*	2.65* 2.60*	moist
PV3	13.4* 11.1*	2.4*	
PV4		4.9* 3.5*	

It is clearly shown that radial growth of *N. pumilio* shows different significant fluctuations along the dendroecological transect. Dry sites at low and intermediate elevations show the most consistent pattern in the appearance of a cycle around 11-yrs which may be attributed to the 11-yr sunspot cycle. Towards moist environments, this signal is no longer apparent in the tree-ring records. The appearance of short-term fluctuations is inhomogeneous along the transect and may reflect site-specific factors like fruiting cycles, etc.

Discussion

According to the results obtained in this study, *Nothofagus pumilio* records environmental fluctuations of different frequency depending on the site conditions. Thus, the complexity of the high mountain environment is reflected in its growth rings. Hence, care should be taken about site selection for developing chronologies which may be considered as representative for the whole region. Dry sites of low to intermediate elevations might be useful to record the 11-yr sunspot cycle.

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A Late-Glacial forest in the lignite mine of Reichwalde – An interdisciplinary project

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Since 1997 the „Landesamt für Archäologie Sachsen“ has been excavating a vast and very well conserved Late-Glacial pine and birch forest (c 14.000 YBP) in an open-cast lignite mine in Reichwalde (Oberlausitz, Saxony). Its discovery led to an interdisciplinary research project for the reconstruction of the climate, vegetation and landscape of Oberlausitz in the Late-Glacial, in which ecophysiologists, geologists, isotope researchers, archaeologists, palynologists, vegetation historians and dendrochronologists collaborate. In this poster we present some dendrochronological aspects and the future aims of the project. In some parts of the moor, increasing water levels have resulted in the ideal environment for good preservation of wood. Since the Late-Glacial forest is situated in an area predestined for winning lignite, it was possible to excavate these sites on a large scale. This provided us with more than 2000 samples, which enhances the relevance of the dendro-ecological research. Based on the data of the trees already examined, we found that 87% of the pines were less than 110 years old and that only a few attained an age of 150 years or more. This is the typical age structure for regularly disturbed forests, e.g. fire-dominated forests, which implies that it has been frequently rejuvenated by fires. When we examine the anatomical features of the wood, we often find sudden decreases in tree-ring width, which can indicate a raise of the ground-water level. A combination of charcoal rests, overgrowing callous tissue, a decrease in tree-ring width and missing rings is known as a fire scar. Based on this feature, we made a local fire chronology (fig.1). Fire-events of 24 synchronized pines are marked with arrows. This chronology could not yet be fit onto the pine chronology of Central Europe, because the influence of the fires has been more important for tree growth than climate influence. However, age verification was achieved through 14 C-analysis (11890 ± 31 BP). The fire frequency of c 10-20 years is remarkably high.

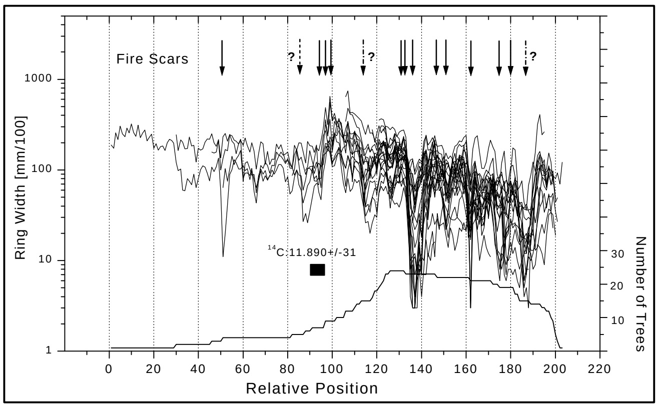

Figure 1: Late-glacial fire-chronology of the Reichwalde-Forest

In the next few years, the goals of this project are:
Reconstruction of structure and composition of the late-glacial woods including their undergrowth (shrubs and herbs).
Highly resolved climate reconstruction of the Late-Glacial in the Oberlausitz region by multiproxy data (palaeo-geography, stabile isotopes, tree-ring width, pollen, botanical macrorests, modelling of the tree growth)
Landscape and sedentation history and their connection as a model for the Oberlausitz
Testing recent ecophysiological relationships in other climate circumstances (late-glacial), in an era of high climate-fluctuation.
Extension of the tree-ring-chronology and the tree-ring based ^{14}C-calibration in late-glacial

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SECTION 7

FOREST DYNAMICS AT THE TIMBERLINE

The Potential Timberline:
Determination with dendrochronological methods

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Introduction

Polar and alpine timberlines have often been used as study sites for global change research (for references see Innes 1991, Holtmeier 1995, 2000). Special emphasis was given to climatically induced dynamics in the timberline ecotone (Szeicz & MacDonald 1995, Scott et al. 1997, Jacoby et al. 1998, MacDonald et al. 1998a, b; Eronen et al. 1999, Gervais & MacDonald 2000). Present-day timberlines are often not in balance with the modern climatic conditions because of human impact like reindeer herding at northern timberlines or alpine pasturing in the European Alps (Holtmeier 2000). Therefore, studies that refer to recent climate driven timberline dynamics have to contribute to the problem, that the potential climatic limit of the forest may be much higher than the actual timberline. Thus, this paper focuses on the determination of the timberline-altitude that is possible under present climatic conditions, called the 'potential timberline' (Holtmeier 2000).

Photo 1: View northward over the study site on the north-west facing slope of the Piz da Staz. Red line: Northeast facing border of the study site. October 1998

Study site

The methods for determining the potential timberline will be discussed on the basis of data from the Upper Engadine, Central Alps, Switzerland. The study site (photo 1) is located on the northwest facing slope of the Piz da Staz. The timberline was lowered to 2200 m a.s.l., mainly by alpine pasturing. Alpine pastures were used frequently up to the 1950s. Occasional use occurred until the 1970s. In the timberline ecotone between 2200 - 2400 m a.s.l., microclimatic conditions are influenced by the locally varying microtopography. Swiss stone pine (*Pinus cembra* L.) and European larch *(Larix decidua* Mill.), that dominate the subalpine forest (*Larici-Pinetum cembrae*) (Keller et al. 1998) also form the timberline.

Methods

For the determination of the potential timberline two central questions have to be answered:

1. Does a certain threshold of stem number per area of juvenile growth in a given altitude guarantee reforestation?
2. Does apical or terminal growth of the juvenile growth in a given altitude guarantee reforestation?

At the potential timberline, a sufficient stem number per area is required to ensure a minimum density of the stand to form a forest. If apical growth of the juvenile trees is insufficient, they will turn into stunted instead of erect growth forms. Thus, both criteria are relevant, so that stem density and apical growth rates have to be analysed.

Tree distribution was mapped for Swiss stone pine and larch for every tree higher than 2 m. For smaller trees (0,4 - 2 m high), stem density was mapped on the basis of a 10 x 10 m grid for a sample area of 150 x 400 m. Spatial interpolation (IDW - Inverse Distance Weighted) (Philip & Watson 1982, Watson & Philip 1985) was calculated using a geographic information system (Arc View). Dendrochronological samples were taken from 500 trees. Trees that were too small for the use of a conventional increment corer (5 mm diameter) were sampled with an increment puncher (Forster et al. 2000). In order to determine the exact age of the trees, the samples were taken as close as possible to the root collar. Ring width was measured with an accuracy of 0,01 mm with LINTAB and TSAP (Rinntech, Heidelberg). The growth curves were synchronized by the use of pointer years (Schweingruber 1996) and the so called "Datierungsindex" (Schmidt 1987). Frost ring analysis was done according to Glerum et al. (1966). Mean yearly apical growth was calculated as the ratio of tree height and tree age, mean yearly number of frost rings as the ratio of the total number of frost rings per tree and tree age.

Results

The distribution of larch and Swiss stone pine at timberline displays an altitudinal gradient, which is concealed by the strong influence of microrelief (Figs. 1 - 2). Stem density of both species generally declines with increasing altitude. Swiss stone pine and also larch are mainly found at exposed sites. Trees higher than 2 m are only found up to about 2300 m a.s.l., whereas smaller trees are also present at higher elevations up to 2400 m a.s.l..

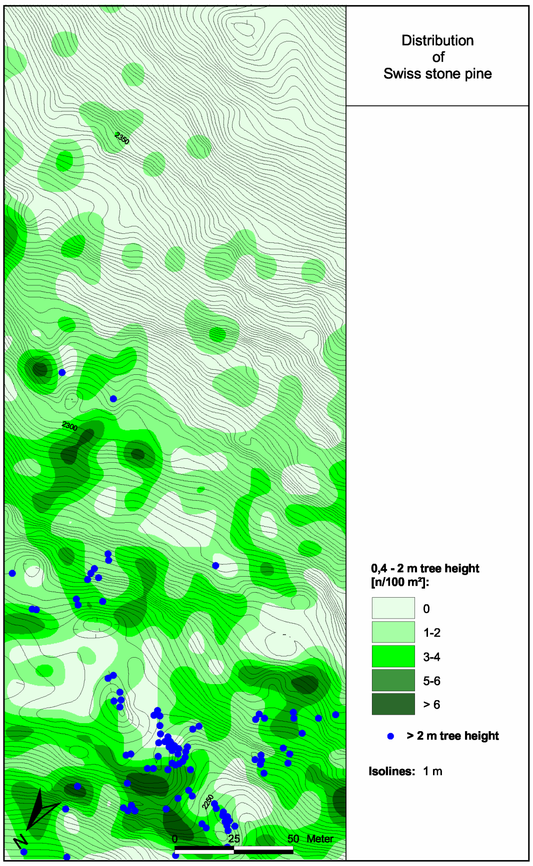

Figure 1: Distribution of Swiss stone pine on the study site (from Müterthies 2000, modified)

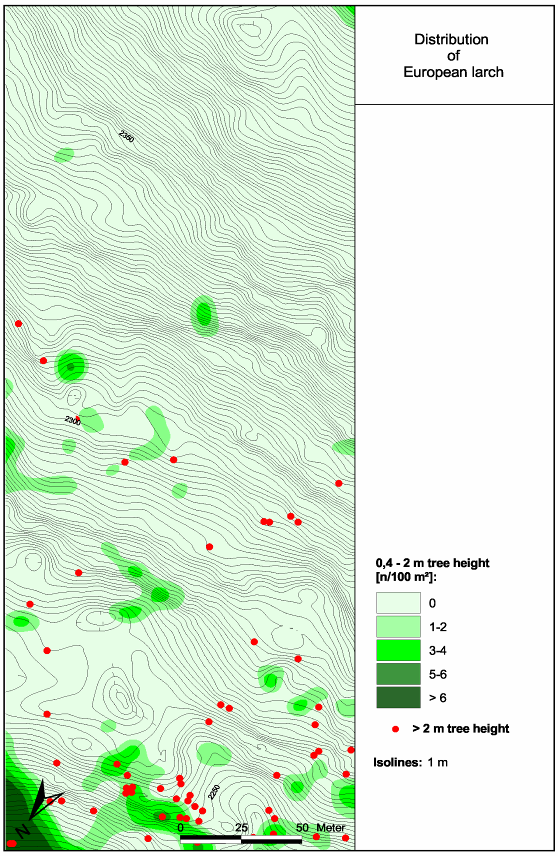

Figure 2: Distribution of European larch on the study site (from Müterthies 2000, modified)

The apical growth rates of Swiss stone pine and larch are increasing with age at elevations up to 2300 m a.s.l. (Fig. 3). Trees at higher elevations show a reduction of apical growth with increasing age from about 3 cm/a to less than 1 cm/a, which is contradictory to the normal age trend. Beside this altitudinal effect, a high variability of apical growth of trees of the same age can be observed for both tree species.

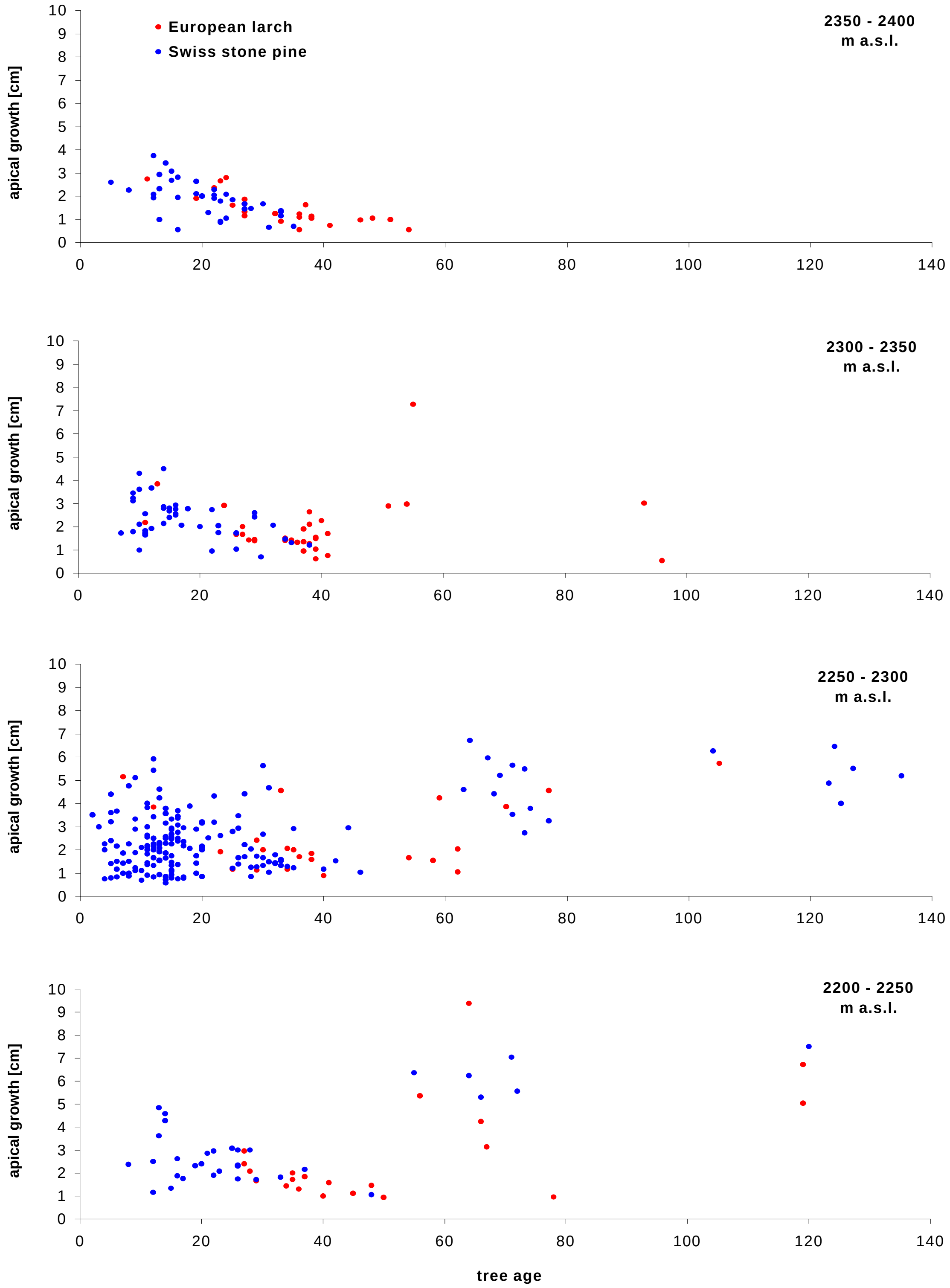

Figure 3: Mean yearly apical growth of Swiss stone pine and European larch in relation to tree age and altitude

An altitudinal differentiation can also be observed for the occurrence of frost rings in Swiss stone pine and larch (fig. 4). Both tree species are more frequently damaged by frost at higher elevations. The mean yearly number of frost rings of Swiss stone pine increases from 0,02 frost rings per year at 2250 m a.s.l. to 0,15 frost rings per year at 2400 m a.s.l.. A similar trend can be observed for larch. At 2250 m a.s.l., 0,02 frost rings per year can be found. This number increases to 0,13 frost rings per year at 2400 m a.s.l.. Beside this general trend it has to be mentioned that above 2350 m a.s.l. all Swiss stone pines and above 2300 m a.s.l. all larches, show frost damage, whereas at lower altitudes some trees show no frost rings at all.

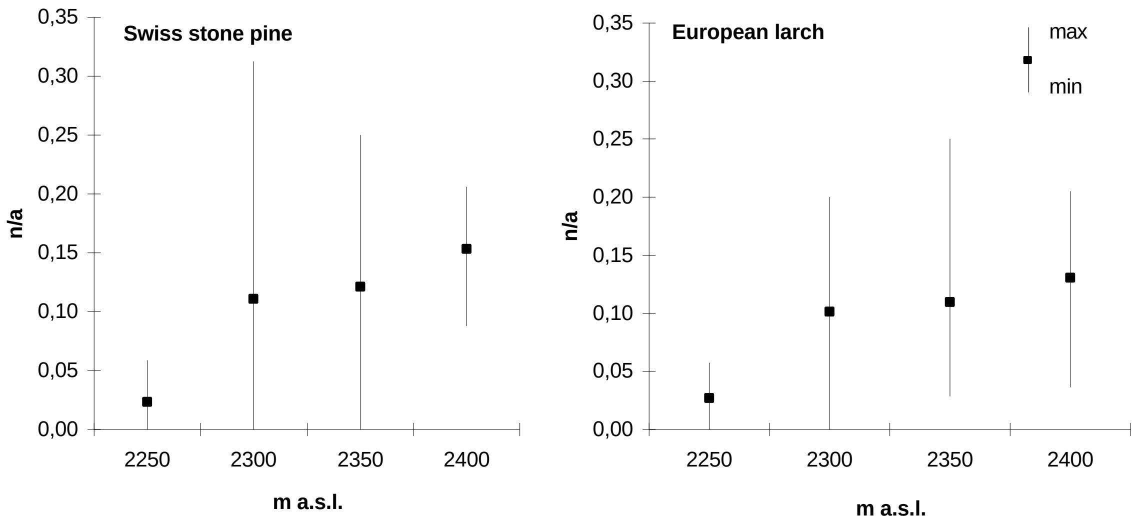

Fig. 4: Frost rings in Swiss stone pine and European larch in relation to altitude

Discussion

From the results of the frost ring analysis it can be concluded that frost damage of timberline trees (for references see Tranquillini 1979, Sakai et al 1987, Holtmeier 2000) increases with elevation. Consequently, the decreasing height growth of timberline trees (Tranquillini 1968, Schönenberger et al. 1995, Senn et al. 2001), might be attributed not only to lower temperatures in general, but also to a higher frequency of frost damage. While smaller trees, which enjoy warmer microclimate close to the ground and protection against frost damage by snow cover, grow well even at 2400 m a.s.l., mean yearly apical growth gradually declines as tree height increases, because the terminal shoot is exposed to the rough conditions of the free atmosphere (Holtmeier 2000, Müterthies 2002). Frequent frost damage at the terminal shoot leads to stunted growth forms like table trees, which are often found at the uppermost boundary of the timberline ecotone (Holtmeier 1974, Holtmeier 2000, Müterthies 2002).

Even though juvenile growth occurs up to 2400 m a.s.l., the results of the growth analysis clearly show that apical growth is insufficient for reforestation above 2300 m a.s.l. . Thus, the potential timberline can be expected at 2300 m a.s.l. (Müterthies 2002). The results of the growth analysis show, that the uppermost occurrence of regeneration at 2400 m a.s.l. is not identical with the potential timberline at 2300 m a.s.l. In conclusion, the position of the actual potential climatic timberline can not be determined by simply mapping the highest occurrence of juvenile trees.

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Growth conditions at the upper and lower forest limits in the mountain-forest steppe of Northwest Mongolia

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Introduction

The mountains surrounding the Uvs Nuur basin in northwest Mongolia are characterised by larch woodland, which exists within the altitudinal range of the mountain-woodland steppe. This woodland area constitutes the most southerly extension of the Light Siberian Taiga. Within the zonal semiarid steppe climate, these larch forests are exclusively found on north-facing slopes, while the remaining areas are occupied by mountain steppe vegetation. This distribution is mainly due to differences in exposure to solar radiation. On north-facing slopes, the reduced radiation input results in thermal, hygric and edaphic site conditions that favour forest growth. In areas sloping towards the Uvs Nuur basin, the forests are limited to the zone between 1700m (lower limit) and 2400m (upper limit) a.s.l.

Material and methods

Observations focused on six main study areas comprising a total of 25 sites in the Turgen-Kharkhiraa and Khan Khökhiyn mountains that encompass the Uvs Nuur Basin in the Northwest of Mongolia (Fig. 1). A total of 1200 samples (stem cores and cross-sections) were collected. Dendrochronological and dendroecological methods were used to record the tree ring width, age structure, and growing behaviour, and to assess the role of climatic influences, as described comprehensively by Fritts (1976) and Schweingruber (1983). Tree-ring curves were determined for each stand on the basis of 30 selected tree cores or cross-sections. Monthly air temperature and precipitation data for correlation with tree-ring curves are available from the meteorological stations of Ulaangom at 939m a.s.l. and Baruunturuum at 1232m a.s.l., with records beginning in 1952 and 1961, respectively. Their distance from the study sites is 20 and 40 km, respectively.

In addition, temperature and precipitation were recorded at eight data-logger locations in June to September 1997-1999 along a transect that extended from the basin to the watershed (Krüger *et al.* 2001) (fig.1). By using regression equations determined from the continuous data-logger records, it was possible to extrapolate the temperature and precipitation data of the meteorological stations for the lower and upper forest limit. Soil temperatures were recorded at 5 - 30cm depths at several sites between the lower and upper forest limit for the period of one year (1997).

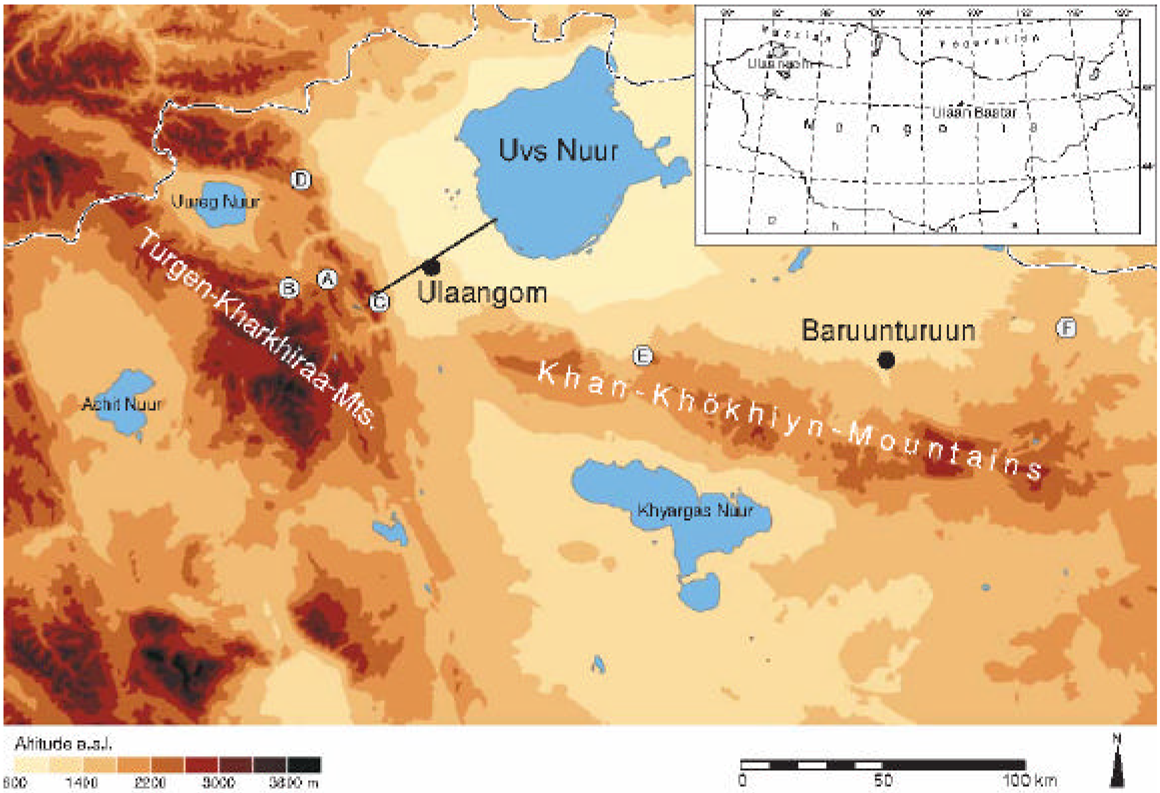

Figure 1: Map of the study area showing the location of the six areas (A-F) that provide the focus for this study and the transect of data-logger measurements.

Results

According to the climatic data measured in the years 1998 and 1999, the average temperature for the months of June - August is 15°C at the lower forest limit (1700m a.s.l.) and decreases to 11°C at the upper forest limit. Summer precipitation (June - September), however, increases from 105mm to 145mm from lower to upper forest limit. Precipitation measurements carried out in the interior mountain region in 1997/98 confirm this trend.

The tree-ring curves of sites near and at the upper forest limit are significantly and positively correlated with temperature and precipitation, although the correlation between tree-ring width and temperature is higher than between tree-ring width and precipitation (fig. 2). It could thus be deduced that low air temperatures thermally control the upper forest limit. Mid June to mid August soil temperatures at 10 cm depth, however, are 1 - 2 K higher at the upper forest limit than at the lower forest limit.

This suggests that average air and soil temperatures play a less important role as limiting factors than extreme events, such as late frosts, that prevent a further expansion of larch to higher altitudes. Such late frosts are proved by soil temperature records and the existence of frost rings that occur in the same years throughout the study area (fig. 3). These frost rings are predominantly present in the first 20 growth rings of the trees. It can thus be inferred that only young trees are susceptible to frost damage. Trees that have survived these late frosts presently form the stands at the upper tree limit. It is conceivable that, favourable temperature and moisture conditions presumed (in particular rising temperatures), the absence of late frosts for long periods could lead to a shift of the tree line to higher elevations.

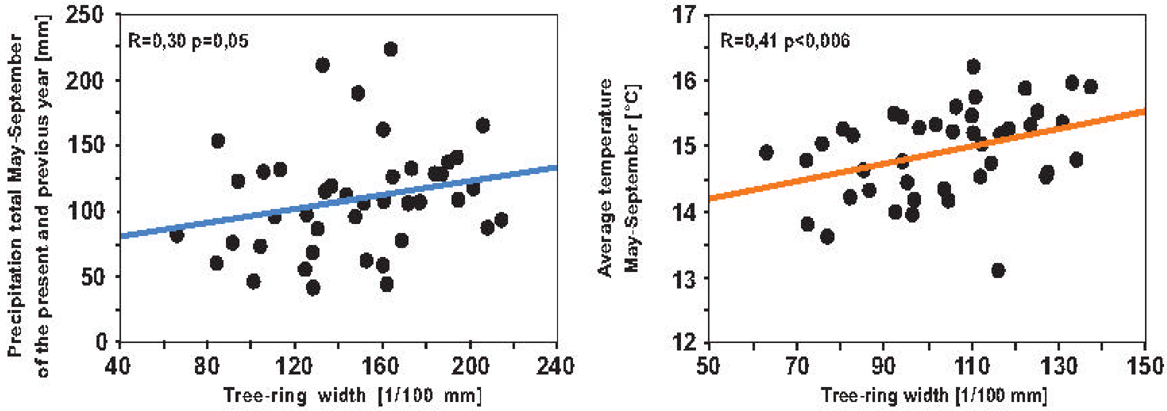

Figure 2: Correlation diagrams for locations near the upper forest limit (2300-2400m a.s.l.) for the time period 1950-1995: (left) correlation between tree ring width and total precipitation for the months May-September of the present and previous year, (right) correlation between tree ring width and average temperature of the months May-September. R = Spearmann's Rank Correlation, p = significance level

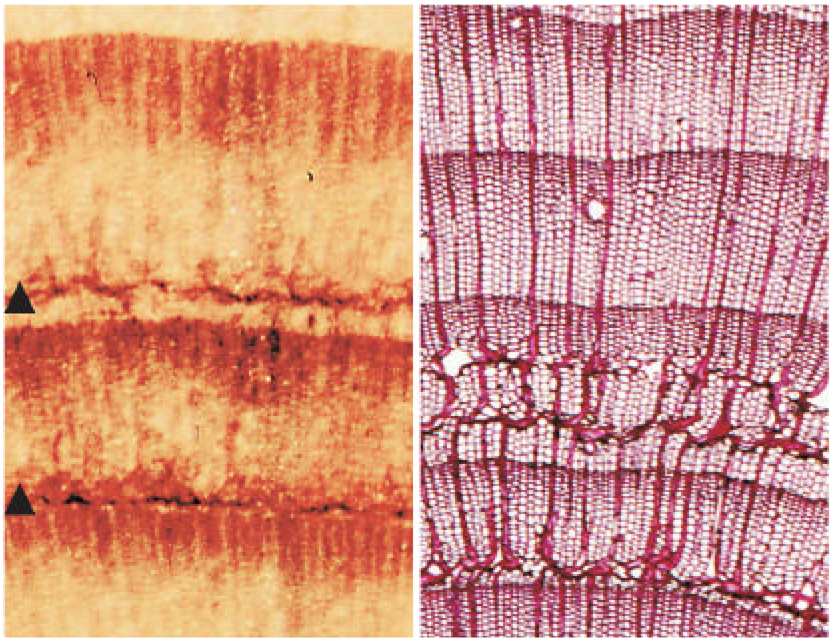

Figure 3: Frost rings of the years 1966, 1967 and 1968 at a site at the upper forest limit in the Turgen-Kharkhiraa-mountains: left) stem cross-section, right) microsection.

At the lower forest limit on the slopes facing the Uvs Nuur Basin, the lack of moisture is the key limiting factor. Low precipitation combined with relatively high temperatures result in narrow tree rings. Total precipitation for the months of June to August and tree ring width is highly positively correlated. Average June - August temperatures and tree-ring width, however, are negatively correlated (fig. 4).

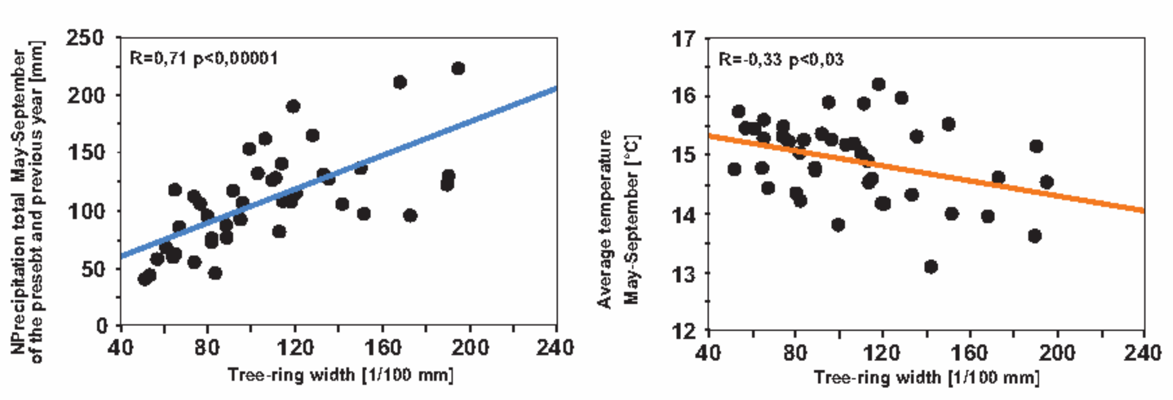

Figure 4: Correlation diagrams for locations near the lower forest limit (1700-1900m a.s.l.) for the time period 1950-1995: (left) correlation between tree-ring width and total precipitation for the months May-September of the present and previous year, (right) correlation between tree-ring width and average temperature of the months May-September. R = Spearmann's Rank Correlation, p = significance level.

The frequent occurrence of double rings (pseudo-rings or false rings) resulting from dry periods during the growing season is a further proof for frequently occurring drought-induced stress (fig. 5).

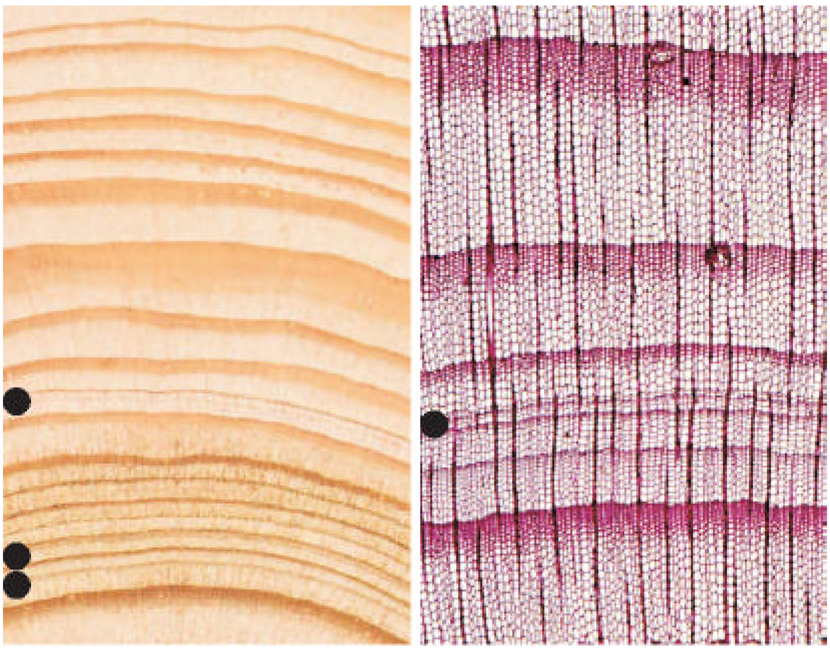

Figure 5: False rings at a site at the lower forest limit in the Turgen-Kharkhiraa-mountains: left) stem cross-section, right) microsection.

At 1700m a.s.l., the lower forest limit is currently located on slopes with an angle of approximately 25°. Immediately below this elevation, the slopes grade into the gently sloping pediments that lead towards the Uvs Nuur. Gentle slopes receive more radiation, resulting in generally less favourable site conditions and restricting or preventing a forest expansion further down slope into an even dryer and more drought-prone environment.
In the eastern part of the Khan Khökhiyn mountain range, the lower forest limit is also found on steep slopes at about 1400m. According to the data of the Baruunturuun meteorological station these eastern areas receive higher precipitation and experience a different distribution of precipitation. Temperatures, however, differ solely due to the 300m elevation difference (fig. 6a and 6b). Due to the more favourable moisture conditions, these areas do not experience well developed drought periods so that double tree rings are quiet rare.

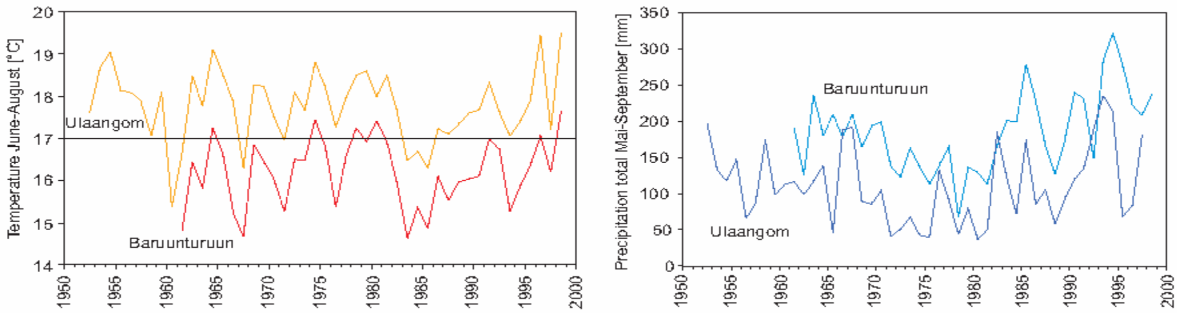

Figure 6: Selected climatological data for the stations Ulaangom (939 m a.s.l.) and Baruunturuum (1232 m a.s.l.): left) average temperature for the months June-August, right) total precipitation for the months May-September.

In conclusion, the comparison of the tree-ring curves shows that, in areas showing the same regional climate, growth conditions at the lower forest limit differ to such an extent from those at the upper forest limit that only minor similarities exist between the respective tree-ring curves (fig. 7).

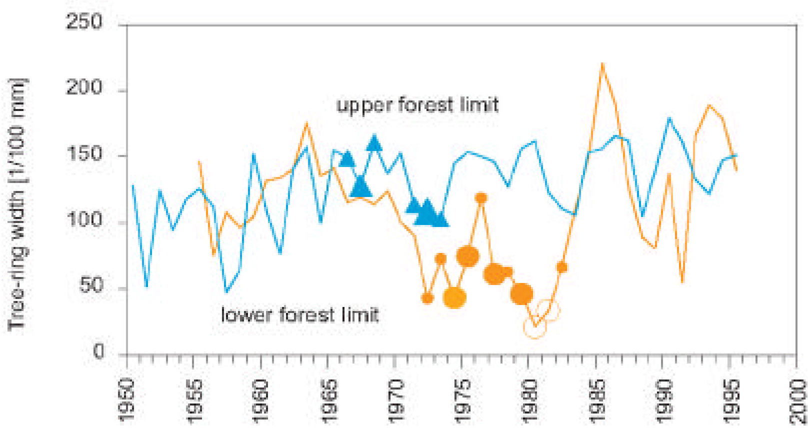

Figure 7: Tree-ring curves (raw data of tree ring width) for a site at the upper and lower forest limit showing the location of the frost rings (triangles), false rings (dots) and light rings (circles). The size of the symbols indicates their relative occurrence frequency within the stand.

The original assumption of decreasing tree-ring widths with increasing elevation and corresponding decrease of temperatures can not be confirmed. The measured increase in precipitation obviously compensates the effect of decreasing temperatures. With respect to basal area increments as calculated from tree-ring widths for the same time periods, very little difference exists between the upper and lower forest limit. The shape of the curve at sites at the lower forest limit, however, is characterized by significant drought induced interferences. At the upper forest limit, the shape of the curve is largely smooth. Both growth curves show a rising growth trend (fig. 8).

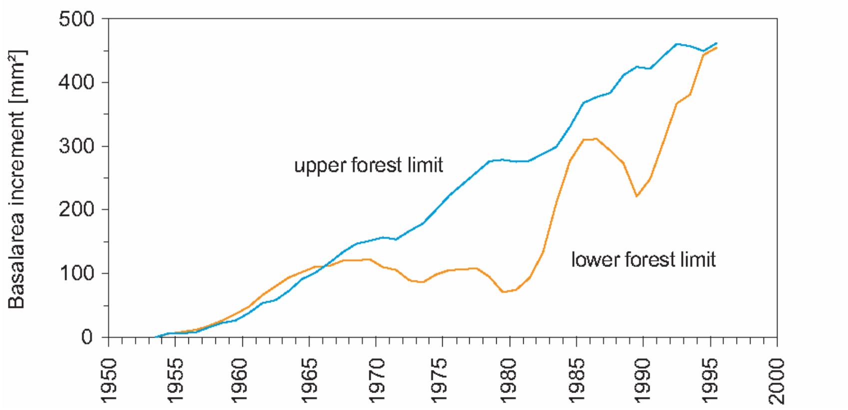

Figure 8: Growth curves (5-year moving average) of the same sites as in Fig. 7. The dips in the curve for the lower forest limit mark periods of low precipitation and thus corresponding narrow tree rings.

Conclusion

Precipitation or more generally climatic conditions and soil moisture constitute a key factor for the existence and dynamics of the larch forests in the mountain forest steppe of Northwest Mongolia. At the upper forest limit the findings suggest that average air and soil temperatures play a less important role as limiting factors than extreme events, such as late frosts. The latter prevent a further expansion of larch to higher altitudes. Only the young trees are susceptible to lethal frost damage. Trees that have survived these late frosts presently form the stands at the upper tree limit. It is conceivable that, given favourable climatic conditions (in particular rising temperatures), the absence of late frosts for long periods could lead to a shift of the tree line to higher elevations. The lower forest limit is mainly controlled by low precipitation. Given the present moisture conditions, a continued expansion downwards onto the gently sloping pediments and thus into a drier and more drought prone environment, can not be expected.

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Space-time variability of climatic influences on the growth patterns at the lower and upper timberline of the mountain forest steppe of Mongolia. Preliminary results and future dendrochronological research in Mongolia

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Abstract

The highly continental Mongolian climate is characterised by a high spatial and temporal variability. This variability results from Mongolia's location in the transitional zone between different atmospheric circulation systems. The sparse density of weather stations and the short data record of 40-60 years maximum cannot reflect this climatic variability. Based on previous dendrochronological research in northwestern Mongolia a wide network of sample plots within the range of larch forests in the mountain forest steppe of Mongolia will be established at the upper and lower tree line. In six study areas, the regional disparities of the climatic impact on tree growth will be characterised using chronologies of ring width, maximum late-wood density, isotope analysis (O^{18}/O^{16}; C^{13}/C^{12}) and the frequency of extreme events (represented by pointer years and frost rings). These chronologies of annual ring width, maximum late wood density and isotopes represent differences in the temporal variability of the general growth conditions and can be used to reconstruct summer temperatures and precipitation. The chronologies will also be available for large scale comparisons with adjacent regions. As spatial disparities of tree growth represent local and regional impact of climate, age class chronologies as well as single years will be analysed. This synoptic approach will be the first to describe the climatic variability in space and time in the Mongolian mountain forest steppe. It will also provide a better basis for the interpretation of tree ring chronologies of single sites.

Introduction

Mongolia is characterised by an extreme continental climate with a high spatial and temporal variability. Well defined cold and dry periods recur regularly during summer and occasionally, extremely cold and snow-rich winters affect different parts of the country. This so called "white zud" occurred e.g. in the years 1999 and 2000 (Batima and Dagvadorj 2000). According to the present state of knowledge, the high climatic variability is the result of the interaction of different circulation systems (Yatagai and Yasunari 1994, 1995). The climate of Mongolia is, in the first instance, determined by the Siberian high pressure system (also known as the Asian or Mongolian High). From winter to late spring, the centre of this high pressure system is often located above northern Mongolia (Zhang and Lin 1992, An and Thompson 1998, Samel et al. 1999). According to Yatagai and Yasunari (1995), the western jet converges with southwesterly monsoonal air masses. The East-Asian monsoon, the Indian summer monsoon and the Pacific high pressure zone are other circulation systems that influence the precipitation regime of Central Asia (Yatagai and Yasunari 1994). Mongolia lies in the area of intersection between these systems. Their influence and extent varies from year to year and is also modified by convective thunderstorms during summer (Krüger et al. 2001; Zhang and Lin 1992).

On the background of this general climatic framework, it can be expected that the growing conditions for larch forests vary greatly within the mountain forest steppe region, in particular in regard to the quantity and the spatial and temporal distribution of precipitation.

Preliminary Results

Preliminary evidence about local and regional growth patterns of larch forests in northwestern Mongolia has already been obtained within the framework of the DFG-funded research project „Structure and dynamics of larch forests in the mountains of the Uvs Nuur Basin" (Treter 1999, 2000a, 2000b, Treter et al. 2002). In this study, tree-ring chronologies of sites at the timberline sites proved to be highly sensitive indicators for singular weather and climatic events as well as for medium to long term climatic variability.

Dendrochronological studies were carried out in between 1995 and 2001 at 110 sites in 11 regions (6 in Mongolia and 5 in Tuwa) along the mountains that fringe the Uvs Nuur Basin. For this relatively limited area, it was possible to identify clear differences in the temperature and precipitation signals recorded in the tree-ring chronologies from upper and lower timberline sites as well as along north-south and west-east running transects (Fig. 1).

These should be interpreted as an expression of the spatial and temporal variability of climatic influences and growth behaviour. These results indicate that climate reconstruction based on single site chronologies are of limited value in respect of representing a larger region.

At the upper timberline of the Turgen-Kharkhiraa-Mountains and the Tannu-Ola-Mountains, it was possible to identify several years during which simultaneous late frosts varied in intensity within and between sites. At lower timberline sites in the same area, an increased occurrence of false rings in the period 1970-1980 as a result of marked droughts also exhibits spatial variability in intensity (Block and Treter 2001; Block and Treter, this volume).

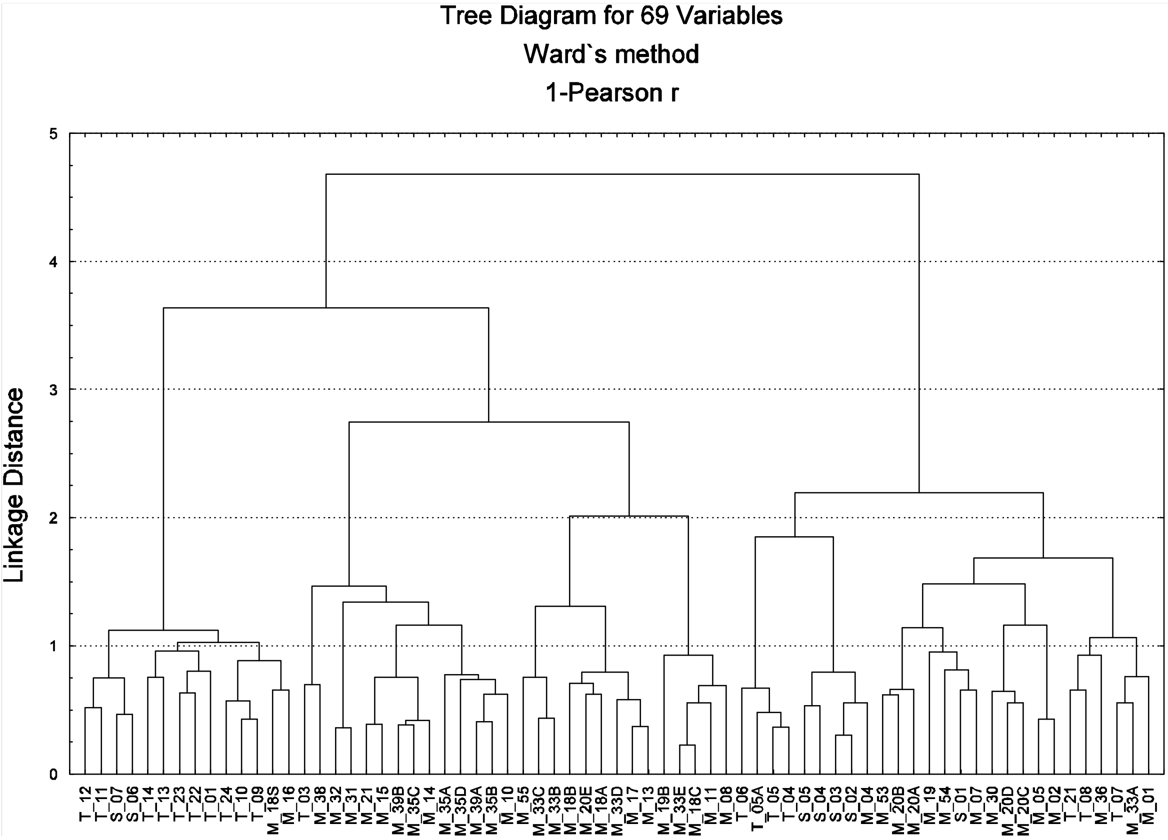

Figure 1: Dendrogram of the results of a cluster analysis (Ward's method using Pearson correlation coefficient) of 69 selected sites with similar length of chronologies (M = sites in Mongolia, T and S = sites in Tuwa).

Since 1995, several dendrochronological studies have been carried out in Mongolia within the Mongolian-American Tree-Ring Project (MATRIP) led by G. Jacoby. These studies mainly focused on ring width of *Pinus sibirica* and *Larix sibirica* at 15 widely separated sites including relatively few trees sampled at different elevations. The main aim of this research is the use of regional climate reconstruction reveal the effect of global climate change on Mongolia (Dagvadorj and Mijiddorj 1996; Jacoby et al. 1996; Jacoby et al. 1999; Baatarbileg et al. 2001; D'Arrigo et al. 2001; Pederson et al. 2001). The main results can be summarised as follows: (a) The increase in precipitation found in eastern Mongolia during the last few decades lies within the long term variability. (b) There is evidence of climate changes occurring in Mongolia, whereby the increasing trend for temperature corresponds to the hemispheric.

Future dendrochronological research in Mongolia

To extend the existing extensive dataset, future research will be aim to cover the entire Khangai-Mountains and the southern part of the Khentei-Mountains. Within this enlarged framework, the following aims are paramount:

1. Regionalisation of the growth patterns of *Larix sibirica* at the upper and lower timberlines within the range of the mountain forest steppe in western and central Mongolia in order to infer the spatial structure of climate regimes.

2. Reconstruction of summer temperatures and precipitation conditions for the last 200 years on the basis of regional chronologies of the parameters ring width, maximum late wood density and, at selected sites, variations of stable isotops.
3. Comparison of regional chronologies with chronologies of individual sites used in the Mongolian-American Tree Ring Project (MATRIP), as well as with chronologies from neighbouring areas to validate signals of global climate change in Mongolia.

To achieve these aims, it is planned to establish a tree-ring network encompassing six or more regions containing a minimum of three sites each at the upper and lower tree limit. This network will be linked to the existing small-scale but comprehensive experimental network in the Uvs Nuur Basin in Northwest Mongolia and the sites in the northern Tannu-Ola-Mountains (Tuwa Republic).

To characterize spatial growth patterns, tree-ring curves will initially be established for individual trees. From these site chronologies of ring width and maximum late wood density will be developed for individual age classes. Finally those will be combined into local or regional chronologies for the upper and lower timberlines.

The analysis of individual years with respect to extreme events and different tree ring characteristics (pointer years, frost rings, false rings) is important for a synoptic approach to the regionalisation of climatic disparities (Tessier et al. 1997). This approach, however, requires a dense network of chronologies like it already exists in our study area and which we are planning to extend along the Khangai-Mountains to the east. The intention is to record the intensity of the reactions of tree growth to different climatic influences such as drought or cold periods across the entire experimental network. The characterisation of ecological conditions generates criteria for the comparability of the respective sites within a site as well as across the entire network. The characterisation of ecological conditions generates criteria for the comparability of the respective sites.

According to previous results, the use of age class chronologies gives new insights in the question whether all trees of the same age class within a defined area react in a similar way to the same climatic event.

Based on more than 200 year old chronologies of ring width, maximum late wood density and isotope variations and climate data of the closest meteorological stations, the reconstruction of past temperature and precipitation conditions will be accomplished. When considering the variations of the

Various wood parameters among the individual chronologies it shall be possible to local from regional growth and large scale growth and climate patterns. It is intended to characterise the temporal variability of climate in general and of individual climatic events (e.g. late frosts) and their regional effects in particular. The inter comparison of these regional climatic reconstructions, however, can contribute significant information about spatio-temporal disparities with respect to the growth patterns of larch forests within the sampling network.

Finally, the more than 200 year old chronologies of ring width, maximum late wood density and isotope variations will be compared with individual chronologies of the Mongolian-American Tree Ring Project (MATRIP) as well as with chronologies from the tree-ring network of the Siberian Altai Mountains, in southern Siberia and other, more distant areas in collaboration with other research groups.

This comparison is also expected to lead to indications about the extent of climate changes in Mongolia in relation to global changes . The dendrochronological research in Mongolia and in the Tuwa Republic shall be carried out in collaboration with the following individuals and institutions:

Dr. N. Baatarbileg, Department of Forestry, National University of Mongolia, Ulaanbaatar, Mongolia.

Dr. A. Bräuning, Institut für Geographie, Universität Stuttgart, Deutschland.

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Dr. J. Esper, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft (WSL), Birmensdorf, Schweiz.

Prof. Dr. G.H. Schleser, Institut für Chemie und Dynamik der Geosphäre (ICG-4), Forschungszentrum Jülich, Deutschland.

Prof. Dr. F.H. Schweingruber, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft (WSL), Birmensdorf, Schweiz.

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SECTION 8

GEOMORPHOLOGY

Spruce trees as a mean of dating soils – reforestation after the clearings in the Valley of St. Antönien (Switzerland)

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Abstract

During a search for evidence of former clearing activities in the valley of St. Antönien (Switzerland), slope deposits of translocated topsoil material were discovered that indicate a period of higher geomorphodynamic activity after a slash and burn period. These slope deposits were dated by dendrochronological studies of spruce trees (*Picea abies L.)*. The dendrochronological and pedological results were compared to a pollen diagram of the peat bog "Capelgin" on the same slope, showing a clear decrease of *Picea abies* during the late Middle ages which might be correlated with the slash and burn period and the development of the slope deposits.

Research area

St. Antönien (NE of Graubünden, CH) belongs to the areas in the Alps that are strongly influenced by geomorphodynamic activity. One main reason for this phenomenon is the instability of the Flysch sediments (Nänny 1948). The research area is situated on the NW-exposed slope of the Chrüz (2200 m a. s. l.), characterized by several sackungen of the Flysch. Often peat bogs developed in the resulting depressions. Below 1800 m a. s. l. these bogs are surrounded by subalpine *Picea abies* forest. Under the protection of the forest cover and due to the relatively slight inclinations (20 to 25 °), the old horizons of slash and burn activity as well as the slope deposit have been conserved.

Material and methods

This investigation aims to combine the results of three examined "natural archives": trees, soils and a peat bog. The peat bog, "Capelgin" (1680 m a. s. l.), is surrounded by a subalpine spruce forest that has conserved the slope deposits. 78 increment cores of 39 spruce trees were collected and subjected to the standard procedures used in dendrochronological research, such as sample surface preparation, cross dating and ring-width measurement (LINTAP/TSAP).

The soils and its horizons were described using the nomenclature of the AG Boden (1994), and the standard parameters 'grain size', pH, Corg., and Fe(d/o) were measured. In addition, three cores from the peat bog "Capelgin" were taken. The 2 m thick organic sediment was analysed using palynological methods. The programs TILIA and TILIA *GRAPH were used for producing a diagram, in which the visual zonation is based on the percentual distribution and spectrum of the pollen. Time scales used for the diagram are based on AMS radiocarbon dates.

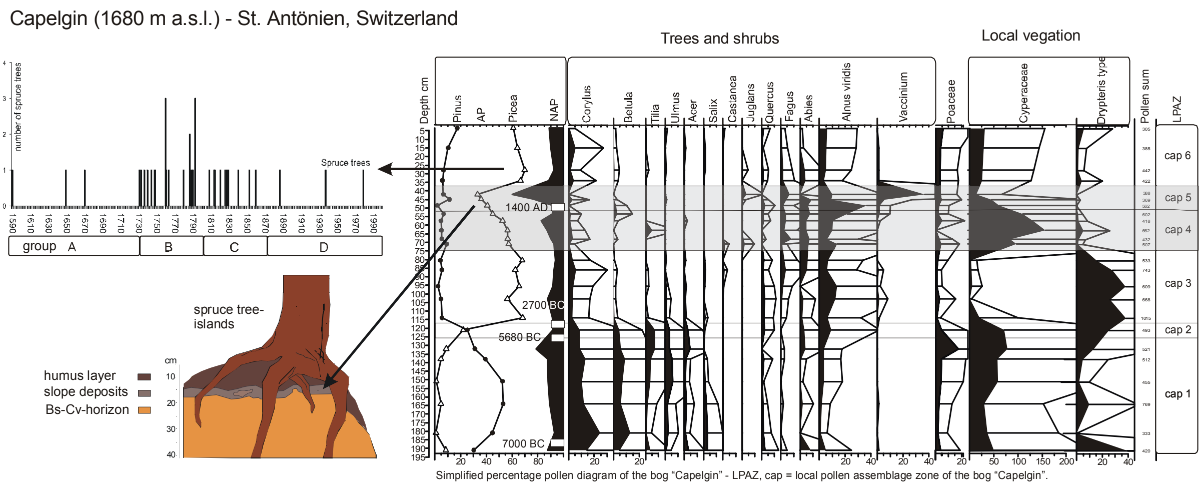

Figure 1: Simplified presentation of the combination of the dendrochronological, palynological and pedological results.

Results

1. Age structure and position of the spruce trees

Most of the 39 examined spruce trees grow directly on the slope. Only few are close to the peat bog, with one individual tree in the bog, which happens to be the oldest (ca. 1590 AD). Four age classes could be defined. The natural reforestation probably started in the 17th century. This is documented by the earliest trees (group A: Ad 1650 – 1730), which grow on relatively stable sites. The trees in the two largest groups, B and C, date to the 18th and 19th century. These groups not only differ by time but also by place. The site of the younger trees (Group C: AD 1800-1900) is located at the downhill border of the bog. In contrast to the older stand of spruce trees (group B :1730 – 1800 AD) these younger trees do not cover the soil deposits. In the middle of the 20th century the youngest trees (group D) germinated close to the border of the peat bog.

2. Slope deposits

During the Holocene the alpine podzol developed in the silty slope deposits of the Flysch under *Picea abies* cover. Especially the upper organic layer and the Ae-horizon were washed downhill after the burn and slash activity. The mixture of humus-, Ae- and Bs-material is preserved under spruce trees that grow on elevated islands (0,5 m high). The soil between the "tree islands" eroded by cattle driven into the forest.

3. Landscape and vegetation history

The peat bog "Capelgin" is about 9000 years old. After 3000 BC a general retreat of the forest limit occurred in many parts of the Alps (Wick & Tinner 1997; BURGA 1991; Oeggl & Wahlmüller 1994). This Mid-Holocene climate deterioration is documented in Figure 1 as a period of very slowly growing peat and a decline of *Pinus*. The change to a cooler and more oceanic climate might have supported the expansion of *Picea abies.* Around 2200 BC the *Picea abies* forest became dominant. Simultaneously the *Cyperaceae* declined due to a lack of light and water (Fig 1., LPAZ cap 3).

Beginning at LPAZ cap 4 (Iron age), human impact occur combined with deforestations (Fig. 1). This is accompanied by the first appearance of anthropogenic indicators (i.e., *Cannabis, Plantago lanceolata, Juglans, Castanea and Cerealia*).

The strongest human interferences took place in the 15th century, showing a decrease of the Picea curve from 70 to 35%. After the 15th century it rises again to 60-7%.

Preliminary discussion - connecting the disciplines

At least since the Iron Age, in the secluded valley of St. Antönien evidence of human activities has been archived in buried slash and burn layers as well as in the pollen record and archeological sites (Rageth 1998). The timberline was lowered by human activity through the creation of pastures. Human impact was strongest during the Late Middle Ages, when the Walser people came into the valley. They lowered the timberline another 200 meter to the altitude of the peat bog “Capelgin”(1680 m a. s. L.). This is well recorded by the decline of the *Picea abies* pollen concentration. The clearings were followed by erosion, which led to the formation of slope deposits. At the beginning of the 17th century, spruce trees started to establish. The reason is possibly a cooling of the climate, which caused people to move out of the valley (Holzhauser & Zumbühl 1988; Pfister 1988). This reforestation marks the end of the period of increased geomorphodynamic activity. The whole process took about 150 years. During the last 300 years the examined areas of the slope have remained in a stable condition.

Acknowledgements

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The applicability of roots in Dendrogeomorphology

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Introduction

The possibilities to reconstruct recurrence frequencies of geomorphical processes using dendrochronological methods are limited, due to the fact that most analyses focus on growth reactions in the stems of directly influenced trees. Frequent perturbations of the root system of a tree by erosive processes in most cases only can be analysed if they cause specific growth reactions in the trees' stem (e.g., Bégin *et al.* 1991). With the exception of age determinations of adventitious roots for the purpose of reconstructing past debris-flow events (Strunk 1995), roots have hardly played a role in geomorphological studies.

Dendrochronologists have only sporadically used the total age of exposed roots to quantify soil erosion (e.g., Eardley 1967; LaMarche 1968). Efforts to determine exposure-related diagnostic anatomical features in the growth rings of roots (Fayle 1968) have shown the potential of root studies for the field of dendrogeomorphology. However, so far all attempts have failed to identify diagnostic anatomical features with which the first year of exposure can be dated accurately. The research presented here is based on Fayle (1968) and more recent studies (e.g., Carrara and Caroll 1979; Danzer 1996; Krause and Eckstein 1993; Morneau and Payette 1998). It is focused on the analysis of wood-anatomical variations in the annual growth rings of coniferous roots caused by exposure due to geomorphical processes, and explores the possibilities of determining and dating anatomical changes in exposed roots as well as their significance for the estimation of erosion rates.

Material and methods

In order to get a firm grip on the diagnostic features related to root exposure, first the so-called "common structure" of growth rings of buried roots has to be determined. For this study, root samples were used from different depths below the soil surface. The samples were derived from a wide variety of sites in Germany and Switzerland. The large size of the original data set enhanced the possibility to exclude (or include) side specific influences to the shape of structural variations. The sampling strategy involved geomorphological mapping of each study area as well as the detailed documentation of the position of the exposed and unexposed roots. In this manner it is possible to determine the process causing root exposure (Gärtner 2001). The study was restricted to conifers (*Larix decidua* Mill., *Picea abies* (L.) Karst., *Pinus cembra* spp. *sibirica*), because in most cases the growth rings in the roots of coniferous trees are clearly visible. Discs (i.e. cross sections) were taken of the exposed and buried roots at a minimum distance of ca. 50 cm from the stem, in order to exclude disturbances caused by the proximity of the stem.

After the discs were dried and sanded (using a 100 to 600 grid), their age was determined. Macroscopic features (e.g., occurrence of tangential rows of resin ducts, changes in latewood characteristics) were documented. To analyse cell-structure variations within the growth rings, thin cuts were taken using a sledge microtome. A detailed description of the preparation of cell-structure analysis can be found in Schweingruber (1978).
To visualize the cell structure, monochromes were taken from the prepared samples. These photographs were digitised for the purpose of analysing features such as the number of cells per growth ring and the ratio of earlywood (EW) and latewood (LW) cells. A LINTAP measurement device was used to measure ring width as well as the dimension of cells (length of cells in radial direction, width of cells in radial direction). Cell size was calculated by multiplying the length and width of cells (Gärtner et al. 2001).

Results

For getting a firm bases to determine diagnostic features related to root exposure, the so called "common structure" of growth rings of buried roots had to be analyzed.
This analysis concentrated on roots sampled at different depths below soil surface. The buried roots of all studied species show significant growth variations, related to their distance to the soil surface (Fig. 1). Roots growing more than 15 cm below soil surface show the "typical" root structure (Fig. 1, left). Growth-ring boundaries are indistinct (mostly one row of latewood cells only), the different growth layers are often distorted, and wedging rings are frequent.

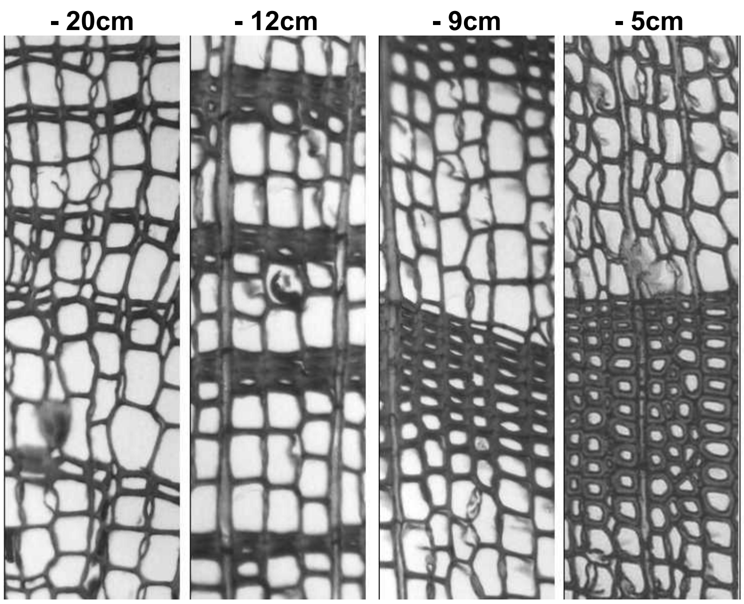

Figure 1: Differences in cell structure of buried Larix decidua roots regarding their distance to the soil surface (-20 to -5cm). Source: Gärtner 2001, p.52.

The closer the position of the root to the surface, the more distinct the growth rings become. The number of cells in EW and LW increases and cell-wall thickness (mainly in LW) increases as well.

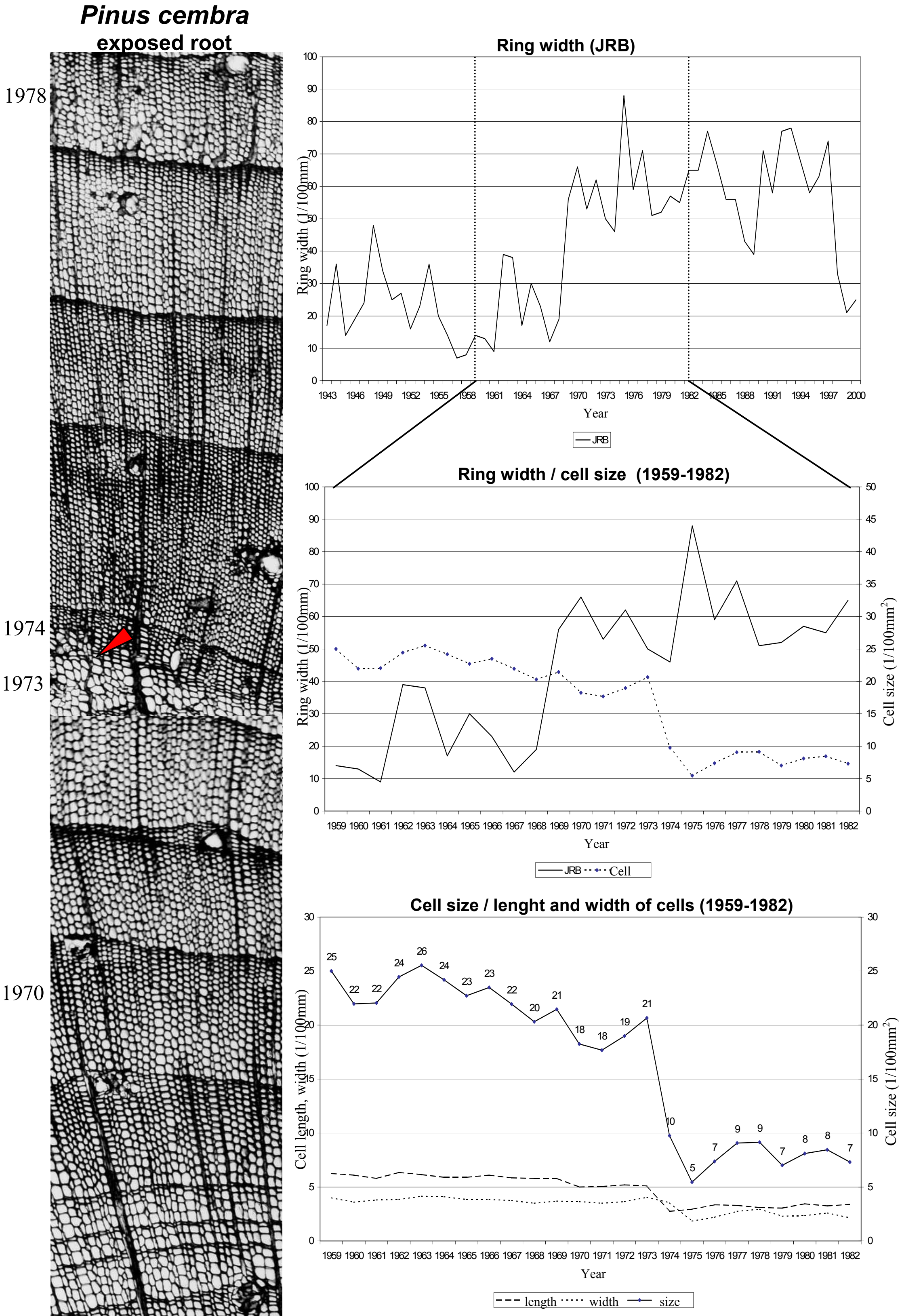

Figure 2: Cross section of an exposed Pinus cembra root and related diagrams of ring width (1), cell size changes (3) and a comparison of ring width and cell size changes (2). The root was exposed in 1974. The arrow indicates callous tissue that leads to a resin pocket (not visible) on the left. Source: Gärtner, 2001, p. 77.

The cell structure of roots growing near the soil surface closely resembles the structure of stem wood. Given the fact that the studied roots have never been exposed, this shows that such a structure should not be interpreted as a sign of exposure. In addition, it means that we can exclude the influence of light as a main cause of similar changes in the cellular structure of exposed roots.

The analyses of exposed and buried roots shows that there is no fixed time interval required for a change of the structure of exposed roots; I noted a wide variety of gradual and rapid changes. However, I did find a feature in the cell-size variations of exposed roots that can be used to diagnose the time of first exposure. This feature, occurring in the exposed roots of all studied tree species, consists of a size reduction of EW cells of ca. 50% or more (Fig. 2). This striking, enduring change in cell size only appears in exposed roots and is restricted to the exposed parts of the roots only. Buried parts of the same roots do not show this feature. Although a species such as *Pinus cembra* in general develops a rather low content of latewood cells, meaning that the stem-like structure in general is not as distinct as it is for other tree species, even the exposed roots of this species show this 50% reduction (Fig. 2).

Discussion and conclusion

There are significant differences in root anatomy, caused by different kinds of erosive processes. Taking into account that root structure also differs according to the distance to the surface, the study of roots is not limited to determining the date of their initial exposure. A combination of the variations and additional features present in root structures, such as the appearance of reaction wood, enables the reconstruction of the changing conditions over time that resulted in root exposure.

In general, specific anatomical features can be related to (i) sudden erosive events causing an immediate and complete change of the size and shape of EW and LW cells, and (ii) continuous denudation causing a gradual change of LW cells first. Although the causal factors are still in part uncertain, these changes are not randomly distributed in the growth rings. We are even able to discern the type of exposure from the root structure.

At about 5 cm beneath the soil surface, growth rings appear “stem like”. This implies that a stem-like shape of the growth rings in roots can no longer be interpreted as a sign of exposure. Furthermore, the notion that light is the main factor causing anatomical changes in roots has become questionable.

Many uncertainties still exist concerning the degree of influence of some environmental factors on the growth of roots. However, the analysis of root structure in relation to the distance to the soil surface offers new and exiting possibilities for the reconstruction of e.g. soil erosion.

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Dendrogeomorphological analysis of the enlargement of cracks at the Wellenkalk-scarp in the southern Thuringia Basin

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Introduction

The Wellenkalk cuesta scarp in the Thuringia Basin (Fig. 1) is characterised by the occurrence of massive block displacements. Their initial phase is marked by the formation of tension cracks. Until now, dendrogeomorphological studies of corresponding movement rates are rare. However, the study of affected trees offers many possibilities for the reconstruction of past and recent mass movements, especially using anatomical analysis of the growth-ring structures of affected roots.

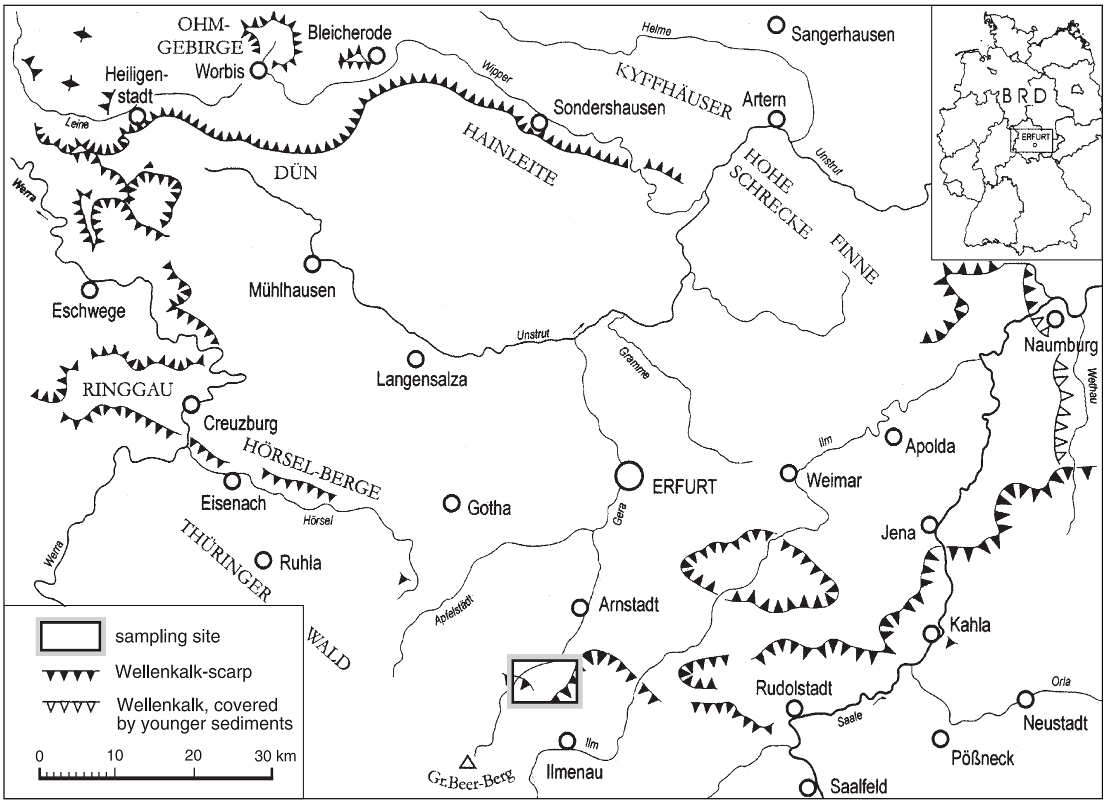


Figure 1: Wellenkalk scarp in the Thuringia Basin (Thüringer Becken). (Johnson & Schmidt 2000: 97; after Weber 1955).

In this study we focus on stems and roots of *Picea Abies* (L.) Karst growing at the tension cracks at the top of the Wellenkalk scarp. We analyse variations in growth, which are considered to explicitly reflect dynamic slope patterns. Of special interest in this context are structural variations in the xylem of the stem (growth reductions and formation of compression wood) and of the root (eccentricities and cell size reductions).
The purpose of our study is to measure the relatively slow geomorphological dynamics of block movements during the initial phase of the opening of the crack. In this context we focussed on the relationship between the dynamics of geomorphological processes and extreme precipitation events, a relationship that has been described frequently (e.g., Ackermann 1958; Johnson 1974, 1981, 1984; Johnson and Schmidt 2000).
The basis for the dendrogeomorphological evaluation presented here is a combination of methods, including detailed characterisation of the terrain in the form of detailed geomorphological mapping, dendrochronological data analysis, and the analysis of recognisable variations in the cell structure of the roots.

Site selection

The studied sites are situated about 16 km South of Arnstadt, between Angelroda to the North and Geraberg to the South, in the area of the "Kammerlöcher" (Fig. 1). The occurrence of mass movements is limited to the west-facing slope of the scarp, from the "Kirchwald" to the "weißen Stein". Cracks at the Wellenkalk-scarp of the Kammerlöcher were chosen to provide a setting for the study of recent block movements. According to Johnson (1981) the movement of Wellenkalk-blocks generally takes place very slowly, in the range of millimetres per year. When selecting the sites, attention was paid to their position along the crack, in order to ensure that enlargement of the crack would have influenced the growth of the trees. To ensure the comparability of the different sites, we selected trees of one species only: *Picea Abies* (L.) Karst.
We took samples at three sites, which we termed 01, 02 and 03 respectively. Sites 01 and 02 are located at a tension crack, and site 03 on a displaced block (Mauerscholle). The reference site was selected with the precondition that the tree stand would be undisturbed by mass movements.

Methods

Tree cores were taken with an increment corer. At the reference site we sampled 30 trees. Because the influence of reaction wood is minimised by slope-parallel extraction, the cores were extracted in the *a* and *b* directions shown in Figure 2, (at a height of 1.30 m). At sites 01, 02 and 03, four cores were taken from each disturbed tree in the directions *a*, *b*, *c* and *d* at the height of 1.30 m (Fig. 2). At site 02 it was also possible to sample two roots growing across the tension crack. The environment of the disturbed trees and roots was mapped geomorphologically at scale 1:50.

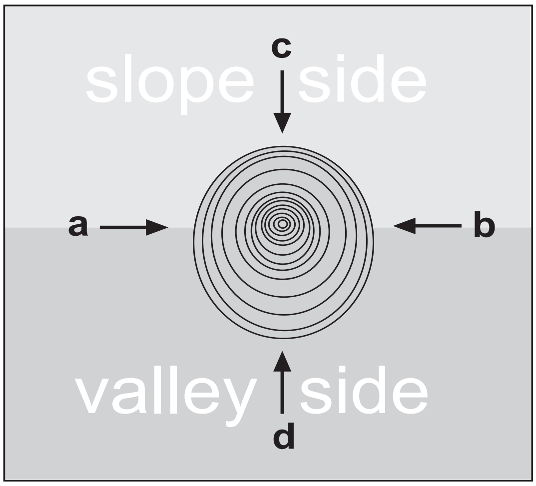


Figure 2: Coding of the core-directions

In the laboratory, the cores were fixed onto wooden core mounts. We took slices from the root samples at regular intervals and prepared them for further measuring. We also prepared microtome slices of selected samples. The data series were generated by visual analysis of the growth patterns and, next, by using a standard system for the measurement and ring-width analysis (TSAP).

Results

General

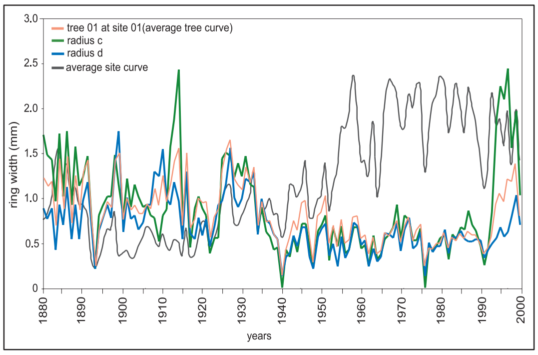
The results of our study show an obvious influence of mass movements on tree growth. Growth reductions (stem), formation of reaction wood (stem, roots) and variations in cell size (roots) provide information on the date of the opening of the crack. From the year 1953 onwards, at each surveyed site the opening of the crack increased to such a degree that that tree growth became remarkably disturbed.

Using the collected data, it was possible to determine periods of crack movements at sites 01 and 02. All sampled trees at these sites show patterns of prominent movement for the years 1884 - 1885, 1899 - 1901, and 1910 - 1915. Crack movement occurred in the years 1953 (site 01) and 1954 (site 02), with preliminary phases of opening joints in the 1930's and 1940's, respectively. After the opening of the crack, the growh patterns of the trees only differed in detail. Between 1981 and 1985, the trees at both sites again reacted synchronously, due to a less intense movement of the crack. Between 1994 and 2000 only tree 01 at site 01 (Fig. 3) records a repeated intense opening of the crack.

The results of the investigation at site 03 (displaced block; Mauerscholle) clearly support the hypothesis that the crack opening at sites 01 and 02 is younger than the formation of the displaced block. The crucial reduction in the growth pattern of the sampled trees at sites 01 and 02 cannot be found in the ring patterns of the trees at site 03.

Tree analysis (example)

Figure 3: View from the crack to the sample tree 01 at site 01



Fiure. 4: Comparison of the tree radii c-d (site 01) and of the average tree curve with the average site curve

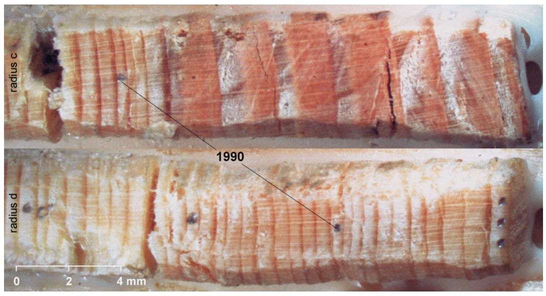


Figure 5: Photo of the compression wood formation (radius c, top) from the year 1994 on compared to radius d (bottom).

For site 01 we compared tree radii *c* and *d* to the average curve of tree 01 (*a*-*d*) and the average site chronology (Fig. 4). From the year 1953 onwards a persistent growth reduction occurred. Based on the position of the tree (fig 3), we assume that the opening of the crack caused serious damage of the roots. In core *c* we detect a notable reaction, by the formation of compression wood, from the year 1994 onwards (Fig. 5). This marks the most recent movement of the rift at site 01. The movement impulse that caused the tangential deviation of the tree was preceded by an extreme precipitation event. On April 12th of 1994, the climate station of Gräfenroda (4 km NW of site 01) recorded 85 mm of precipitation, which exceeds the monthly averages for the period 1973 - 2000 with 85% (Fig. 6).

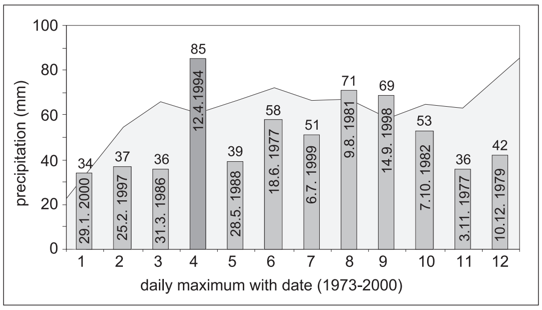


Figure 6: Comparison of the absolute daily maxima with the monthly averages (grey,background) climate station Gräfenroda (Meteorological Service)

Root analysis

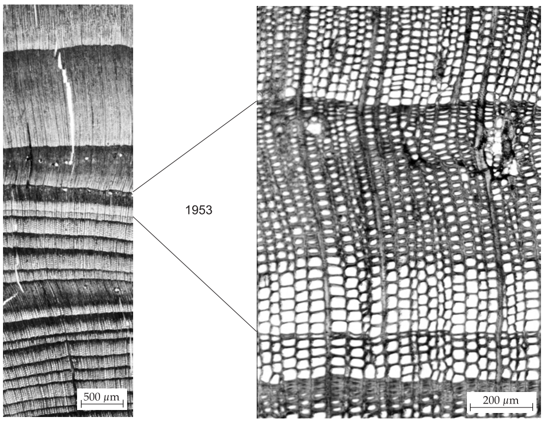


Fig. 7: Microtome of the root slice 4DK0201f

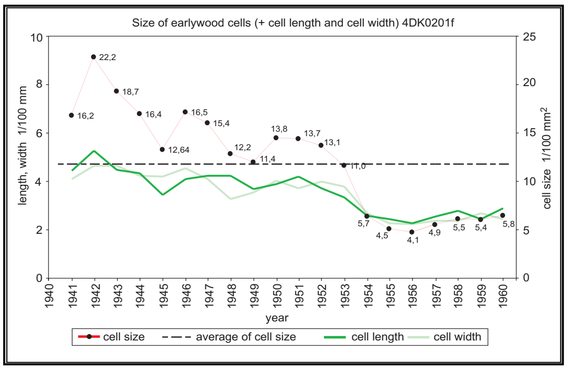


Fig. 8: Cell size measurements of the cross-section 4DK0201f

Root samples of site 02 were analysed using the method of Gärtner (2001). The findings confirm the results of the dendrogeomorphological analysis of the site 01 material and allow an even better approximation of the date of the crack opening. Remarkable compression wood formation occured during the year 1953 (Fig 7). From 1954 onwards, a noticeable reduction of the earlywood cell size took place (Fig 8). This reduction exceeded 50%, the threshold value for root exposure (Gärtner 2001). In other samples along the root the same structural changes were noted, implying that the roots were exposed over a partial length of 450 mm.

Summary

Relating the crack width to the dates of the opening of each crack, the following average movement rates were obtained:

Site 1:

Tree analysis: 21 mm / a (1953 - 2000) crack width near the tree 1m

Site 2:

Tree analysis: 35 mm / a (1954 - 2000), crack width near the tree 1.65m

Root analysis: 28 mm / a (1953 - 2000), crack width next to the root sample 1.35m

Microtome analysis: 450 mm long root piece was exposed as a result of an event

Site 03:

The sampled tree on the displaced block (Mauerscholle) does not show any remarkable growth reduction in the year 1953, in spite of the small distance (15 m) to site 02.

Phases of intense movements of the study sites between AD 1900 and 2000 could be correlated to extreme precipitation events.

We conclude that the combination of root- and stem-structure analysis provides a powerful dendrogeomorphological tool for the study of mass movement, in this case the determination of widening rates of cracks at the Wellenkalk-Escarpment in the Thuringia Basin.

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Datierung der Ausbreitungsgeschwindigkeit von Thermokarst-Hohlformen in Westsibirien mit dendrogeomorphologischen Methoden

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Thermokarst ist ein geologisches Phänomen, das durch Landformen charakterisiert ist, die durch den Kollaps und das Tieftauen des Permafrosts verursacht sind. Durch das Abschmelzen des oberflächennahen Eises im Untergrund entstehen dabei geschlossene runde oder ovale Hohlformen, die sich mit Schmelz- und Niederschlagswasser füllen oder vermoort sind. Solche Thermokarsthohlformen sind typisch für arktische und subarktische Regionen. In der subarktischen Taiga entstehen sie natürlich durch Windwurf oder Feuer, anthropogen auch durch Rodungen.

Unser Arbeitsgebiet liegt am Fluß Synya in Westsibirien, etwa 30 km oberhalb seiner Mündung in den Ob (65° 03'N, 64° 42'E). In dieser Region, am Südrand des diskontinuierlichen Permafrosts kommt es in einem Bestand von Pinus sibirica zur Bildung und Ausbreitung von Thermokarsthohlformen. Das Wachstum der Bäume begann zwischen 1820 und 1850 AD. Nach und nach werden sie von den lateral wachsenden Hohlformen beeinflußt. In der ersten Entwicklungsphase geraten sie in die zwei bis drei Meter hohe Böschung der Hohlform und werden schief gestellt. Das Druckholz gibt uns den Beginn der Schiefstellung an. Nach und nach sinkt der Baum mit der tauenden Böschung ein. Schließlich gerät das Wurzelwerk in das Niveau des sommerlichen Wasserspiegels, wodurch das Wachstum des Baumes drastisch zurückgeht. Schließlich stirbt der Baum ganz ab, bricht nach einigen Jahrzehnten um und wird in das aufwachsende Moor inkorporiert. Die Ausbreitungsgeschwindigkeit der Hohlform beträgt zwischen 4 cm und 8 cm pro Jahr.

Bioindikation von Blockgletschersystemen im Turtmanntal (Wallis, Schweiz)

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Das Ziel der durchgeführten Arbeit ist die Rekonstruktion der früheren und aktuellen Permafrostverbreitung im Rahmen der climate change - Forschung. Dies gelingt nur durch die Kombination verschiedener Ansätze und Methoden in unterschiedlichen räumlichen Skalen.
Der hier verwandte Ansatz basiert auf der Nutzung von Pflanzen als Indikatoren für die Verbreitung von Permafrost. Obwohl die klimatischen und topographischen Bedingungen einen starken Einfluß auf die Vegetation ausüben, können mit Hilfe der Bioindikation Informationen zum Vorkommen von kriechendem Permafrost gesammelt werden. Sichtbar wird dies über ausgewählte Arten und Gesellschaften, die an Permafrostbedingungen (vor allem an Bewegungen der Oberfläche) angepaßt sind.
Zunächste diente eine geomorphologische Karte – basierend auf Feldkartierungen und Luftbildinterpretation – der Erfassung der offensichtlichen Permafrostindikatoren, Blockgletscher und protalus ramparts, welche als typische Formen der Permafrost-gebundenen Prozesse zu sehen sind. Die genaue Kartierung von Stirnen (Länge, Neigung, Exposition) und Oberflächenstrukturen ermöglichte eine Abschätzung der Aktivitätsgrade der Objekte (aktiv, inaktiv, fossil). Die vorgestellte Arbeit konzentrierte sich auf eine Sequenz von Blockgletschern unterschiedlicher Aktivitätsgrade.
In einem weiteren Schritt wurde die Vegetationsbedeckung anhand von Bewuchsstruktur (Kräuter, Sträucher, Bäume) und durch die Ableitung von Pflanzengesellschaften (Braun-Blanquet, 1964) kartiert. Diese Aufnahmen bildeten die Basis für die Indikatorwert-Analyse (Lauber & Wagner, 1996) aller Arten, die die Untersuchung der geoökologischen Zusammenhänge, besonders der Pflanzen – Permafrost – Beziehung, ermöglichte. Das schloß die Interpretation der lokalen Prozesse, hier im Besonderen die Oberflächenbewegung, mit ein. Zusätzliche Studien fokussierten auf die dendrochronologische Untersuchung einiger Zwergsträucher (auf inaktiven Blockgletschern wachsend), sowie einiger Bäume (auf einem fossilen Blockgletscher wachsend).

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