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TRACE

Tree Rings in Archaeology, Climatology and Ecology

Volume 3

Proceedings of the DENDROSYMPOSIUM 2004
April 22nd - 24th 2004, Birmensdorf, Switzerland



ASSOCIATION FOR TREE-RING RESEARCH



GESELLSCHAFT FÜR JAHRINGFORSCHUNG

Edited by:
Holger Gärtner, Jan Esper, Gerhard Schleser

**Umwelt
Environment**



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Preface

In April 2004 the third TRACE (Tree Rings in Archaeology, Climatology and Ecology) conference was held in Birmensdorf, Switzerland. The conference was hosted by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL.

This volume of extended abstracts is the result of excellent oral and poster presentations and fruitful discussions within TRACE 2004.

The annual TRACE conference serves as a platform for the Association for Tree-Ring Research to present the state of the art as well as new research perspectives in the field of dendrochronology, to stimulate further investigations and collaboration between different research groups, and to strengthen dendrochronological sciences in European research.

About 80 scientists and students from Austria, Belgium, England, Germany, Italy, the Netherlands, Poland, Russia, Switzerland and USA attended the meeting. In total, 32 talks and 16 posters were presented, covering the topics (1) Ecology, (2) Geomorphology, (3) Climatology, (4) Isotopes and (5) Methods. This current volume contains 23 extended abstracts based on these presentations.

We want to thank all participants of TRACE 2004 for the fruitful discussions during the meeting, and for contributing to this volume.

We are grateful to Ulf Büntgen, David Frank, Rolf Niederer, Daniel Nievergelt and Kerstin Treydte for all the work they have done to realize the conference.

We also thank the reviewers of the papers compiled here for their efforts and timely response.

TRACE 2004 was sponsored by (1) Swiss Academy of Sciences, (2) Swiss Federal Research Institute WSL, (3) RINNTECH, and (4) MIGROS.

Holger Gärtner

Jan Esper

Gerhard H. Schleser

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SECTION 1

ECOLOGY

Investigation of the interactions between pine and beech in two-layer mixed stands using methods of tree-ring research

W. Beck

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Introduction

The conversion of pure even-aged coniferous forests existing at large areas, for instance in the north eastern German lowlands, is an avowed will of forestry and society in Germany and in many other European countries. Objectives of forest conversion are to overcome uniformity of forest structures, to get a higher degree of naturalness of tree species distribution, to get a higher degree of structural and biological diversity and to enlarge stability and robustness of forests against biotic and abiotic threats. An additional objective of forest conversion pronounced and investigated by the Institute for Forest Ecology and Forest Assessment is the hydro-ecological importance of forests for drinking water supply.

Model region: North- eastern German lowlands

The water budget of the north-eastern German lowlands is limited by the amount of precipitation of about 600 mm/yr. Sandy soils with low water holding capacity are the predominating substrate. The increase in summer temperature during the last 100 years in the region near river Oder is about 3,5°K. Typically drought periods occur during mid-summer. High loads of nitrogen depositions during the last 50 years emitted by industry, traffic and agriculture have changed site conditions considerably (ANDERS et al., 2002). The north-eastern German lowlands represent a border region of the natural distribution of the tree species beech (*Fagus sylvatica*), pine (*Pinus sylvestris*) and oak (*Quercus petraea* and *Q. robur*). Actually the share of pines in the forests is about 80%, however the natural portion is about 11%. Of the existing forests 74% are pure coniferous, 14% pure broadleaved and 11% mixed stands. That's why silvicultural policy aims to the enlargement of the broadleaved forest types to about 3% and of mixed forests to about 30%, according to 287.000 ha in total. This situation at large led to the wording of the scientific question: What are the ecological conditions and effects of forest conversion from pure even-aged pine stands towards pure beech stands via consecutive stages of mixed pine-beech stands (ANDERS et al., 2004) ?

Experimental design and methods

A series of sample plots was installed as a chronosequence of consecutive stages within the forest conversion process, starting with

- a pure pine stand (age: 84 years),
- a two-layer mixed stand (pine 51 years, beech 11 years),

- a two-layer mixed stand (pine 76 years, beech 33 years),
- a two-layer mixed stand (pine 114 years, beech 53 years) and
- a pure beech stand coming from a pine-beech-mixed stand (age 101 years)

at equal soil types with similar soil properties and inside the same forest district with equal climatic conditions. The research project comprised the following assessments:

- physical and chemical soil properties including humus layer,
- water fluxes in structural differentiable stand ranges (pine dominated; beech dominated; pine and beech in intensive mixture),
- soil biology and root ecology in pure and mixed stands of pine and beech,
- stand structure, net primary production and growth analysis of pure and mixed stands.

Within the forest growth assessment methods of tree-ring research were applied. The following investigations were carried out to acquire data and results on pure and mixed stands of pine and beech:

- stand-structural parameters and net primary production,
- recording of intra-annual diameter increment courses by high resolution measurements,
- taking increment cores of pine and beech sample trees to reconstruct growth development, actual growth behaviour, dependence on neighbourhood relations and climatic sensitivity,
- modelling climate impact on tree growth.

From the results obtained by the investigations mentioned above two examples were chosen to present the value of methods of tree-ring research within a framework of multi-disciplinary forest ecological research.

Results

Course of intra-annual diameter growth

The tracking of the seasonal course of diameter growth by high resolution circumferential measuring tapes is a suitable method to find out how weather influences growth activity. The secondary diameter growth of trees comprises the processes of cell division, cell enlargement and cell wall thickening which are running mainly simultaneously. Only the process of cell enlargement is measurable by macroscopic methods. The values obtained from high resolution diameter increment measurements are overlaid by fluctuations of moisture content inside stem and bark. Despite of these constraints the method of tracking the seasonal course of diameter growth by high resolution circumferential measuring tapes is suitable and useful to improve our knowledge on short-term reactions of different tree species to heat and drought or to precipitation events. Additionally a comparison can be made between the growth courses recorded in pure and in mixed stands. Figure 1 displays such a comparison between a pure pine stand, a mixed pine-beech stand and a pure beech stand.

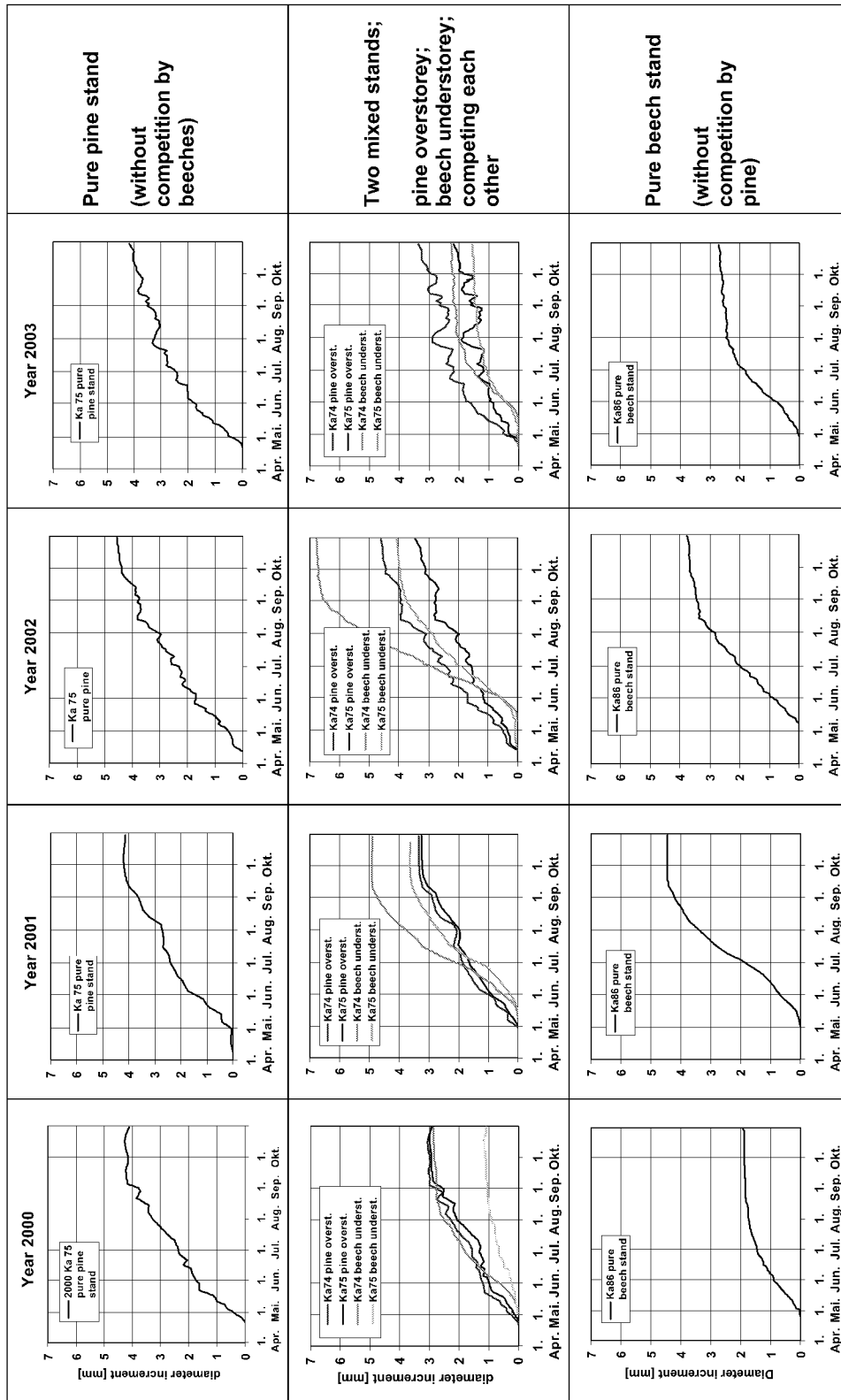


Figure 1: Comparison of intra-annual diameter growth course of pines and beeches in pure stands and in mixed stands

The following facts are discoverable:

- Generally the seasonal course of diameter increment of both, pine and beech follows a sigmoid curve.
- Pine reacts to transpiration stress (soil water shortage or high air temperatures) immediately. If the water shortage persists for several days or weeks stem diameter decreases. After a drought period pine can continue its growth immediately with the new supply of water.
- The seasonal growth course of beech is more stable than the one of pines. Beech is able to continue its growth in times of shrinkage of pines, due to water shortage. Apparently beech is able to use the existing soil water content more intensively than pines.
- Though weather conditions in the years 2000 to 2003 were distinctly variable, pine in pure stands shows nearly the same growth rates. Apparently pine is a very stress-tolerant tree species.
- Growth rates of beech in pure stands clearly reflect the actual weather conditions. Growth is enhanced by moist summers and depressed by hot and dry conditions.
- Growth course and growth rates of pine and beech in mixed stands are clearly affected by the increased water demand of two consumers which occupy the whole living space completely, aboveground as well as belowground. Growth rates of understorey-beech are stronger varied by weather conditions than those in pure stands. Growth rates and growth courses of overstorey-pines in mixed stands are also stronger varied compared with those in pure stands.
- When beech starts to grow, pines have taken up water already since 17 days in the average. Water resources for beech in mixed stands are limited already at the beginning of the growing season. Beech ends its growth 27 days earlier than pine. The growing season of beech is 43 days shorter than that of pine (comp. table 1). Seemingly the daily rate of water uptake by beech should be substantial higher than this by pines.

Table 1: Duration of diameter growth activity of pine and beech. Specified are the dates at which 5% and 95% of the total diameter increment of the season is reached. In the time span between "date 5%" and "date 95%" therefore 90% of the total annual diameter increment is produced.

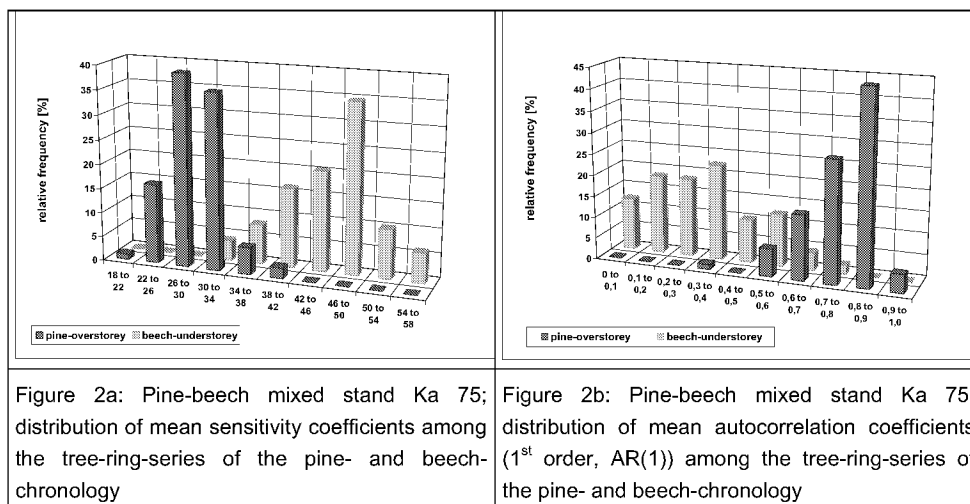
year	pine			Beech		
	date 5%	date 95%	Duration [no. of days]	date 5%	date 95%	Duration [no. of days]
1994	08. May	17. Sep	133	23. May	28. Aug	98
1995	06. May	21. Sep	139	09. May	05. Sep	120
1996	05. May	14. Sep	133	24. May	05. Sep	105
1997	04. May	03. Sep	123	22. May	24. Aug	95
1998	27. Apr	15. Sep	142	16. May	15. Aug	92
1999	18. Apr	04. Oct	170	25. May	20. Jul	57
2000	01. May	02. Sep	125	09. May	17. Aug	101
2001	08. May	12. Sep	128	11. May	14. Aug	96
2002	19. Apr	01. Oct	166	21. May	09. Sep	112
2003	28. Apr	05. Oct	161	14. May	30. Aug	109
average	30. Apr	18. Sept	142	17. May	22. Aug	99

- The modified growth behaviour of both, pine and beech in mixed stands clearly reflects the shortage of water resources and the superior role of interspecific competition.

The presented examples in figure 1 demonstrate that by application of high-resolution increment measurements valuable results on both climatic impacts on growth as well as on relations between different tree species in a mixed stand can be obtained.

Analysis of tree-ring series

Besides the analysis of long lasting diameter growth trends the investigations aim at the impact of climate on growth reactions of pines and beeches in pure and in mixed stands. From at least 30 dominant overstorey-pines and understorey-beeches increment cores were taken. After drying and sanding ring widths were measured using a LINTAB-device. Tree ring curves were detrended in two consecutive steps by i first order autoregressive process and ii smoothing splines. Parallel to the procedure of detrending first order autocorrelation-coefficient and sensitivity of each series was recorded. These two parameters together are appropriate to assess the ability of the two tree species to respond to climatic stress. Calculated values of sensitivity of tree-ring series express the mean size of alterations from year to year expected to be mainly caused by environmental factors. In that sense it has to be understood as a result or effect of climate impact. The autocorrelation coefficient exhibits the opposite. It describes the dependence of ring width at year t from that of year $t-1$. This dependence from earlier events is an expression of inertness of tree growth. High degrees of autocorrelation coefficient and significant autocorrelations of higher order represent a far reaching ability of trees to adapt to climatic stress. This ability is surely species specific. Figure 2 presents the distribution of sensitivity and 1st order autocorrelation coefficient of the chronologies of overstorey-pines and understorey-beeches.



Obviously pine is less sensitive to climate than beech and has a higher ability to adapt to climate events than beech as denoted by larger first order autocorrelation. Those are clearly more sensitive and show only low degrees of autocorrelation. Evidently beech seems to be more susceptible to climatic stress.

In a next step it is tried to describe annual growth reactions expressed by the time series of tree-ring indices dependent from climatic variables. The main aim is to predict effects of drought on tree and stand vigour. For the modelling approach the following preconditions were fixed:

- the models should be simple, not primitive,
- the number of variables should be limited,
- the models should enable forecasting of effects within reasonable limits of climatic assumptions.

Extreme values of tree-ring-index in time-series were chosen to be an appropriate variable to express the effect of favourable and unfavourable weather conditions during the growing season. Mostly such values of tree-ring-index represent pointer years or event years. This means on the other hand that years with tree-ring index values close to 1,0 have to be excluded, because they only compound the random noise inside the complex relationship of the climate-growth system. Deviations of precipitation und air temperature from normal values of the months from May till September were taken into consideration to form one variable for precipitation and one variable for temperature. Additionally, deviations of late winter temperatures (January to March) from normal values were included. The regression model which was performed is described by

$$y = a_0 + \sum_{p=1}^4 a_p \cdot x_p$$

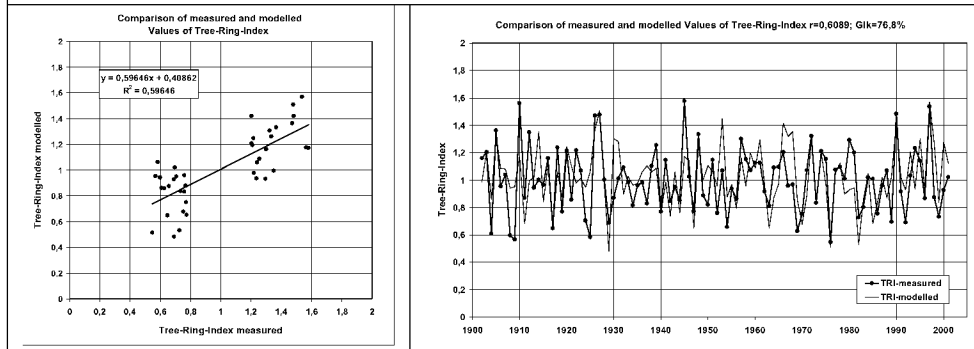
with:

- y: tree-ring index
- x_1 : mean daily temperature deviation for the period May till September
- x_2 : mean daily precipitation deviation for the period May till September
- x_3 : interaction term; $x_3 = x_1 \cdot x_2$, because x_1 and x_2 are correlated
- x_4 : mean daily deviation of late winter temperature from January to March
- $a_0 \dots a_4$: parameters of regression

The modelled results of climatic impact on growth reactions of over storey pines and under storey beeches of the mixed stand Kahlenberg 75 are shown in figure 3.

Pine-beech-mixed-stand Kahlenberg 75

Overstorey: Scots pine (*Pinus sylvestris*)



Understorey: Beech (*Fagus sylvatica*)

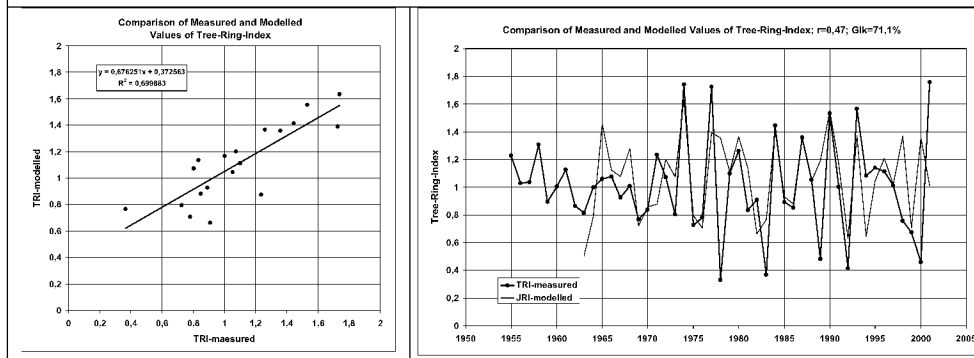


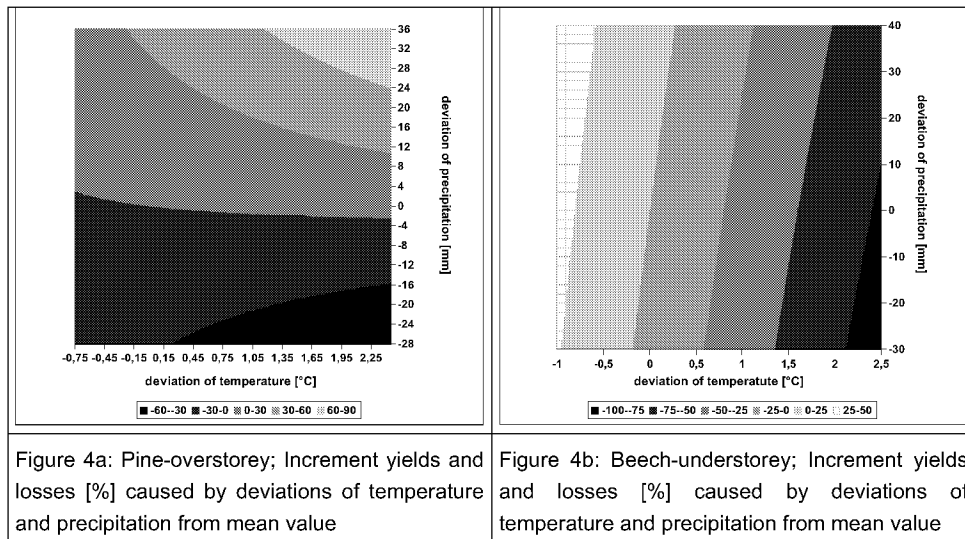
Figure 3: Results of climate-growth modelling for pine-overstorey and beech-understorey; left side, scatter plots: match of measured and modelled values of tree-ring index used in regression procedure; right side: match of measured and modelled values of tree-ring index time series.

These results from regression analysis seem to be quite reasonable. Besides the coefficient of determination the parameter "Gleichläufigkeit" (Glk) is appropriate to evaluate fidelity of mapping growth response by the model. The special meaning of the dependent variable tree-ring index (*TRI*) enables an additional interpretation. Values of $TRI > 1.0$ denote wide rings, values of $TRI < 1.0$ denote narrow rings. Therefore relative increment changing (*IC*) can be calculated:

$$\Delta IC[\%] = 100 \cdot (TRI - 1).$$

In that way increment gains or losses arise dependent from the constellations of temperature and precipitation during growth season. So the effects of drought and heat on tree increment

and vigour can be displayed inside the existing range of values of the time series (figure 4). Following basic relations are observable: The strongest increment losses of pines are caused by hot and dry conditions. If precipitation is sufficient increment is rising with increasing temperatures. Highest yields are bound to warm and wet conditions.



Beeches react with increment losses to elevations of temperature. Additional rain can compensate effects of high temperatures only in a small extent. This characteristic coincides with the general climatic claims of this tree species, the natural area of distribution of which is clearly stamped by Atlantic conditions. In the north-eastern German lowlands an ecological border situation is reached. The competition of pines and beeches concerning water resources in the mixed stand results in an aggravation of the conditions, especially for the beeches.

Conclusions

Methods of tree-ring research can contribute inside a framework of multi-disciplinary forest ecological research in a striking manner. Since decades methods in the fields of dendrochronology, dendroecology and dendroclimatology are well developed or are still under development. Findings as exemplified here cannot be obtained by other scientific disciplines. That's why it is very urgent to incorporate finally methods of tree-ring research as an integral part of forest ecosystem research. Actually this still seems to be more an exception than the normal case.

The enhancement of our knowledge on effects of climatic impacts on tree and stand vigour is of great importance especially regarding climate change. It is necessary and urgent to elaborate our quantified findings on all important native and foreign tree species. This provides the basis for realistic calculations of a future distribution of tree species, forest

structures and decisions concerning the choice of native or foreign species or provenances. Such improved knowledge and reliability for decision making is needed for a reasonable silvicultural policy. It is a duty of forestry to accompany and to design this process of forest conversion which is probably enforced by climate change.

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Spatial differences and temporal patterns of ring-width and density chronologies of the mountain forests of northern Central Asia

J. Block¹, V.N. Magda², D.V. Ovtchinnikov², A.V. Kirdyanov² & U. Treter¹

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Introduction

During the last ten years a dens network of tree-ring sites was established in northern Central Asia. Sample plots were preferably selected at the local lower and upper tree line respectively.

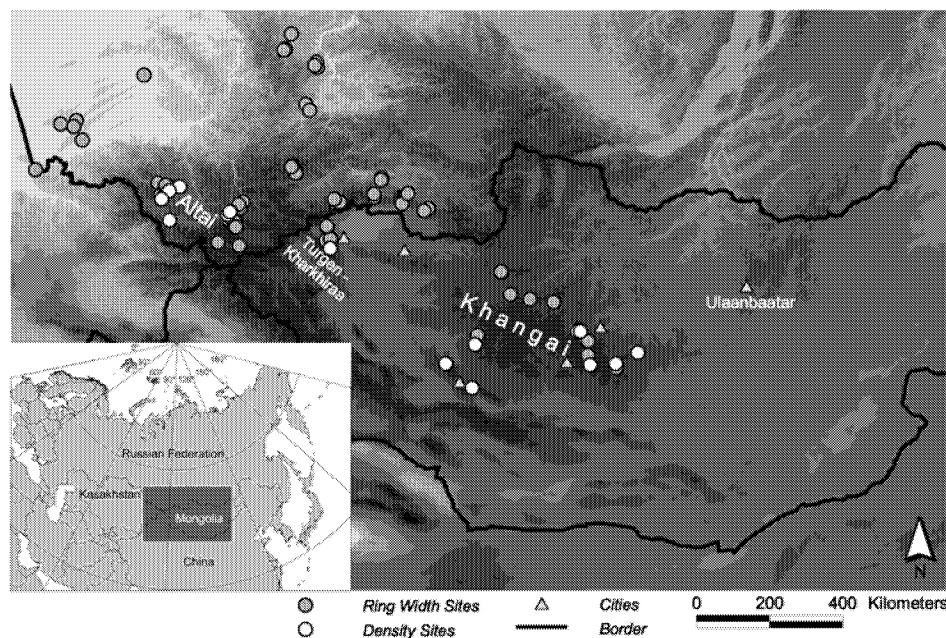


Figure 1: The research area with tree-ring width and density sites

Most parts of Mongolia, as well as several parts of Southern Siberia belong to the arid and semiarid regions of mid-latitude Eurasia. In this region the latitudinal vegetation belts from the boreal forest in the north to the steppe- and semi desert ecosystems in the south are broken by the vertical distribution of the vegetation in various mountain ranges (Sommer 2000). This leads to a mosaic of different forest types close to each other (Block et al. 2004).

Semi arid regions are generally fragile ecosystems (Yatagai 2003) and climate change may cause changes in the extend and composition of forest easily (Treter and Block 2003).

Most of the sites were located in the mountain ranges of the Republics of Altai, Tuva and Mongolia. Few sites are situated in the forest steppe in Southern Siberia. Besides the measurement and analysis of tree-ring width, a network of tree-ring density sites was established (Fig. 1).

Material and Method

Increment cores and stem disks were taken at preferably selected sample plots at the local lower and upper tree line. Most samples were taken from Siberian Larch (*Larix sibirica* Ledeb.). In addition at a couple of sites at the upper tree line samples from Siberian Pine (*Pinus sibirica* Du Tour) were collected. Only in the forest steppe areas in the mountain forelands larch is absent and samples were taken from Scots Pine (*Pinus sylvestris* L.). For the comparison of ring-width and density chronologies only larch sites are included.

Dendrochronological methods, as described by Fritts (1976), Cook and Kairiukstis (1990) and Schweingruber (1996) were used to prepare and measure samples and crossdate ring width data using TSAP and COFECHA. After separate crossdating in Erlangen and Krasnoyarsk the data was joined and crossdated again. Then the ring width data was processed with ARSTAN to site chronologies.

The samples for the measurement of wood density were prepared and measured as described by Schweingruber (1983, 1996). The measured data of maximum latewood density was crossdated and the first 50 years of every tree-ring density series were removed to reduce the influence of age trend. Then the data was processed with ARSTAN to site chronologies.

For the analyses of the spatial and temporal patterns of tree-ring width and density Pearson's correlation coefficients and cluster analyses were used (Block et al. 2004, Magda et al. 2004).

Results

Cluster analyses and analyses of correlations between tree ring width chronologies of the whole region for longer time periods (100 to 300 years) show well defined groups. All sites from upper tree line, as well as the sites from lower tree line form one separated group with high cluster distance between each other (Block et al. 2004). In these groups of upper and lower tree line sites different regions are represented as subgroups. For shorter periods, which were investigated with stepwise clusters with a 25 years window, changes in these groups were found (Magda et al. 2004). Moving correlations, which were calculated between sites from upper and lower tree line show periods with positive, negative and without correlations. This explains the switch of some sites to different groups in several periods. The moving correlations between sites are correlated with summer temperatures (Block et al. 2004). This paper is focused to the 14 sites for which ring width and maximum density chronologies are processed (see Fig. 1).

Spatial differences

The results of cluster analysis for the common period from 1811 – 1994 of the 14 sites for which ring width and maximum density chronologies are available, show different results for ring width and density data (Fig. 2). The highest cluster distance for ring width chronologies was found between a group of lower tree line sites of Mongolia including one intermediate site from Altai (Fig. 2a, 1-2) and a group of upper tree line sites from Mongolia and Altai and lower tree line sites from Altai (Fig. 2a, 3-5). In this second group the lower tree line sites are clearly separated from the upper tree line sites.

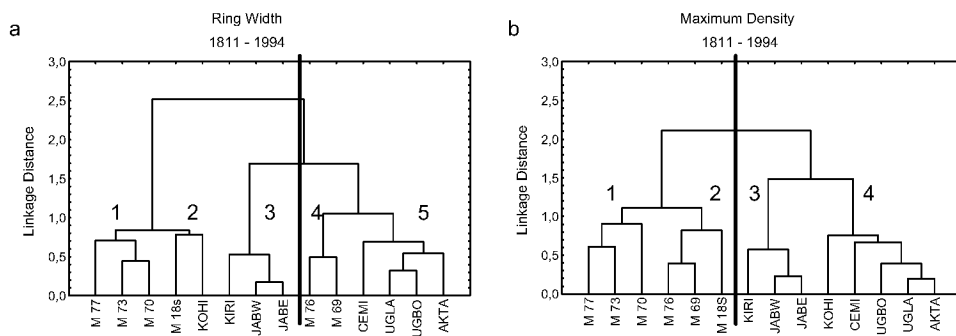


Figure 2: Tree Diagrams (Ward's method, 1-Pearson r) for ring width (a) and maximum density (b) for the 14 selected sites for the common period. Black line in a) divides upper and lower timberline sites, black line in b) divides sites from Mongolia and Altai. Numbers mark groups from upper (a4, a5, b2, b4) and lower timberline sites (a1, a2, a3, b1, b3).

The tree diagram for density chronologies (Fig. 2b) shows the highest cluster distance between the two investigated areas of Mongolia and Altai. In the two main groups the sites from lower and upper tree line of each region form well divided subgroups (Fig 2b, 1-4).

Temporal patterns

For the analysis of the temporal patterns only the six sites in Mongolia were selected. The results of cluster analysis for the common period from 1811 – 1994 are nearly equal, except the intermediate site M 18s, which belongs in the tree diagram of ring width chronologies to the group of lower tree line and in the tree diagram of maximum density chronologies to the group of upper tree line (Fig. 3a and b).

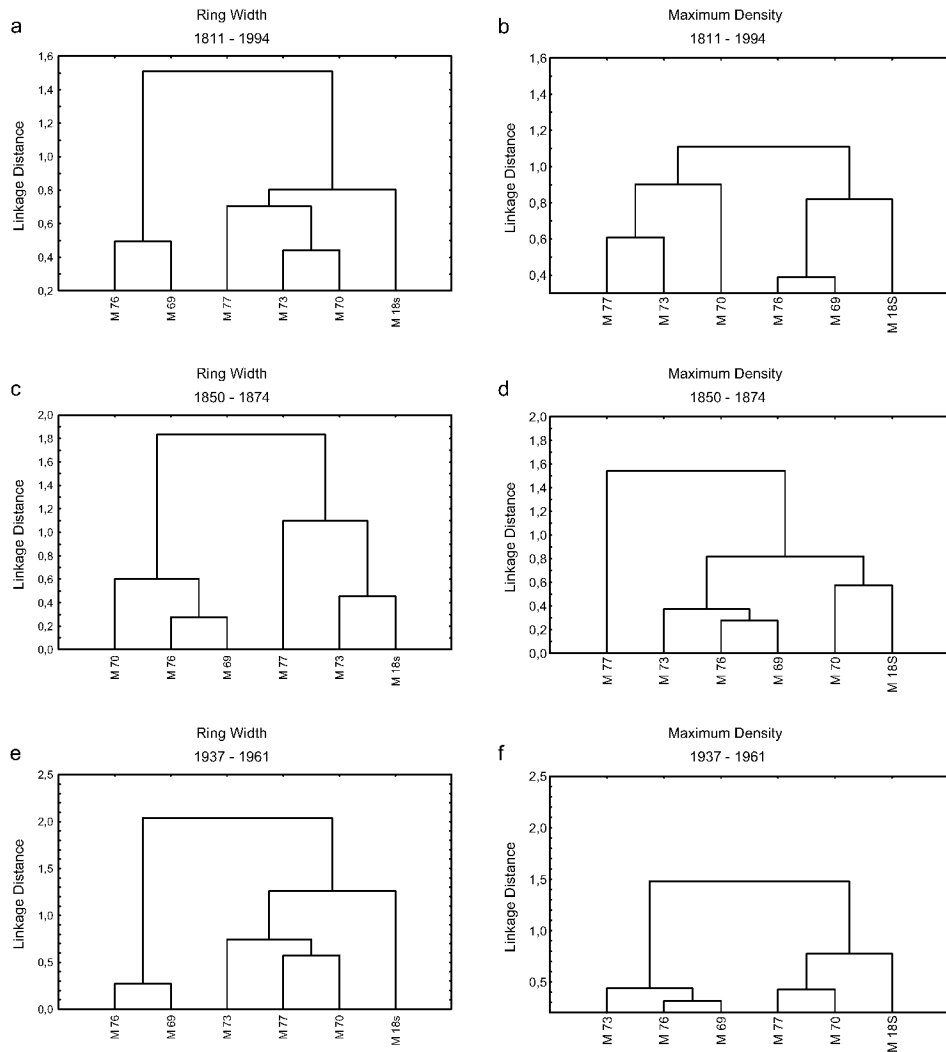


Figure 3: Tree Diagrams (Ward's method, $1-Pearson\ r$) for ring width (a, c, e) and maximum density (b, d, f) for the 6 selected sites in Mongolia for the common period (a, b), a period with lower differences between upper and lower timberline sites (c, d) and a period with higher differences between upper and lower timberline sites (e, f).

The stepwise cluster analysis with 12 years steps and a window of 25 years have shown several periods with different distribution of sites in the tree diagrams. The two periods 1850 – 1874 and 1937 – 1961 shown in Fig. 3 represent extreme differences between a known cold period in the 19th century and a warm period in the 20th century (Ovtchinnikov 2002).

The tree diagrams for the warmer period in the middle of the 20th century show the same clear groups for upper and lower tree line sites then the tree diagrams of the common period, but the differences in the groups are much smaller, especially in the diagram for the maximum density chronologies (Fig. 3f). For the cooler period in the middle of the 19th century the clear groups of upper and lower tree line sites disappear and some sites from lower tree line switch to group of upper tree line sites (Fig. 3c) or be separated (Fig 3d). The cluster distances show that the differences between regions become stronger then the local differences between upper and lower timberline sites of one region.

Conclusion

The analyses of ring width and density chronologies show clear spatial differences and temporal patterns. The comparison of the results from cluster analysis for the whole region and the common period show, that ring width data has bigger differences between upper and lower tree line sites and the data of maximum density has bigger differences between the regions (Fig. 2). Considering the dependence of density values from summer temperature (Schweingruber 1996), the sites in Mongolia belong to different temperature regimes then the sites in Altai, or trees show different reaction to temperature due to other factors. In the ring width data also the moisture signal is included, but decreasing moisture influence with increasing elevation of the sites can lead to more or less common reaction of trees at upper tree line sites in both regions (Fig 2a, 4-5).

The results of stepwise cluster analysis show clear temporal patterns. In the cooler period of the 19th century the moisture stress of some lower tree line sites decreased and the temperature signal in these sites became stronger. The result is that some sites start to become closer to upper tree line sites. In addition it seems that in this period the differences of the temperature signal are higher then the signal of moisture, which increases the cluster distances between regions, see for example the separated site M 77 in Fig. 3d, which is the most eastern site in the Khangai Mountains. In the warmer period in the middle of the 20th century, the moisture stress in this semiarid region increased. The sites are divided in the two groups of upper and lower tree line sites. The trees at the upper tree line are able to react more or less to the influence of temperature because they have enough moisture. At the lower tree line during this period the reaction of trees to the influence of temperature is decreasing due to the lack of moisture. This fact could explain the high cluster distance between upper and lower tree line sites for this period (Fig 3e-f).

Analysis of ring width and maximum density chronologies gave similar but not always equal results. The analyses of temporal patterns in one region gave nearly equal results for ring width and maximum density chronologies but the analysis between Mongolia and Altai show different results. It is concluded, that the analyses of maximum density chronologies can give more detailed results for the interregional comparison of tree ring sites then the ring width chronologies.

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Sources for map in Figure 1 were obtained from GTOPO30, US Geological Survey (USGS) and the Digital Chart of the World.

Regeneration dynamics of Norway spruce (*Picea abies* L.) on a subalpine meadow near the treeline in Sedrun, Kt. Graubünden, Switzerland

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Introduction

Recently, the European alpine region undergoes substantial changes as far as land-use and climate are concerned and these trends are going to continue. The global average surface temperature has risen by about 0.3 to 0.6 degrees and the mean global temperature of the last decade was the warmest of the last 1000 years (IPCC 2001). Since plant growth in alpine tree-line ecosystems is temperature limited (Körner 1999), global warming is expected to have drastic effects on plant growth, vegetational composition and tree line position in the alpine region (Körner 1998, Rolland et al. 2000, Moiseev et al. 2004). These effects interfere with ongoing land-use changes. In the last few decades a majority of former agriculturally used grasslands in the Swiss mountain areas near the treeline have been abandoned because of decreasing commercial value. Some of these areas undergo a process of tree invasion while others do not. These meadows provide a unique opportunity to study natural regeneration dynamics of Norway spruce near the tree line. We investigated the regeneration patterns on a south-facing, since 1950 abandoned meadow at 1900 m a.s.l. in Sedrun, Kt. Graubünden, Switzerland. Tree establishment and growth dynamics were studied using dendroecological methods and an assessment of vegetation and soil was conducted in order to investigate the relationship between site properties and tree establishment. The following questions were of special interest: 1. Does the regeneration on this site consist of different successional states and is succession moving slope upwards away from the former forest edge? 2. In what dynamics does the process of tree establishment proceed? 3. Do growth patterns depend on the distance from the former forest edge and slope position and what factors control growth at this site?

Materials and methods

Data sampling was conducted along five transects of 60 m length starting in the mature forest and ending in the upper-slope area of the former meadow. Increment cores and stem discs of 95 saplings were sampled. Per tree, two cores or stem discs were extracted; (i) one at the base of the stem above the root collar in order to obtain an accurate age estimation, and (ii) another one at the lowest vertical growing point of the stem in order to analyse radial growth without the interference of reaction wood. Tree height, stem diameter at extraction height and the amount of vertical branches (multiple stems) of each sapling was recorded.

Additionally, 21 mature trees at the former forest edge were cored at breast height to serve as a reference.

The sampled increment cores and stem discs were sanded and digitally measured using the software program TSAP (Rinn (Heidelberg)) and subsequently synchronised. All samples of the mature trees of the former forest edge were standardised (double-detrending) applying the software package ARSTAN (Version 6.05P) (Cook 1985). An analysis of simple correlation was conducted between the detrended masterchronology of residuals and the monthly temperatures. Along three transects a vegetation assessment of 48 1x1 m-plots in total was conducted and 17 soil profiles were dug and described.

Results and discussion

Site description

Three different successional states could be identified along the transects using tree density as indicator for the state of regeneration: 1) Close to the forest edge: Up to 15 m distance from the former forest edge tree density varied between 0.3 and 0.6 trees / m². 2) Middle slope: Between 15 m and 35 m distance from the forest edge tree density decreased to approximately 0.1 trees / m². 3) Upper slope: From the distance of more than 35 m to the forest edge on, tree density was lower than 0.025 trees / m².

The soil was characterised as Podzol with a thick raw humus (Gisi 1997). The organic topsoil layers tended to increase slope upwards while the humus-mineral horizon (Ah) decreased in thickness.

There was a significant difference in vegetation structure between the successional stages (for each vegetation layer: Kruskal-Wallis, $p > 0.05$). Vegetation ground cover was increasing with distance from the former forest edge, while bare ground occurred mostly in the old forest and in the area close to the forest edge. The cover of the herb and grass layer was abruptly decreasing slope upwards and dwarf shrubs were dominating middle and upper slope with a cover of about 90%.

An analysis of Ellenberg values (Ellenberg 1974), which are ecological indicator values, revealed an increase in the average moisture value of the assessed species slope upwards, while the average nutrient value and reaction value were decreasing (all Ellenberg values: Kruskal-Wallis, $p > 0.001$). This indicates a change to wetter, more acid and nutrient poorer conditions slope upwards, respectively with distance to the former forest edge. As far as vegetation composition is concerned a change from woodland species (for instance *Avenella flexuosa*, *Melampyrum sylvaticum* and *Vaccinium myrtillus*) to open heath species (for instance *Calluna vulgaris*) was detected with distance from the former forest edge.

The area close to the forest edge seems to be the most advanced state of the three identified successional states. The results above show that there exists a close relationship between the three successional states and vegetation and soil characteristics. The abrupt decrease of tree density could be a consequence of harsher environmental conditions with distance to the former forest edge. The area close to the forest edge takes an intermediate position in

vegetation structure and composition as well as in environmental conditions between the old forest and the open heath of the middle and upper slope.

Regeneration dynamics

The main establishment period took place about 15 years after the abandonment of the agricultural use, from 1965 until the beginning of the 1980's, in the whole study area irrespective of the distance to the former forest edge (Fig. 1). Only in the area close to the forest edge, some trees were established before and after this period. Therefore, tree establishment must be favoured in this area. Tree establishment on this site seems to be a continuous process. However, tree establishment in the middle and upper slope region has ceased since the beginning of the 1980's despite periodical mast fruiting in the region. We conclude that the absence of any regeneration might be due to a lack of suitable microsites, which were already occupied by regeneration during the past decades (Donnegan and Rebertus 1999).

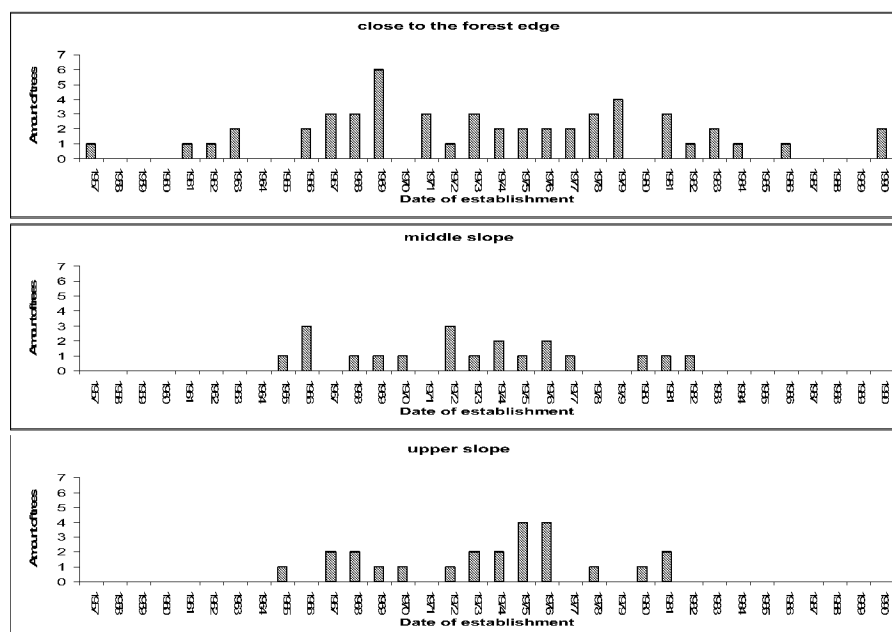


Figure 1: Tree establishment per area.

Growth dynamics

There was no significant difference in tree height between the three areas, but maximum tree height tends to decrease slope upwards. The ratio height / age decreased significantly slope upwards (One-way ANOVA, $p=0.029$). This leads to the conclusion that vertical growth must be favoured close to the forest edge due to better growth conditions.

There was a noticeable difference in growth forms between the three areas (Fig. 2). The forming of vertical branches (multiple stems) became more frequent slope upwards (Kruskal-Wallis, $p=0.001$). Forming of vertical branches is normally induced if the main stem breaks or dies and subsequent branches get upright and overtake the function of a leader shoot (Marr 1977, Schönenberger et al. 1994, Ott et al. 1997). This makes it likely that biotic and abiotic factors which damage the main stem axis, for instance snow pressure, snow mold, frost or winter desiccation, were more frequent or more intense slope upwards with increasing distance to the protective influence of the forest edge.

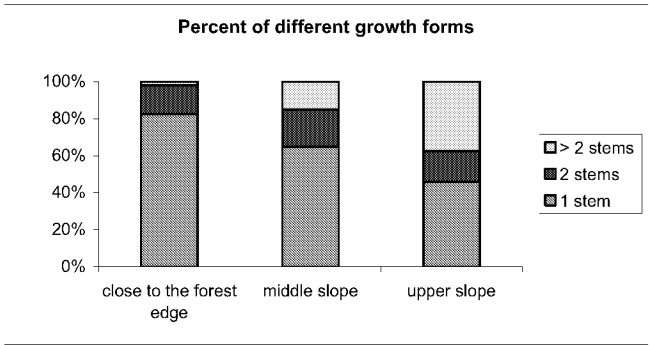


Figure 2: Percent of vertical branches per area.

The comparison of the mean radial growth curves (Fig. 3) revealed no difference in growth patterns between the three different areas of the regeneration, but an enhancement of radial growth since 1990 of all the saplings. Mature trees at the former forest edge showed no such effect. Since all sampled saplings showed this increased radial growth irrespective of their position in the research area or their age (the age of the saplings ranged from 13 to 46 years), we conclude that only a common factor such as climate can act as a trigger.

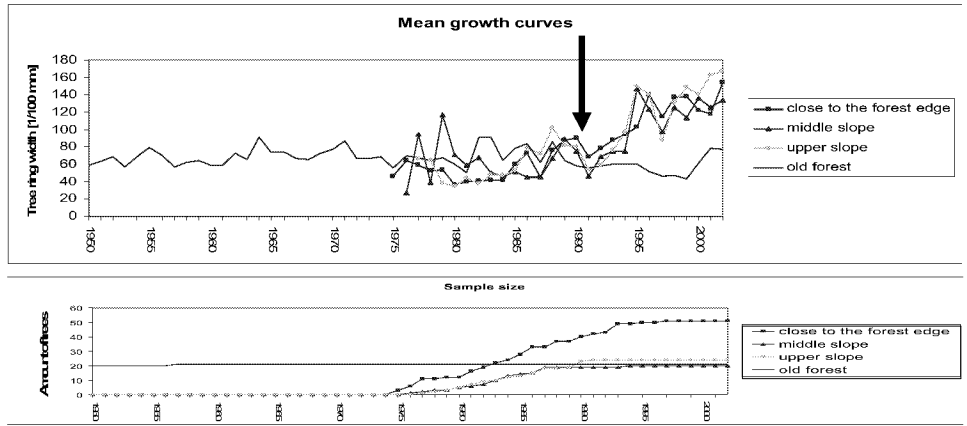


Figure 3: Mean radial growth curves per area and calendar date.

Therefore, a climate-growth analysis was conducted, which revealed that growth at this site is mainly limited by the mean June and especially July temperature (Fig. 4).

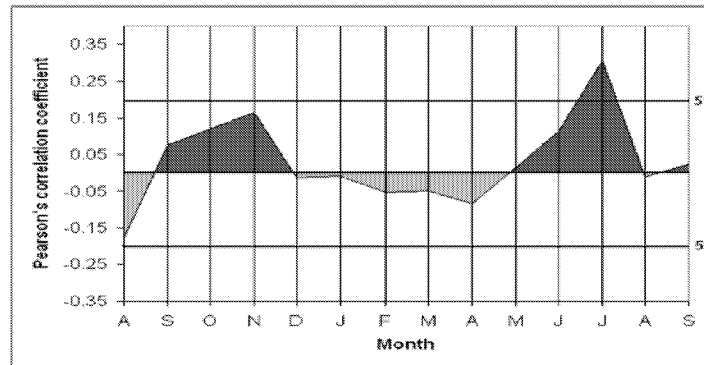


Fig. 4: Correlation between the mean June-July-temperature and the standardised mean radial growth curve of the mature trees in the old forest. The lines indicate the 5%-level of significance.

The analysis of the temperature anomalies for this region (Fig. 5) revealed higher mean June-July temperatures since 1990 compared to the average of the last 40 years. This coincides with the beginning of the period of increased sapling growth rates. A similar growth increase in tree rings of young conifers in the subalpine region related to climate warming has been reported by several authors (Neumann and Schadauer 1995, Jungwirth 1998, Paulsen and Körner 2001).

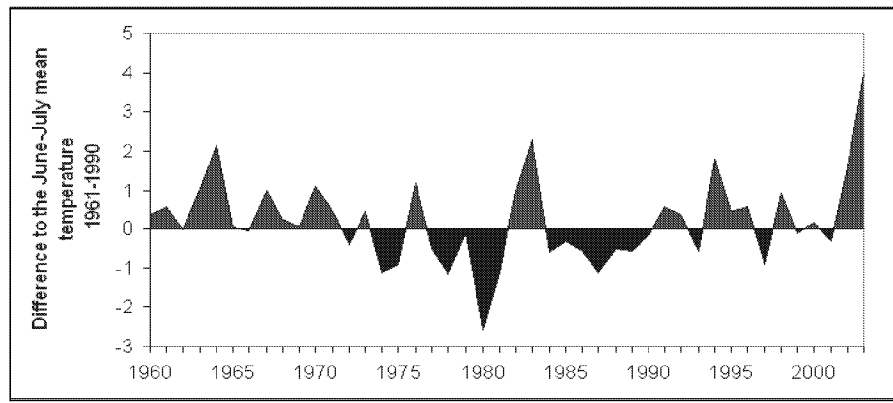


Figure 5: Anomaly of the mean June-July-temperature in the last 40 years.

Conclusions

The here presented results allow the following conclusions:

- Vegetation and soil patterns as well as growth patterns show that environmental factors are changing slope upwards and growing conditions get worse. This indicates a steep environmental gradient on the study site.
- Since the age distribution of the regeneration is not depending on slope position, the process of tree establishment is not a succession moving away from the former forest edge. Most trees were established in the same period. Only close to the former forest edge, regeneration continued after this period. The absence of tree establishment in the middle and upper slope for the last two decades is likely to be a consequence of the lacking in suitable microsites.
- Growth form and height growth depend on the position on the slope. Trees close to the former forest edge are able to grow taller than trees in the middle and upper slope. And trees in the middle and especially in the upper slope form more often multiple stems what indicates harsher conditions slope upwards.
- Therefore, tree establishment and growth patterns on the site are the result of environmental conditions that vary in space and time. Growth and establishment is favoured close to the forest edge.
- Enhanced radial growth rates coinciding with a period of increased summer temperature was detected for all saplings. This suggests that radial growth of young Norway spruce reacts sensitive to warmer summer temperature.
- Our findings underline the importance of available microsites for tree establishment near the tree line, the strong influence of highly variable environmental conditions on growth and establishment and the sensitivity of the tree-line ecotone to increasing summer temperatures.

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Contributions to the ecology of common beech as derived from tree-ring analyses

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Introduction

Tree rings are used in a wide range of scientific fields. Dendrochronology is one of these fields to which dendroecology can be assigned as important discipline. Its intention is to get environmental and physiological information about the various growth influences from tree-ring sequences, structures or other signals storied in tree rings. Forest scientists use dendroecological tools in order to get information, for instance, about:

- the growth potential of trees under different site and climatic conditions;
- former or recent environmental influences – biotic or abiotic, natural or anthropogenic – which have a distinct effect on trees growth, vitality or ecological fitness;
- range of site specific reactions to these influences or, as derived from this, the ecological range of a certain tree species.

Concerning the latter point, the presented contribution focuses on following questions:

- How distinctly reflect tree-ring widths of Common beech (*Fagus sylvatica* L.) environmental influences?
- What kinds of climatic influences mainly control radial increment of beech in Central Europe?
- What kinds of environmental changes will mainly affect growth and vitality of Common beech in Central Europe?

Data background and analyses

Background of the following evaluations are tree-ring data of more than 43 beech stands in Southern Germany and around 20 beech stands at sites on the eastern, western, northern and southern part of Europe (Dittmar et al. 2003a/b). To avoid effects of competition and suppression, only dominant trees (tree class 2 according to Kraft 1884) were sampled at each site. Normally, at each of 20 sample trees, 2 increment cores were taken. Measurement, synchronisation, dating and the analyse of climate-growth-relationships were carried out according to Dittmar & Elling (1999) and Dittmar et al. (2003a/b), respectively. In order to characterize the temporal variation of site specific water supply, water-balance calculations were carried out according to Rötzer et al. (2004).

Sensitivity of Common beech tree-ring series

Typical for beech is a high sensitivity of ring widths at most of the investigated sites. While measuring ring widths in mixed stands, one will usually find a higher sensitivity at beech series compared to other tree species, e.g. coniferous trees (Figure 1). The mean sensitivity is a degree of the intensity of growth fluctuations from year to year and of the frequent occurrence of particular narrow or wide rings. Typical for beech are also sharp reactions in single years without lag effects, that means: extreme narrow up to even missing rings, and a complete recovery of increment in the following year. A high sensitivity in ring widths reflects a sensible reaction to environmental factors. This characteristic makes beech highly suitable for dendroecological analyses.

Sensitivity is especially high, if one factor with a high variability from year to year limits growth. Depending on the site, however, beech can be sensitive to very different influences as shown by the climate-growth relationships described below. Beside a high sensitivity, another repeated observation is remarkable: Beech has an underestimated high growth potential on warm and dry sites (cf. Elling & Dittmar 2003). Compared to spruce, for example, beech is much more drought resistant.

Climate-growth relationships

In southern Germany climate-growth relationships were studied along an altitudinal gradient between around 300 and 1450 m a.s.l. (Dittmar & Elling 1999, Dittmar et al. 2003a/b). At low altitude sites, ring widths of beech are strongly related to water availability. High temperatures, because they are normally accompanied by low precipitation, reduce ring widths. By contrast, at high altitude sites, above around 800 m, temperatures and ring widths are positively correlated. There, even negative correlations between water availability and increment were often found. Under these site conditions temperature, radiation and the length of the vegetation period are the main growth limiting factors.

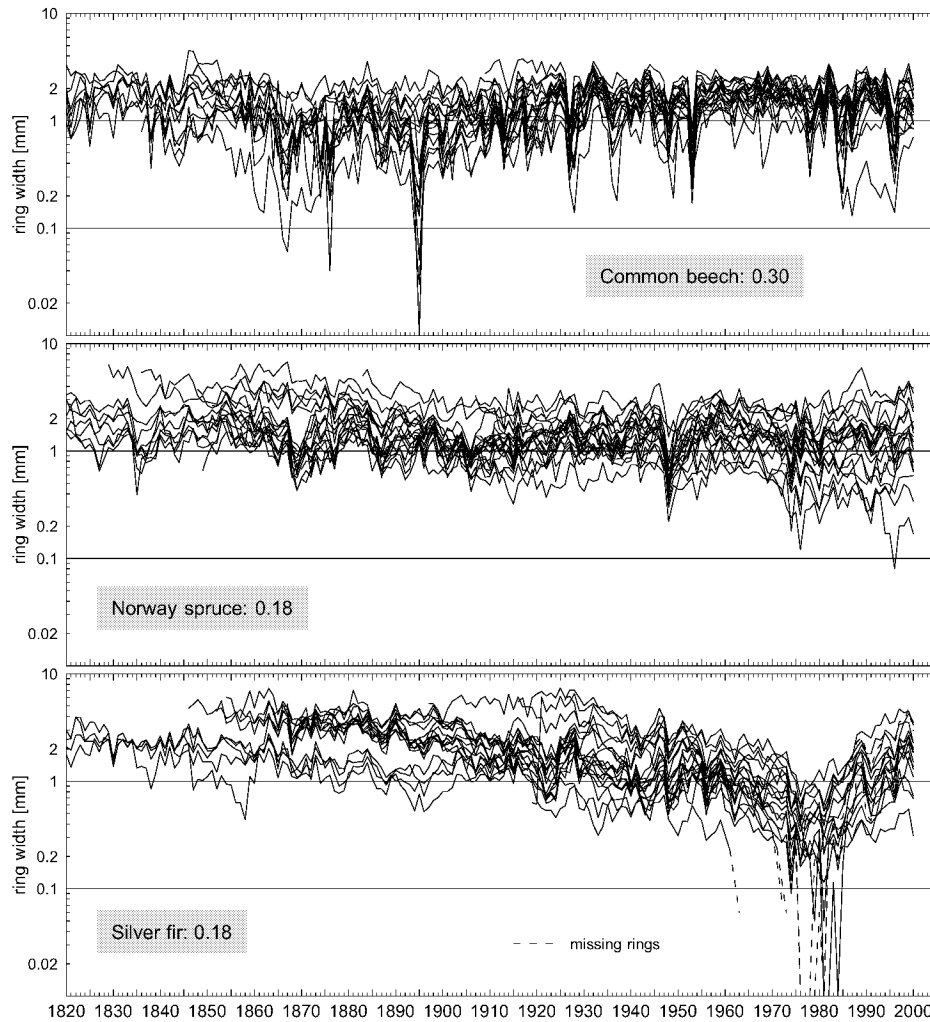


Figure 1: Tree-ring widths of Common beech, Norway spruce, and Silver fir at the mountain Brotjacklriegel (Bavarian Forest, 965 m a.s.l.). For each tree species radial increment of 20 dominant trees (tree class 2 according to KRAFT, two radii per tree) are plotted in semi-logarithmic diagrams. Plotted with dotted lines are series after the occurrence of missing rings. The sensitivities of tree-ring data were calculated for comparable time spans excluding the growth depression of Silver firs around 1980: 1775 – 1970 for Common beech, 1793 – 1970 for Norway spruce, and 1797 – 1970 for Silver fir. (tree-ring data according to RIFFESER and AMBROS 2001, REISCHL 2002).

Water balance and radial growth

In dendrochronology and dendroecology, normally precipitation data are used in order to establish relationships between water availability and tree-ring growth. Sometimes also the climatic water balance is applied. But despite of an often overestimated evapotranspiration (Laatsch 1969), the climatic water balance takes no stand and site specific properties into account. In the presented investigations, a site and soil dependent water balance model was established for a more realistic estimation of water supply (Elling et al. 1990, Rötzer et al. 2004). The model HyMo (for details see Rötzer et al. 2004) provides long-term daily values of different water balance parameters. As input data the meteorological parameters temperature, precipitation, air humidity, wind speed and radiation are used. These parameters, measured at climatic stations, were transformed with regional and time specific transfer functions in order to obtain site specific conditions. A second set of input data are soil and stand properties carefully evaluated at each site. Additionally, HyMo takes snow smelting, fog precipitation and phenology into account. As continuous records daily data of climatic stations can be used, HyMo enables the retrospective calculation of water balance data. In this way, it is a valuable tool for dendroecological analyses as shown by the example in Figure 2.

At one site in Northern Bavaria near Würzburg, climatic and soil conditions cause a distinctly water limited growth (Figure 2a). A strong correlation between the actual available water content of the soil and the ring widths was obtained (stronger than between precipitation and radial growth: $r = 0.42$, $p < 0,01$). By contrast, at the high altitude site of the Bavarian Alps, no – even an almost significant negative – correlation between soil water content and radial growth was found. There, water availability is not restricted in most of the years, but the vegetation periods are often too cold, too wet and too cloudy. Hence, tree-ring widths correlate with temperature (Figure 2b).

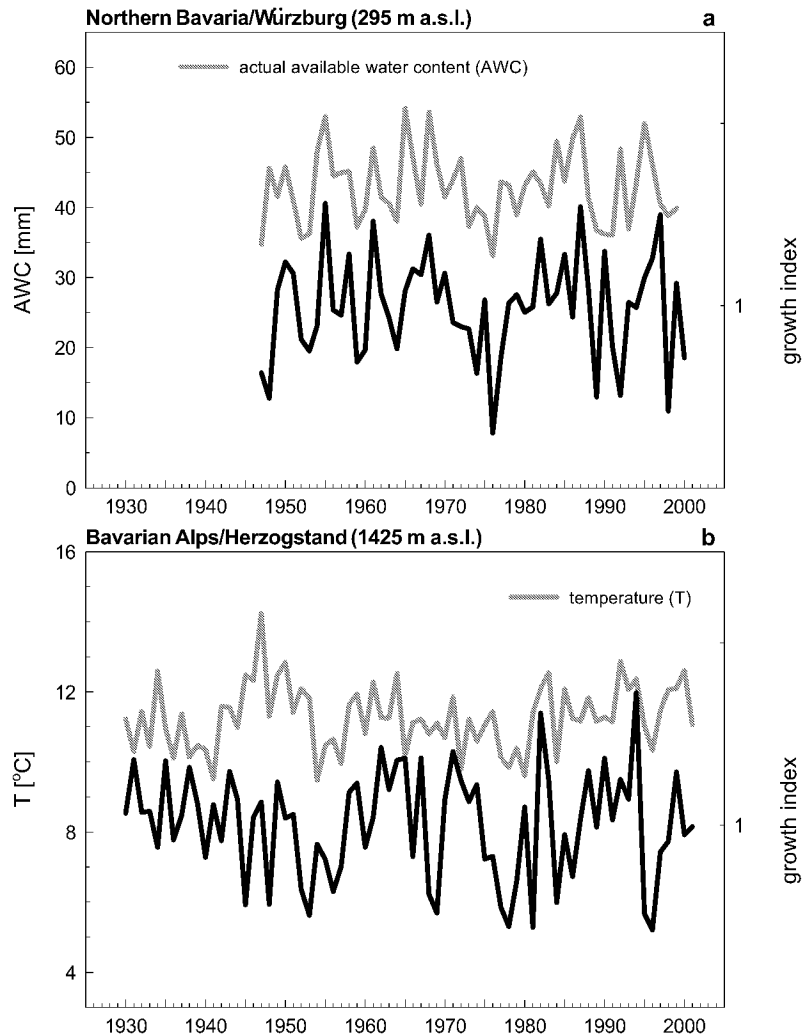


Figure 2: Relation between (a) the actual available soil water content (AWC, averaged for the vegetation period) and the radial growth of beech in Northern Bavaria (correlation: $r = +0.49$, $p < 0.001$, 1947-1999) and (b) the temperature (T, measured at 2 pm, averaged for the vegetation period) and radial growth of beech at the Northern Alps (correlation: $r = +0.23$, $p < 0.05$, 1931-2001). The AWC was calculated with the water balance model HyMo (RÖTZER ET AL. 2004). The average growth index (residual chronology) was derived from 20 trees (40 radii) at each site (tree-ring data according to SCHRAUDER and REITHMEIER 2002 and ELLING and DITTMAR 2003, respectively).

Impact of late frosts

At mountainous sites, an additional important and temperature related factor was found: the impact of late frosts. This factor, however, cannot be detected in continuous climate-growth relationships, but can be the reason of weaker dependences of growth on average weather influences. Sudden cold spells caused by advective transport of cold air at the beginning of the vegetation period can strongly damage the foliage, if temperatures fall below -3°C and fresh leaves are affected. In tree-ring records, we found signals of late frost events especially pronounced, if they occurred during the days around or immediately after leaf unfolding.

Forest sites investigated by dendroecological analyses usually are not located directly nearby meteorological and phenological stations. For the investigation of relations between late frost and pointer years, therefore, the site specific minimum temperatures and the site specific timing of leaf unfolding have to be considered. If corresponding data sets are available, impacts of late frost events on radial growth in certain years can be recognized. One example is shown in Figure 3.

Despite of a high deviation of leaf unfolding data in 1952, until the late frost at 21th of May, leaves of beech at all altitudes at the northern fringe of the Alps should be unfolded. Minimum temperatures, however, only fell below the threshold value for frost damage (-3°C) at altitudes above around 1100 m a.s.l.. Accordingly, only at altitudes above 1100 m signals in tree rings of beech can be expected. Radial series of several stands in different altitudes confirm this expectation (see Figure 4): At lower altitude sites, no reaction – sometimes even a maximum – was found in the year 1952. By contrast, at high altitudes, strong increment reductions occurred and can be related to late frost impacts. In May 1953, many beech trees at sites above around 800 m a.s.l. were affected by a further late frost.

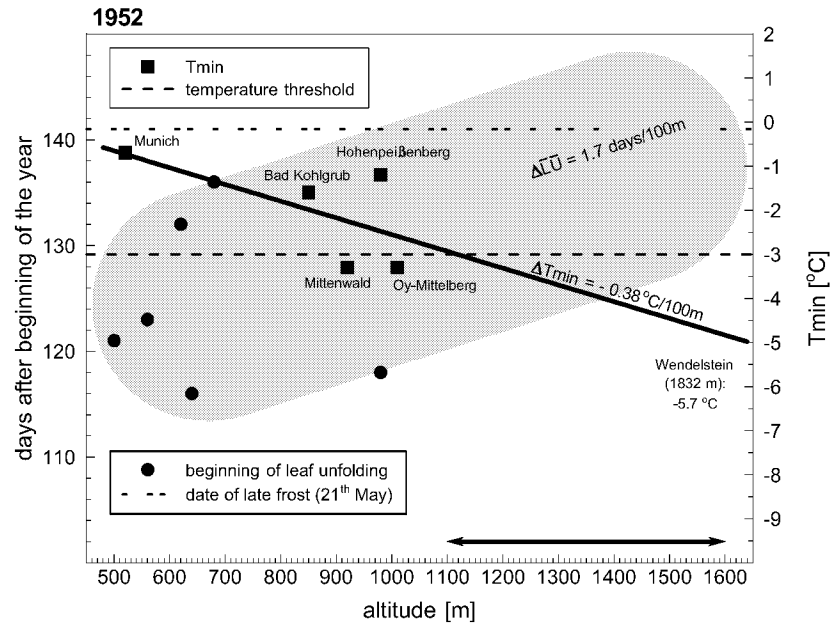


Figure 3: Minimum temperatures (T_{min} , plotted as ■ on the right axis) during the late frost event at 21st May 1952 at different climatic stations and beginning of leaf unfolding (LU, plotted as ● on the left axis) in this year at different phenological stations at the northern fringe of the Alps. The grey area indicate the dispersion of LU data and the long-term average of the altitudinal gradient of LU. T_{min} decrease with altitude during the day of late frost is plotted as regression line. Altitudinal belts, endangered by late frost impacts, are signed by an arrow.

Accordingly carried out investigations of late frost impacts on radial growth of beech for longer periods and at different sites revealed: With increasing altitude the frequency and intensity of late frosts at the beginning of the vegetations period increases and with it also an increasing number of negative pointer and event years can be related to late frost impacts (Figure 4).

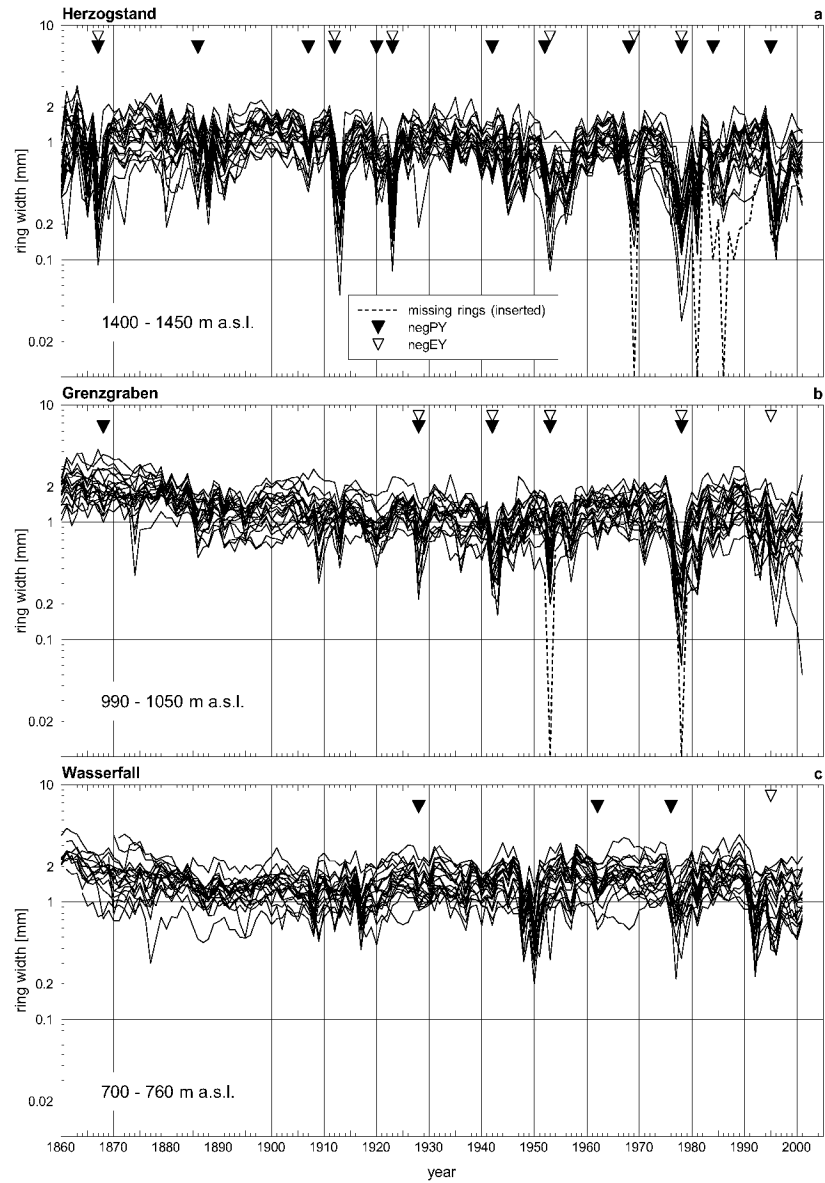


Figure 4: Tree-ring widths of 3 stands at different altitudes at the northern slope below the Herzogstand mountain (Bavarian Alps). For each site radial increment of 20 dominant trees (tree class 2 according to KRAFT, two radii per tree) are plotted in semi-logarithmic diagrams. Missing rings are signed by dotted lines. Signed as triangles are negative pointer (negPY) and event years (negEY), respectively, according to DITTMAR and ELLING (1999) which can be related to late frost events in the same years.

Conclusions and Summary

- On many sites in Central Europe, tree-ring widths of Common beech reflect a sensitive reaction to environmental influences. This feature favours the application of dendrochronological and dendroecological investigations.
- Depending on the site, however, growth influences are very different: On dry sites – normally at low altitudes – water availability is the main growth limiting factor. By contrast, on mountainous sites, temperature and radiation are the main growth controlling factors. With increasing altitude, the importance of late frosts increases.
- Comparing the increment on different sites, Common beech shows a high growth potential on dry sites in Central Europe.

Concerning the question, what kinds of environmental changes will mainly affect the growth of Common beech, following is concluded:

- Increasing temperatures will not be a serious problem for beech vitality at most of the forest sites in Central Europe. At high altitude sites, warming would even improve growth potential; on condition, however, that the frequency and intensity of late frost will not increase.
- Decreasing precipitation in summer months will only affect radial growth on dry sites and soils with a low water storage capacity. In Bavaria, only a small part of forest sites will be affected.
- The high and increasing input of nitrogen and the high ozone pollution in many Central European regions are considered as serious risk factors for Common beech. At the Northern Alps, growth disturbances since the late 1970s, preceding crown symptoms of a decreased vitality in the 1980s, were repeatedly found by dendroecological investigations in the last years (Elling & Dittmar 2003). During summer 2003, visible ozone symptoms at beech leaves at several sites above around 900 m a.s.l. indicating acute photooxidative stress were observed (Dittmar et al. 2004).
- Further investigations are required to answer questions about long-term impacts of nitrogen and ozone on the vitality and ecological fitness of Common beech in Central Europe. As shown by this contribution, tree-ring data should be more considered in this context by the application of suitable dendroecological tools.

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The effects of the opening of a construction site on high-mountain tree vegetation

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Introduction

The objective of this study was to estimate the impact of construction site activities on tree vegetation in a high-mountain area. The site was opened by one of Italy's main energy suppliers (AEM: Municipal Energy Utility), which has had a hydroelectric plant in operation in upper Valtellina since the 1920s. The "New Viola Canal", which was inaugurated in the summer of 2004, is one of several works being created as part of AEM's modernization plans. The canal is situated in a high altitude area of great environmental importance, partially located inside Stelvio National Park. The works leading up to the opening of the construction site being examined here concern the creation of a new water diversion canal to substitute the previous one, and aimed at increasing electrical power production. The "New Viola Canal" is about 15.8 km long and it has been built at an altitude ranging from 1900 to 2000 m a.s.l. The structure is entirely enclosed in a tunnel beginning in Val Verva at an altitude of 1993 m and ending at the outlet in Cancano lake (Val Fraelé) at an altitude of 1900 m. The Cancano lake outlet works consist of a tunnel access portal and a structure for channeling the water flow towards the lake. The outlet works are open-air works and will eventually be covered as far as the end of the inlet chute into the reservoir (fig. 1). The construction site occupies a surface area of about 2800 m². The work being carried out in this area is mainly related to the drilling equipment as it progresses and the unloading, stocking and handling of the debris material from excavation of the tunnel. Lastly, there is a concrete-mixing plant that is directly connected to the railway line, as well as structures serving to reduce environmental impacts. That is a screen in the materials unloading zone to minimize dust emission in the area and a treatment system for waste water and sludge, which are released into the lake.

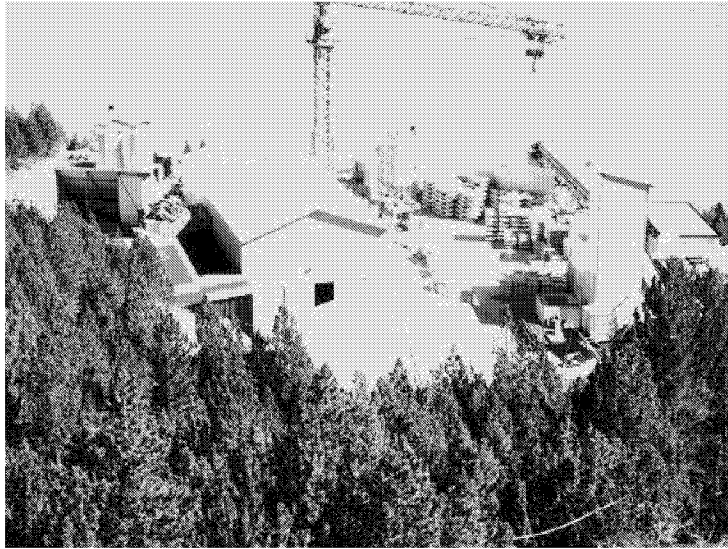


Figure 1: The construction yard viewed from the reservoir road (photo by Maggiolini).

The purpose of this research was to investigate whether the forest present in the vicinity of the construction site has undergone and registered alterations in growth as a result of the increase in natural (dust) and anthropogenic (lead) aeriform emissions caused by the construction work being carried out since 1998. The analyses were performed using dendrochronological and dendrochemical methods.

Methods

As a first step, a dendrochronological sampling was carried out on the basis of a field sketch highlighting the estimate of the thickness of the dust in the area (fig. 2). The tree vegetation is prevalently represented by *Pinus montana*.

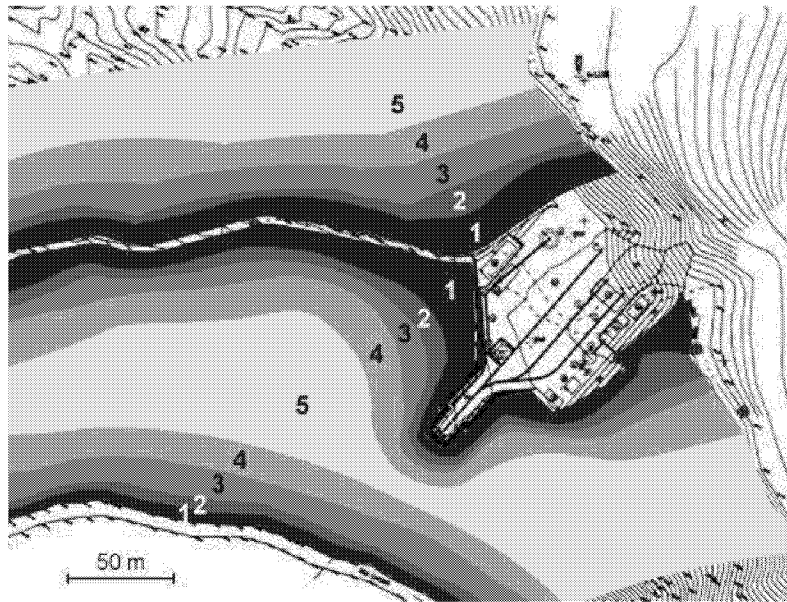


Figure 2: The sketch shows zones characterized by different dust thicknesses. The sequences 1-5 indicate progressive reductions in dust thickness. The dust is also very evident in the vicinity of the access road (sketch by Maggiolini).

This was a local-scale study, carried out by comparison of various chronologies: one representing tree growth in an area devoid of the pollution factor and others made from chronologies of trees present in the area affected by dust. Moreover, a comparison was made between growth before and after the impact began (Cook et al., 1987; Eckstein et al., 1984). Raw and standardized data derived from application of negative exponential functions were both analyzed. The reference chronology was drawn up using 40 samples collected from trees situated in an “unpolluted” area, but identical to the construction site area as regards the general ecological and geological characteristics. Then growth curves were plotted for the samples collected in the analyzed areas, grouped into 3 subzones on the basis of their positions with respect to the construction site and the access road.

Measurements were carried out using the LINTAB system and TSAP software (Rinn, 1996). After measuring all rings in the individual cores and plotting the respective growth curves, the investigation focused on recent years. The mean ring width corresponding to the 5 years preceding the beginning of the disturbance (1993-1997) have been compared with the mean ring width during the operation of the construction site (1998-2003) and then compared with undisturbed trees. Growth variations of more than two times compared to undisturbed trees were considered as meaningful.

Dendrochemical analyses were conducted on some specimens in the zone affected by the presence of the construction site to detect any presence of lead (Pb). Two cores were

analyzed for each tree. Five-year sequences of rings were utilized for these analyses as a means to overcome problems relating to the internal migration of elements from one ring to the next through radial transport. After standard treatment (Orlandi et al. 2002), atomic absorption equipment was used for the analysis of the samples to determine the quantity of lead present.

Results

The differences detected in the growth patterns are reported in fig. 3, referring to the period 1998-2002 vs. 1993-1997. Almost half of the samples analyzed (23 out of 49) showed a striking growth reduction in terms of absolute values and by comparison with the values resulting for the sample zone considered as "undisturbed" (-6,5%). This decrease can be recognized as even more significant if we take into consideration that most of the samples represent young trees (age range: 20-40 years), that is, in a period of their existence in which they tend to grow considerably. In other words, more than 50% of the samples shows a growth reduction more than two times the referring value.

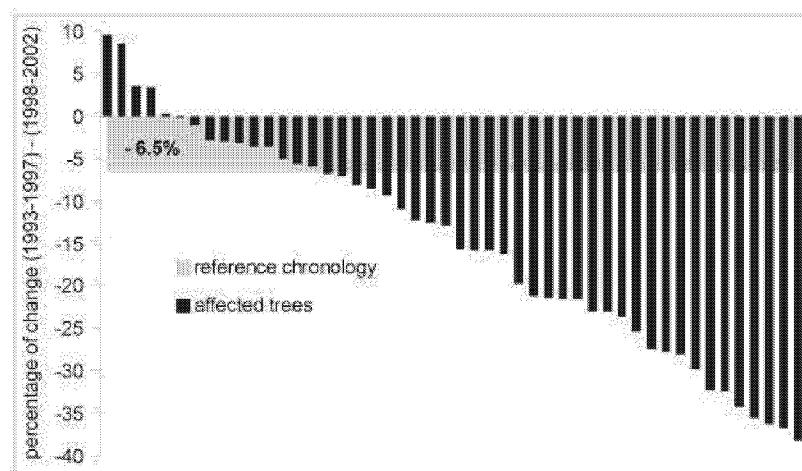


Figure 3: Percentage of growth change between the two referring periods. Each bar represents the single tree growth variation respect to the mean growth variation of the undisturbed trees (grey area).

The results obtained are summarized in fig. 4, where the positions of the sampled trees are indicated, as well as the intensity of the impact, using various symbols. They indicated that most of the trees damaged by the opening of the construction site are found in the vicinity of the source of disturbance (i.e., near the outer limit of the construction site or on either side of the access road), while there were no significant signs of growth reduction in many trees

located 30-40 m from the impact source. In other words, the influence of dust on conifers thus diminishes rapidly.

However, not all samples showed growth reductions. This can be due to less competition for natural resources, which, in turn may be due to the felling of trees for the creation of the construction yard and the access road.

Moreover, some dead trees are located in the zone used for waste water from tunnel excavation during one winter.

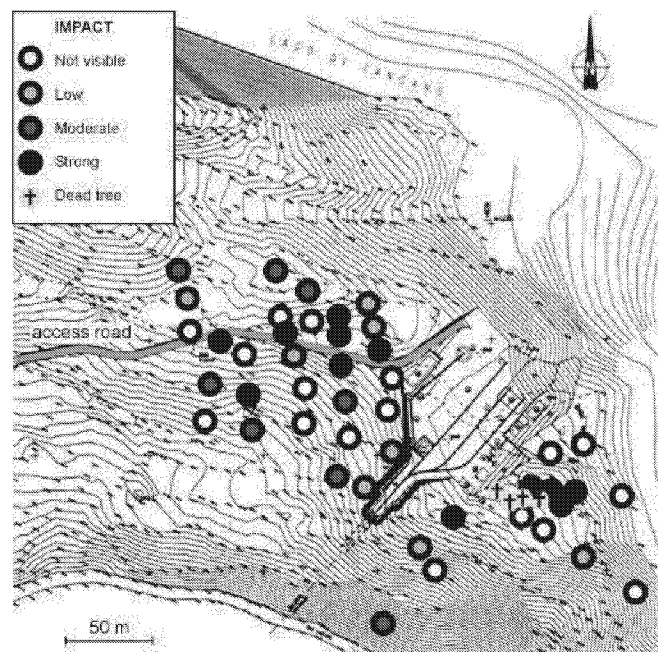


Figure 4: Location of the various individual samples and intensity of the impact on them.

The opening of the construction site thus caused an increase in dust emissions, owing to excavation work and to the massive transit of large vehicles for the transport of waste materials.

As regards the dendrochemical analyses, the results are indicative, since they refer to a few samples only. Moreover, the trees examined were very young, which does not permit a good assessment over time. However, this study has made it possible to obtain a general idea of the evolution of lead concentration over the last 20-25 years in this high mountain environment. A drop in the concentration of lead was observed (fig. 5) for the 1992-1996 period, compared to the previous decade and a little increase was observed for the 1997-2003 period. The decrease can be attributed (with the intensity of traffic in the area being equal) to technological improvements, to new fuels being adopted (e.g. "lead-free" gasoline)

and to lower consumption rates of motor vehicles (with distances traveled being equal). The opening of the construction site could however have caused the increased concentration of lead found for the 1997-2002 period, either directly by construction-related vehicle traffic or indirectly by the increase in tourist vehicle traffic spurred by the improved conditions of the access road to the zone.

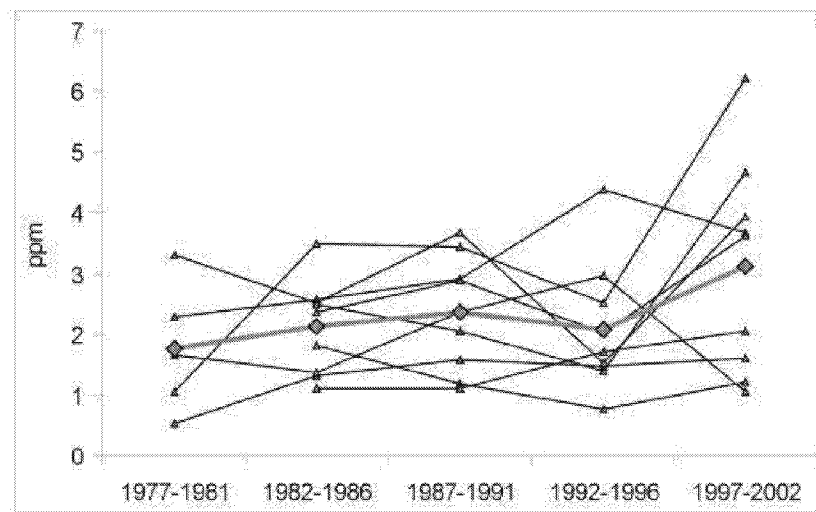


Figure 5: Concentration of lead measured in 5-ring sequences corresponding to the time intervals indicated.

Conclusions

The results obtained demonstrate that the opening of a construction site, with the consequent increase in dust caused by excavation work and by the transit of large vehicles, can change in tree growth severely. This disturbance in the study area diminished somewhat rapidly with an increase in the distance from the source of emission. The damaged trees are close to the working area. However, the results obtained are local and cannot be generalized. In fact, this construction site is relatively limited in extension and numerous natural factors can affect the distribution and permanence (or elimination) of the dust (e.g. wind, precipitation, etc.). Moreover, the study was limited to tree vegetation. Thus, further investigations are needed in the future, also on the other natural components of this environment to follow-up the effects over time, and to verify a recovery of the tree growth. Studies of this type demonstrate that trees can be used for dendrochronological studies of an applicative type even if these results can't be utilizable for a definition of the degree of impact of a construction site in a high mountain environment. However, this pilot study demonstrate the applicability of the method adopted and can be considered a starting point for future studies.

Acknowledgements

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Differences in drought response of *Pinus sylvestris* L. and *Quercus pubescens* Willd. in the Swiss Rhône valley

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Introduction

During the second half of the 20th century, many processes have altered the species composition in the low-elevation (<1200 m a.s.l.) forests in the inner-Alpine dry valley Valais, which is located in the southwest of Switzerland. In the past, the pioneer Scots pine (*Pinus sylvestris* L.) benefited from historical forest managements, such as goat grazing, selective withdrawal of forest products and timber harvesting (Rigling & Cherubini 1999). In recent decades, deciduous species, in particular pubescent oak (*Quercus pubescens* Willd.), have spread as a result of the abandonment of past forest use and ongoing natural succession. In the mean time, the climate has changed towards longer summer drought periods, higher mean temperatures (Rebetez & Dobbertin 2004) and different seasonality for moisture availability. The direct and indirect effects of the factors mentioned above are believed to have led to the locally high mortality rates of pine. In this study, we investigate the differences between pine and oak in their growth response to moisture conditions along altitudinal gradients, to evaluate the influence of climate change on species composition.

Material and Methods

On each of the five chosen altitudinal gradients, three mixed pine and oak sampling plots were studied. For each of the 15 plots, all the trees on an area of 12 m in radius were cored using an increment corer, taking two cores at breast-height to conduct the dendro-chronological analyses and one core at the base of the tree to count the age. After measuring and crossdating the tree-ring widths, standard and residual chronologies were produced, by applying standard procedures in the ARSTAN software package (Cook 1985, Holmes 1994). Response functions, i.e. a multiple regression after extracting the principal components of the climatic predictors, were then calculated using the routine PRECON (Fritts et al. 1991), with the residual chronologies as the dependent variable and the monthly moisture availability from June_(i-1) of the previous to September_(i) of the current year as the independent variables. Moisture availability (Ppot) was calculated as the difference between precipitation and potential evapotranspiration (Thornthwaite 1948). This index was used to arrive at a functional interpretation of the response functions. The analysis was performed over the last 50 years. Two plots had to be excluded from the analysis, because the trees were all younger than 50 years old.

Finally, to point out the species-specific response to moisture, we recorded the percentage of the chronologies responding significantly ($p < 0.05$) to moisture availability, for each month and for the two species separately. For a regional differentiation of the response patterns, the 16 regression coefficients of the 13 plots were introduced into a principal component analysis (PCA) with the statistic software R (Ihaka & Gentleman 1996).

Results and discussion

Species-specific response to moisture

Our results revealed a species-specific response to moisture (Fig. 1), which can be interpreted in terms of different physiological adaptations to climatic patterns in general and to rather dry site conditions in particular.

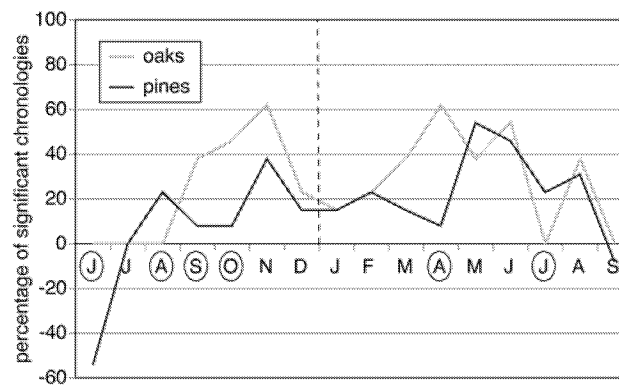


Figure 1: Summarised growth response to the monthly moisture index P_{pot} . Percentage of chronologies with a significant ($p < 0.05$) negative or positive response of pines and oaks from $June_{(i-1)}$ to $September_{(i)}$ are shown. 100% = 13 chronologies. Circles indicate significant differences between oak and pine ($p < 0.05$).

The oaks showed responses to moisture availability from September to November in the previous year. Such response patterns can be explained by a physiological preparation for the next growing season including 1) the storage of metabolic compounds and 2) root growth. The growth of fine roots in autumn and winter may be advantageous in summer-dry climates (Cherubini et al. 2003) and is reported to occur in *Quercus* spp., if soil temperatures are above 0°C (Hoffmann 1974, Teskey & Hinckley 1981). Pines, in contrast, only showed responses to moisture in August and November of the previous year. However, the explained variance of prior growth in pine (originating from response functions with standard chronologies) was much higher than that in oak. These results for pine are quite common in coniferous species (Kienast et al. 1987, Oberhuber et al. 1998, Rigling et al. 2002) and thought to be related to 1) the photosynthetic activity of the needles over more than one year, which causes a lag-effect and 2) the arrangement of shoot length and needle buds in the

previous August. In the current year, oaks started their response with a peak in April already, while pines did not respond before May, but still showed a response in July, the driest month in the year. Thus, oak seemed to react consistent with Mediterranean species with a summer stop of activity, whereas pine as a sub-boreal species was still exposed to the very dry conditions.

However, whether this result for pine points at the need of a prolonged growth period until July (meaning that pine is less well-adapted to such a climate regime), or whether it shows the benefit of being capable to grow in very dry conditions, has to be further investigated on a physiological level. From our point of view, in such dry conditions the former seems more likely.

Overall, oaks appeared to have fewer problems to adjust their physiological activity to times, when sufficient moisture is available (spring and autumn). Given a change in the seasonality of moisture availability towards longer summer drought periods, the risk of cavitation in pines (Martinez-Vilalta et al. 2004) is likely to increase in the future.

Regional differentiation in the response to moisture

Besides the species-specific response to moisture, we found a sub-regional differentiation of the response to moisture availability. For both species, the PCA of the regression coefficients resulted in three groups of similar response patterns: the side-valley plot Eschwald, the south facing plot Eggerberg and the rest of the plots, which are all situated in the lower valley. The plots Eschwald and Eggerberg belong to the more continental Visp region, where the trees showed more pronounced responses compared to the more oceanic Sion region.

From our sampling design, we would have expected an altitudinal differentiation of the response patterns. However, it seems that the sub-regional site conditions such as climate and soil texture, are mainly influencing the growth response of the trees on our study plots.

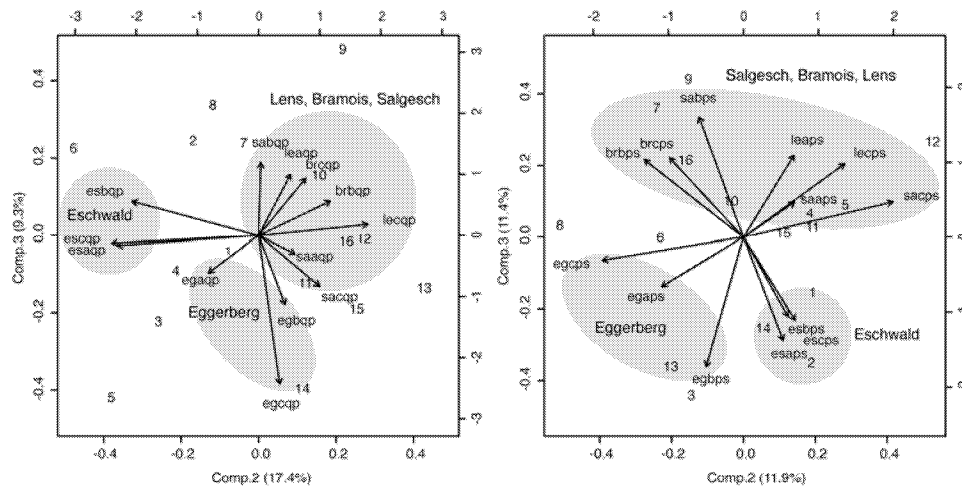


Figure 2: PCA of response to moisture index P_{pot} for oak (left) and pine (right) (second and third component axes). Eschwald and Eggerberg belong to the Visp region, Salgesch, Lens and Bramois belong to the Sion region. Numbers 1-16 stand for the months from June_(t-1)=1 to September_(t)=16; January_(t)=8

Acknowledgements

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SECTION 2

GEOMORPHOLOGY

Interaction between trees and natural hazards in subalpine spruce forests

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Introduction

Forests protect men and infrastructure against natural hazards. The objectives of the tree stability project at the Swiss Federal Institute for Snow and Avalanche Research (SLF) is to understand the interaction between trees and natural hazards such as rockfall or wind as well as the single-tree and stand stability in protection forests, to comprehend the influence of forest management on this stability and to make a cost-benefit analysis of protection forest management.

One sub-project deals with the role of the root system in the anchorage mechanics of trees. Investigations on the interrelations between root architecture and mechanical parameters (e.g. root-soil stiffness and anchorage moment) are scarce (e.g. Neild and Wood, 1999). More information is needed about the anchorage failure of trees and how much trees are pre-stressed before it comes to failure. The forces acting on trees not only cause visible damage such as rockfall scars but may also lead to breaking of roots. After performing winching tests some trees maintained an inclination at the stem base of up to 0.5° (Jonsson *et al.*, submitted). Two reasons are suggested for this phenomenon, soil deformation or damages in the root system. To approach this fact, sap flow measurements were conducted as a non-destructive method to track a decrease in water conductivity due to injury of roots by measuring the water flow in the stem during winching tests. If roots break the water flow at the stem base decreases (Rust and Gustke, 2001).

Rockfall simulation tests were carried out to study the interaction between a rock and a tree. One objective was to predict the energy dissipation of single trees as a basis to improve rockfall models. When a rock hits a tree a transversal wave runs stem upwards and sometimes the tree top breaks off. Wind induced tree swaying leads to breaking of cell walls in the wood referred to as stress lines (Seubert Hunziker and Niemz, 2002). Whether these stress lines also occur after a rockfall impact is investigated in another sub-project.

Methods

Research site

The test site is located in a subalpine spruce forest near Davos, Switzerland, in an elevation of 1800 m a.s.l.. The site has an average slope of 30° in a south-western exposition. The stand density is about 500 trees per hectare, mainly Norway spruce (*Picea abies* (L.) Karst) with a small percentage of European larch (*Larix decidua* Mill.). The soil is a podzolic brown soil with a varying soil depth of 0.2 to 0.7 m and a high percentage of stones.

Mechanical tests

For the winching tests a steel cable was fixed to the stem in 5 m height (Fig. 1) and the tree was equipped with inclinometers at 2 %, 5 % and 20 % of the tree height, respectively. The trees were pulled sideways along the prevailing wind direction during subsequent tests in 0.5° steps from 1.5° up to 3.0° . From the recorded data (pulling force, inclination, and sap flow) and the mass distribution in the tree various information on the performance of the tree and its anchorage in interaction with natural hazards is gained. For further details of the tests and the evaluation see Jonsson *et al.* (submitted).

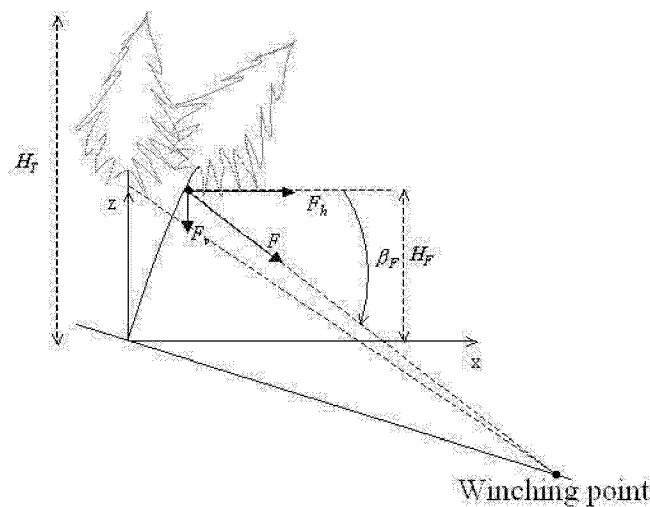


Figure 1: Test set-up of winching test.

For the impact tests, trees were selected that represented the diameter distribution in the plots. With a trolley of a variable impact mass (517 to 917 kg) guided downslope on steel cables a rockfall event was simulated. The velocity of the impact mass was measured on the trolley and the acceleration of the stem at 2 %, 5 %, 20 % and 75 % of the tree height were recorded. The tree's reaction was also recorded using video and high speed cameras for further analysis of the deformation of the tree.

Sap flow measurements

In the vegetation period of 2004 sap flow measurements (Granier system, UP, Ibbenbüren, Germany) were conducted on trees exposed to winching tests. On each tree, three sensors were inserted into the stem at 0.60 to 0.80 m height above ground. One sensor pointed in the direction from where the tree was pulled, the other two were on the opposite side of the

stem, so that each third of the stem was equipped with a sensor. The sensors were sealed against water and sunlight and the power was supplied by solar panels.

The sampling interval was 10 seconds and the logging interval was set to 2 minutes.

Wood anatomy

Stem disks were taken from trees exposed to impact tests (rockfall simulation) in intervals of 0.5 to 2 m along the stem. The last tree rings (2003 and 2004 respectively) were followed through the stem. Microtome slices of 24 µm thickness were cut from different sides of the disk and investigated microscopically with a magnification of 200 to 400. Stress lines caused by the impact were located and their distribution and frequency in the early and late wood were determined.

Results

Mechanical tests

From the winching tests the root-soil stiffness can be calculated (Jonsson *et al.*, submitted). The tests from the trees with the sap flow system will be evaluated later in the year, this is because the evaluation routine needs information about mass distribution which is obtained when the trees are felled after the field tests are completed.

For details on the impact tests and the energy dissipation in the tree see Lundström *et al.* (in preparation) and Foetzki *et al.* (2004).

Sap flow measurements

The sap flow showed a typical variation over the daytime with a maximum during midday and a minimum at dawn. On warm days with a high irradiance a midday depression could be observed.

During the tests the sap flow pattern was monitored. Although the trees had a remaining inclination at the stem base of about 0.5° after being pulled to an inclination of up to 2° at the stem base, no signal in the sap flow was recorded. At an inclination of 2.5° at the stem base, one of the test trees showed a reaction, supposedly first roots broke. This resulted in a reduction of sap flow in one part of the tree, and a compensation in the other part. The other trees have not shown an effect so far although they were pulled to an inclination of 3° at the stem base.

Wood anatomy

Stress lines were found in different heights of the stem. The breaks in the cell wall did not occur evenly distributed but clustered and not in the same frequency on all sides of the stem. The frequency of stress lines was higher in late wood than in early wood.

Discussion

Sap flow measurements

With the test results a critical angle for root breakage can be found. Whether it is dependent on the stem diameter, root architecture, slope or direction of pulling have to be further investigated. First results of winching tests on different sites showed a dependance of the maximal bending moment on the stem diameter (unpublished data). Whether roots already break before the maximal bending moment is reached will be shown in additional tests. If the roots are also damaged during storms and how to quantify the stress for the tree due to these damages are the next questions to answer.

Wood anatomy

The frequency and distribution of the stress lines can be compared with the compression wave that runs stem upwards. The stem deflection and bending stresses during the impact were analysed at the SLF (Lundström and Simon, submitted). Can stress lines in the wood be found at the same heights of the stem where the amplitudes of deflection are predicted by this calculation? Stress lines reduce the tension strength of wood (Sonderegger and Niemz, 2002); this may have an influence on the tree stability.

Further studies could include the deflection propagation in the wood structure and address the differences between early and late wood.

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Dendrogeomorphological research on thermokarst depressions in Western Siberia

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Introduction

Much of the discontinuous permafrost is within 1°C to 2°C below the thawing point and highly susceptible to degradation (Osterkamp, Viereck, Shur et al. 2000). Any additional energy input to the surface will result in a formation of new thermokarst; a degradation form of permafrost with karstlike surface features (Muller 1947).

An alteration of the energy balance can be caused by climatic changes like, for example, increasing mean annual air temperature and precipitation or due to natural or anthropogenic destruction of the isolating vegetation cover, which protects the soil from summer warming. The thickness and period of snow cover has an ambivalent influence on the soil temperature. On the one hand, long snow coverage in spring and early summer shelter from heating, on the other hand early snow in autumn and thick coverage in winter prevent from cooling and freezing of the active layer (Burn & Smith 1990; Osterkamp & Romanowsky 1999; Vaganov, Hughes, Kirdeyanov et al. 1999; Agafonov, Strunk, Nuber 2004).

The formation of thermokarst depressions is initiated by a thawing of the ice-rich upper part of permafrost. The loss of 'excess ice' leads to ground settlement as well as ponding of surface water and melted ground ice. As a consequence a boggy, sometimes water filled depression is formed. Once established, radial widening starts by thermal erosion which subsequently will destroy the surrounding vegetation. Trees affected by the expansion of thermokarst depressions show an eccentric stem growth often associated with compression wood. These wood anatomical features combined with geomorphological research allow to date and reconstruct the development of thermokarst as well as the initiating factors of the thawing process.

Methods

Study Site

The study site is located in western Siberia at the left riverside of the river Synja, a small tributary of the river Ob (65°03'N, 64°40'E). The elevation is approximately 20 m a.s.l. The whole area is underlain by permafrost with an observed active layer of about 40 – 200 cm. The silty soil is covered by an 30 cm thick moss layer under a canopy predominated by *Pinus sibirica*. Mean annual air temperature is about –4.8°C, precipitation is about 480 mm/a. The site encompasses numerous thermokarst depressions with a range in diameter from few metres to several hundred metres.

The investigated thermokarst depression has a diameter of about 80 metres and a depth of about 2 metres. The surface of the depression consists of a 60 cm thick floating peat layer on a water body with a depth of up to 1.4 metres. Measured water temperature is 5.7°C. The soil beneath the water body is unfrozen whereas the position of the permafrost table is unknown.

There are numerous living and tilted trees on the slope of the depression whereas inside the depression dead trees are still standing in a more or less upright position. The number of dead yet still standing trees decline with distance from the bank line. The dead trees fell over and lie well preserved in the water body on the bottom of the depression. These trees can be located with probes and salvaged from the ground.

Methodological Considerations

In the course of the proceeding widening of the depression trees will be affected by the back moving slope. Considering this influence on trees (Schweingruber 1996), resulting tree growth can be classified into three phases (Fig. 1):

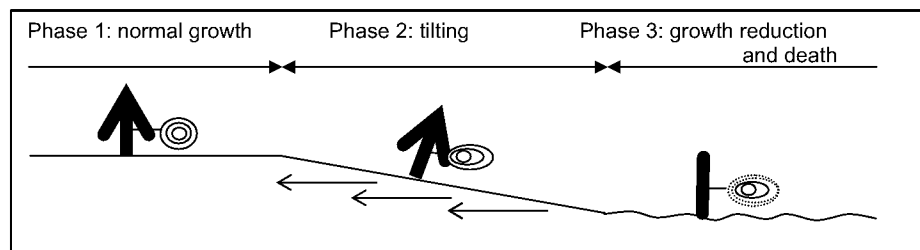


Figure 1: Influence on tree growth

- Phase 1: Outside the depression trees show a normal growth with almost concentric tree rings.
- Phase 2: Affected by the progressing slope, the trees become tilted and react by forming compression wood and/or eccentric tree rings.
- Phase 3: Attaining the boggy depression, the roots of the tree get flooded by the stagnating water inside the depression. Drastic growth reduction starts and ends at last with the death of the tree after a few years.

Sampling

About 235 trees from inside the depression and the surrounding area were sampled. The position of each sampled tree was measured and marked in a map of the depression. Cores ($n = 104$) from living trees were taken in direction of tilting. Cross sections ($n = 131$) were cut from dead trees.

Analysing

The ring widths of sanded samples were measured with a precision of 0.01 mm with LINTAB. The discs were measured usually in two radii, the longest and the shortest one. If the disc indicates a tilting of the tree in more than one direction up to four radii were measured. The samples were crossdated with TSAP. Finally, crossdating was visually verified using standard procedures after Stokes and Smiley (1968).

Results

To reconstruct the rate of widening of the depression it is necessary to determine the average time of tilting as well as the date of death of the trees depending on their distance to the present bank line (Fig. 2).

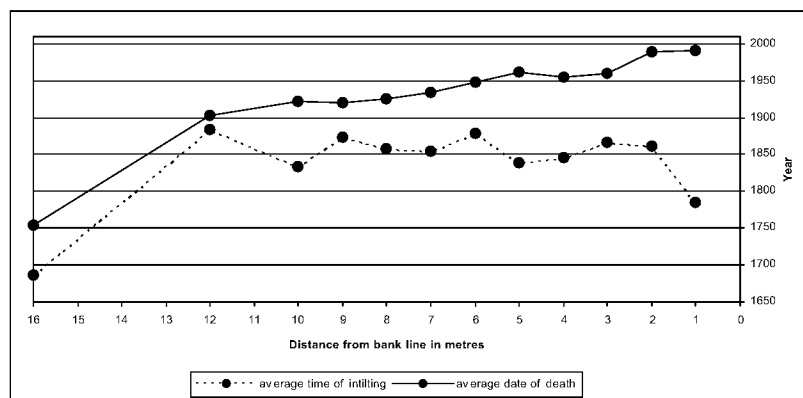


Figure 2: Average time of tilting and death depending on distance (example for the western part of the depression)

The average time of tilting does not show a more or less straight ascending graph with descending distance from the bank line as it theoretically could be expected. On the contrary, there is a concentration of tilting around the year 1850 independent from the distance, which points towards a destabilization of the whole area at that time. The average time of death shows the expected dependence on the distance. At the latest around 1900 the graph shows an acceleration of the widening rate.

The derived average rate of widening for all parts of the depression is about 2.6 – 5.3 cm/a between 1500 and 1750, rises up to 10 cm/a between 1750 and 1900 and stays stable at a high level of about 16 cm/a until today with a maximum rate of widening of 21 cm/a between 1900 and 1920. Figure 3 shows the reconstructed spatial-temporal development of the thermokarst depression since 1500 AD.

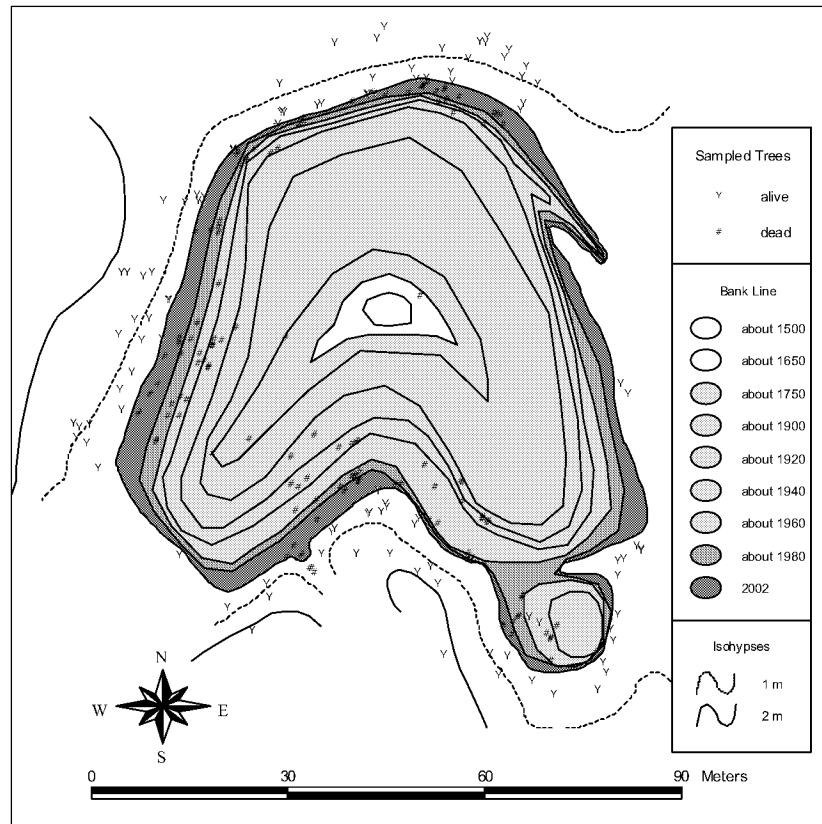


Figure 3: Spatial-temporal development of thermokarst

The bank lines for the time between 1500 and 1900 as well as at the eastern part of the depression are based on a small number of sampled trees. These lines could be verified by the salvaging and analysing of a higher number of sunken trees from the bottom of the depression.

Since we have not yet enough samples from the inner part of the depression, we cannot definitely state if this thermokarst depression is caused by climatic changes or by disturbance of the vegetation.

The number of sampled trees in relation to the different periods, supported by the discovery of charcoal, indicates an almost complete destruction of the former vegetation by a fire between 1822 and 1832. This fire seems to be the main reason for the disruption of the thermal equilibrium of permafrost followed by a destabilization of the whole area around 1850 and an accelerated widening of the thermokarst depression at the latest since 1900.

Conclusion

Dendrogeomorphological analysis of tree rings is an apt method to date thermokarst depressions and to reconstruct their process of widening. Depending on density of tree stands, a temporal resolution of the progressing widening of about 5 to 10 years for hundreds of years is possible. Sequences of aerial photographs may provide a higher temporal resolution but only for the last century. In addition to geomorphological information, tree rings provide climatological and ecological information, which help to reconstruct thermokarst development in a certain area.

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Examples of valley and riverbed form dating by means of tree rings (Mala Panew meandering river, southern Poland)

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Introduction

One of the factors controlling the patterns of meandering river channels is the riparian forest covering the valley floor (Hickin, Nanson 1984; Thorne 1990; Abernethy, Rutherford 2000; Brooks, Brierley 2002). Tree root systems protect the soil and older alluvial sediments against erosion and reduce the supply of material to the riverbed. Hence, rivers flowing through forested areas are not sufficiently charged with material coming from erosion of the valley slides. Lowland and upland rivers crossing the forested areas flow, very often, in a single channel. Frequent dams are formed from trees and Coarse Woody Debris (CWD). CWD is defined as fragments of dead trees longer than 1 m and not less than 10 cm in diameter at the fragment middle point (Van Sincle, Gregory 1990). These fragments fill the riverbed and make the water flow around them, contributing to increased river bendiness and channel roughness (Gregory 1992; Gurnell et al. 1995; Gurnell, Sweet 1998; Kaczka 1999). *Dendrochronological methods have been applied in fluvial geomorphology. Initially this methods concentrated to study of the riparian trees reaction on mechanical stress (Alestalo 1971). Dendrochronological study conducted especially in the mountains river valleys. Scars on riparian trees, adventitious roots and eccentric growth of trees, makes dating of erosion episodes feasible (Sigafos 1964; Hupp 1986).*

Dendrochronological methods in fluvial geomorphology concentrate on the measurement of processes. Within the point bar similar-aged tree lines are observed. These tree lines are older and older when we go outside of the channel. The age of an individual line of trees show river channel lateral migration rate (Everitt 1968; Nanson, Beach 1977; Malik 2002, 2004a). This rate we can also estimate by dating of CWD laying *in situ* under the concave bank and growing on mid-channel islands and paleochannels (Ciszewski, Malik 2004).

Erosion episodes can be estimated by exposed roots analysis. After exposition to erosion wood cells in the tree rings divide clearly into early wood and late wood and start to become fewer. Making use of this process we can date erosion episodes of exposed roots. Roots sometimes have scars. In the roots cross sectional area of tree rings in callous tissue is effected by the mechanical stress of erosion and thus, we can date the bank erosion episodes too (Gärtner et al. 2001).

Study area

The Mala Panew River is a meandering river with a sandy bed which flows through the southern part of Poland (Fig. 1). The river drains an area of 2037 km² and flows through a closed forest for 20 km. The study area is dominated by alder (*Alnus glutinosa*, *Alnus incana*) (42%), pine (*Pinus sylvestris*) (35%), willow (*Salix purpurea*, *Salix fragilis*) (21.5%) and spruce (*Picea abies*) (2%). In addition, ash (*Fraxinus excelsior*), larch (*Larix decidua*) and birch (*Betula pendula*) occur sporadically. Pine monocultures grow on poor sandy habitats at the bottom of the Mala Panew valley. Fragments of a marshy riverside meadow overgrown with ash and alder have been preserved in the area.

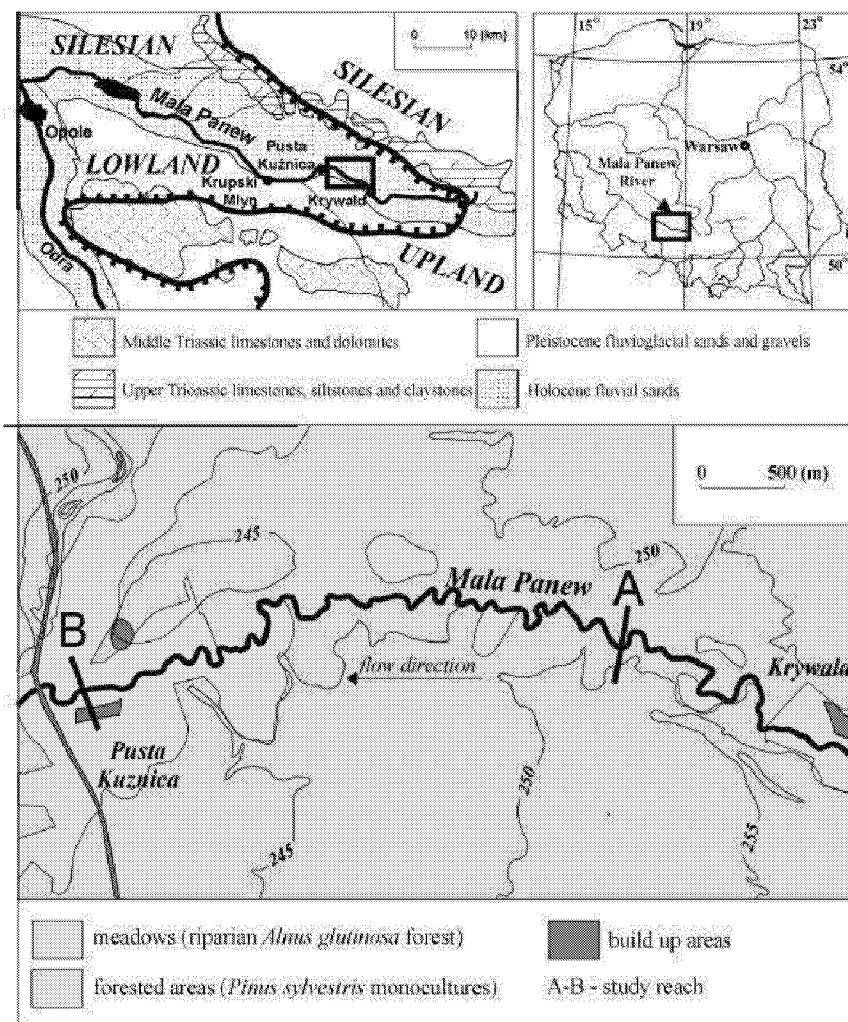


Figure 1. Study area

The study area is located in the upper Mala Panew river basin, where a 4 km reach was selected (Fig. 1). The valley bottom is filled with glacial and fluvioglacial sediments (> 10 m thick). The alluvia are composed of sands of varying grain size. A 2-3 km wide Pleistocene and three Holocene terraces (3-4 m, 2-3 m, 0.5-2 m) are observed in the Mala Panew valley. The mean annual precipitation in the area ranges from 650 to 750 mm. On average, the riverbed is 10 m wide and up to 2 m deep. The most frequent water stages in the Mala Panew river bed are 40-70 cm deep. The highest water stages in the Mala Panew channel occurred in the years 1953, 1966, 1968, 1970, 1982, 1985 and 1997 (Fig. 2).

Methods

Forms and processes investigated by CWD dating

During high discharges concave banks are undercut and the trees growing upon them fall into the channel where they stay as CWD. As the discharge wave subsides, mineral and organic material accumulates with CWD. Behind the CWD special bedforms, for example sand shadows, streamlined depressions, reverse depressions, outwashes and overflow kettles are generated (Malik 2004). When the CWD remain we can date bedforms generated by them. Large amounts of CWD laying *in situ* under the concave banks inform us about the erosion of this bank. Re-deposited CWD can be recognized by the lack of bark and sapwood, which has been separated from the rest of the log during the river transport. To distinguish re-deposited CWD, the analysis of the log orientation against the riverbed axis may also be helpful. Trees *in situ* are usually placed laterally across on the riverbed, whereas re-deposited and re-oriented stems occur in accordance with the riverbed axis direction (Kalicki, Krapiec 1995). Standard dendrochronological methods were used for developing the chronology and for cross-dating the CWD (Fritts 1972; Schwiengruber 1988). For *in situ* CWD dating a local tree ring chronology for *Pinus sylvestris* was constructed from the last 70 years. The chronology was based on tree ring analysis from 10 cores collected from pines currently living in the Mala Panew valley. Another stage of the study was the collection of discs from CWD pines laying in the riverbed. The 22 discs from CWD generated sand shadows and 16 from CWD laying under the concave river banks were collected from about 0.5 m above the root system. The tree rings from CWD disks were cross-dated against the local chronology. The percentage agreement coefficient (Gleichlaufigkeit) was used to evaluate the similarity between the dendrochronological series obtained from individual disks and the chronology.

Forms and processes investigated by trees dating

Another method used for dating the trees tilting into the riverbed and mid-channel islands. The location of mid-channel islands, which relates to the river banks, as well as the dating of trees growing on the islands can also be helpful to determine the age of mid-channel island. The 15 black alders with the largest diameters at breast height were selected. Trees growing on mid-channel islands were sampled using a 40 cm Pressler's borer. The oldest trees growing on individual mid-channel islands informed us about minimal age of this forms. The

distance between the concave bank and mid-channel islands in relation to age of the oldest trees growing on mid-channel island led to dating the mid-channel islands

When the banks were cut, some of the trees growing on them tilted, and bedforms were generated. Consequently we can date the dendrochronological moment of tree tilting and thus describe the erosion episodes. Two cores were taken from all of the 14 tilted trees. One core was taken from the river side and another from the opposite side. Cores from every tree were cross-dated. A striking reduction in tree ring width indicates, the moment of tilting and consequently the occurrence of an erosion episode.

Results

Dating of the sand shadows showed that most of these forms were created in 1997 and 1985, also several in 1983, 1993, 1998. It shows a large correlation between meteorological and geomorphological events (Fig. 2). The large flood from 1997 was connected with intensive erosion because 10 events in this year were recorded. Small erosion episodes occurred in 1991, 1992 and 1998.

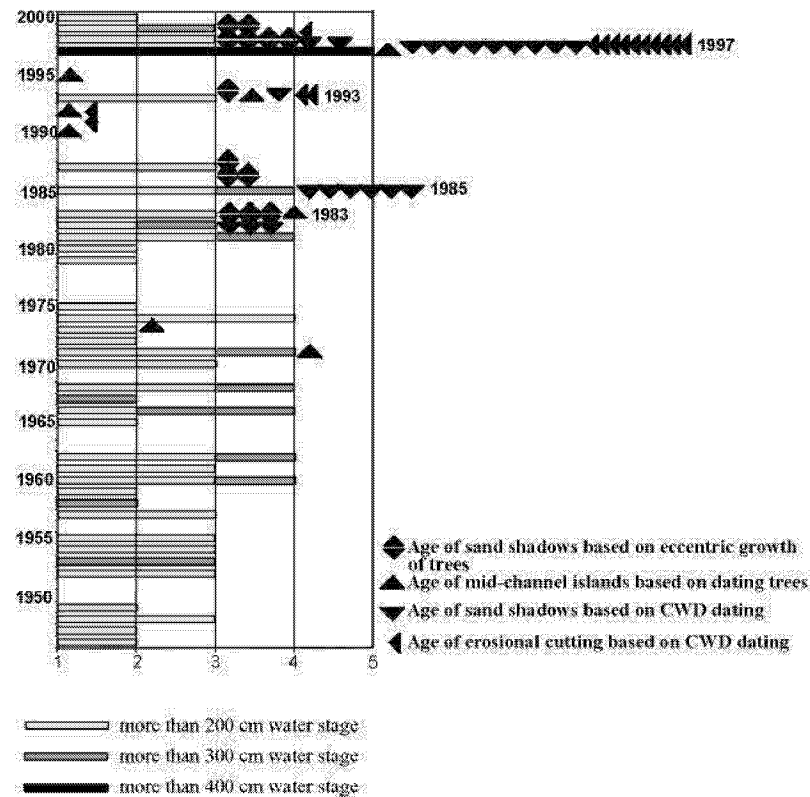


Figure 2: Water stages on Mala Panew River and geomorphology events

The dating of tilted alders showed that most of the trees were tilted in 1998, several events were recorded in 1983, 1986, 1987, 1994, 1999. The most distracted were results obtained from the mid-channel islands that were not double episodes. Erosion episodes were recorded in 1973, 1971, 1983, 1990, 1992, 1994, 1995, 1997.

The most precise results were obtained from CWD dating. There is a high correlation between erosion and meteorological events, especially in 1997 when an extraordinary flood in Mala Panew drainage basin was recorded. About 50 % of dated sand shadows, and bank erosion were intensive in 1997. Dating based on tilting trees was very precise too, but they occurred one year after the intensive erosion. Most of these episodes occurred in 1998 which correspond to the large flood recorded in 1997 with a delay of one year.

The results from mid-channel dating are less precise, there is no correlation with meteorological events. The mid-channel island dating is probably less precise because we are not sure about the age of the oldest tree growing on an individual form. The oldest tree can die during the cutting of the island from the bank. It means, we can only presume the minimal age of the mid-channel island and consequently the maximal lateral migration rate.

Conclusion

We can use dendrochronological dating to reconstruct erosion and accumulation in the riverbed. Most precise are results from CWD dating. Using these methods there is a big correlation between meteorological and dendrochronological events. The reconstruction taken from tilted alders is very precise but the reduction in tree rings forming at least one year after the investigated events. The results from mid-channel islands dating appear to be less precise.

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Determination of the erosion rate of escarpments at the debris-flow fan toe

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Introduction

One characteristic aspect of high-mountain environments consists of the presence of escarpments along rapidly retreating slopes owing to eroding phenomena affecting the foot of the slopes and the presence of accelerated erosion, both of which are due to the activity of watercourses. This paper explains the results of a study aimed at estimating the erosion rate of several escarpments using dendrochronological investigations.

The study area is located in upper Valle del Gallo (Valtellina, Central Italian Alps). This area is occupied by a series of debris flow fans (fig. 1) (Pelfini, 2001; Santilli & Pelfini 2002; Santilli *et al.*, 2002; Pelfini & Santilli, 2003). Fluvial activity has eroded the fan toes along the valley axis, creating escarpments ranging in height from a few meters to over fifty meters (fig.2). The progressive retreat of these escarpments has involved the depositional top of the fans, which is represented by a slightly inclined surface covered by a mountain pine forest. Owing to retreat, the edge of the escarpments gradually reaches the trees, which are begun to slant down towards the bed. However, the pines respond by developing compression wood, in an attempt to regain their stability and verticality. They manage to survive as long as the entire root system is not exposed. When that happens, they die.

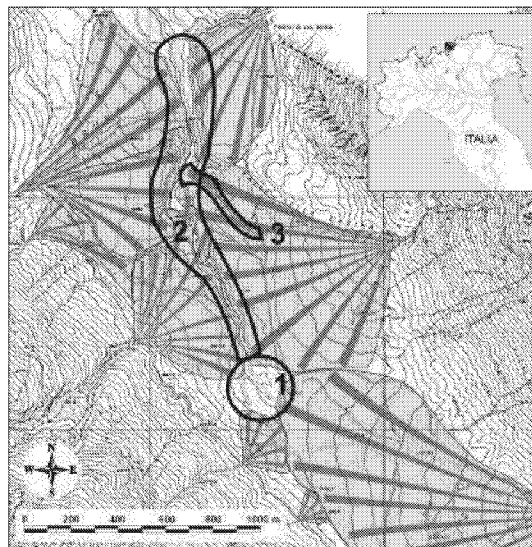


Figure 1: Location of the study area and the three situations analyzed.



Figure 2: The torrent in Valle del Gallo carving the debris flow fan toe, forming high escarpments (cf. 2 in fig. 1) (photo by Santilli, 1998).

Methods

Other researchers have already developed different methods for the study of similar processes, for example Hupp & Carey (1990) and Vandekerckhove et al. (2001).

In this work, the escarpment retreat and erosion rate was studied by determining the distance of the trees from the edge of the escarpments and also the number of compression wood tree rings. Three different situations were analyzed: higher up the escarpments are carved in silty deposits (1 in fig. 1), whereas in the lower section, erosion has affected gravelly deposits (2 in fig. 1; fig. 2). A third situation was also studied, consisting of a lateral channel in one of the debris flow fans (3 in fig. 1).

Stream erosion has caused a deepening of the bed and the retreat of the escarpments due to eroding at the base (fig. 3). As a result, the trees end up in positions that are increasingly closer to the edge of the escarpments. Once they reach the edge, they tend to tilt towards the torrent and slide down the slope. Yet, diverted from their verticality, during this process, the trees develop compression wood even for many years before death.

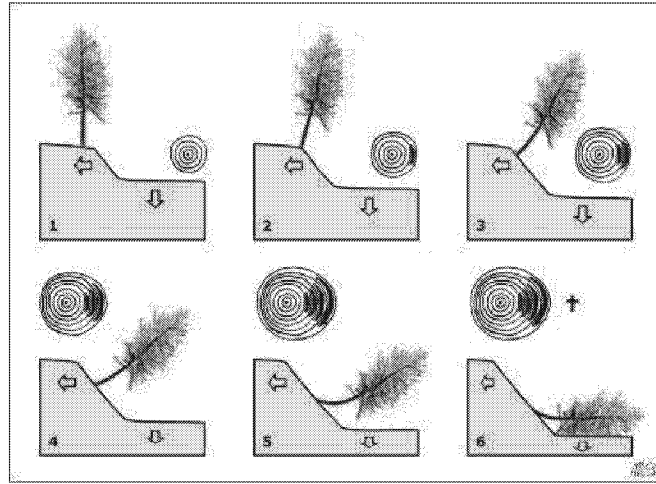


Figure 3: Diagram of the progressive retreat of an escarpment caused by erosion at the foot and the evolution of the trees located on the surface of the fan.

This process constitutes the basis for the calculation of the erosion rate. In fact, the erosion rate of the escarpments was calculated considering that the retreat of the escarpment edge (in centimeters matches the distance between the trees and the edge of the escarpments (fig. 4). This is because erosion usually does not involve the soil layer in the initial part of the process. In fact, the soil tends to lie on the surface of the escarpments (in fig. 4). The erosion rate was thus calculated as the ratio between that distance (d in fig. 4) and the number of rings with compression wood (n in fig. 4).

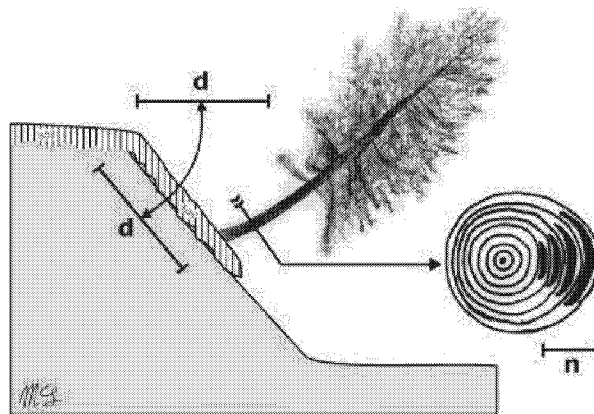


Figure 4: Determination of the escarpment erosion rate: $r = d / n$, where r = mean escarpment retreat rate, d = distance between the tree and the top of the escarpment, n = number of rings of compression wood.

The compression wood can be attributed to the bending of the trees, rather than to other random factors, because only a few compression rings arranged in varying positions were observable in the cores of undisturbed trees. Moreover, no slope processes (such as avalanches, snow creep and/or debris flows) are acting upon these trees analyzed as control elements, as they are growing on a surface that is almost level, far away from the valley slopes, and unaffected by destructive geomorphological processes. When, instead, trees tilt suddenly at the edge of escarpments, they start to develop only compression wood and continue to do so for the rest of their lifetime, or for many years until they regain their stability. The greater the distance of the trees from the edge of the escarpment, the greater the number of tree rings with compression wood - this serves to demonstrate that the growth of compression wood is proportional to the time that has passed since the trees tilted. In addition, this phenomenon is particularly evident when one finds a number of trees that have fallen in a sequence, all of which along the same direction.

A total of 485 trees were sampled, along approximately three kilometers of escarpments (thus making for an average availability of one sample every six meters of escarpment). One or two cores were taken for each tree. Each sample was supplemented with all the information required for an understanding of this phenomenon, such as the characteristics of the tree and its position on the escarpment.

Preliminary results and discussion

The data obtained have made it possible to identify escarpment sectors that share a homogeneous erosion rate. A mean erosion rate was calculated for each one of these sectors and this rate is obviously related to a combination of different factors, including the stratigraphy of the deposits, which varies throughout the valley, the presence or absence of torrent meanders and the quantity of water in circulation.

The range and value of the mean erosion rate calculated differed in the three areas studied. The erosion rate was highest in the silty deposits (1 in fig. 1), where the mean ranged between 4.0 and 7.0 cm/year. This could be related to the existence and development of several small tributaries of the main torrent. In addition, the characteristics of the sediments differ from those of the other sectors. In the gravelly deposits along the main torrent (2 in fig. 1), the erosion rate was lower, ranging from 0.6 - 2.5 cm/year, in the lower valley sectors, where the torrent is permanent, and reaching as much as 1.1 - 4.0 cm/year in the highest sectors, where water flows only after intense precipitation. Only two sectors revealed a much higher erosion rate compared to that of the surrounding sectors (up to 5.1-6.0 cm/year). This is due to the presence of other lateral streams that force the main torrent to shift towards the base of the escarpment, thus increasing erosion at the base. Lastly, the lowest calculated erosion rate was found for the gravelly deposits along the tributary stream (3 in fig. 1), with values ranging from 0.6 to 2.0 cm/year in the various sectors. This stretch of the lateral stream is found in the distal part of one of the fans and it is usually dry, except when intense precipitation occurs.

The erosion rates calculated for each tree showed increasing rates with the increase in the distance between the trees and the edge of the escarpment. This may seem strange, but we

must consider that when a tree falls into an escarpment, the roots grounding it to the original surface are subject to tension. Therefore, the greater the distance of the tree from the edge of the escarpment, the fewer the roots grounding the tree and the greater the tension undergone by the roots. Under these conditions, the trees move faster, due to the force of gravity, and the erosion rate calculated is higher. Taking into consideration all of the trees examined along the main torrent on the gravelly deposits, the mean erosion rate was 2.3 cm/year.

Other data lead us to consider the results obtained as reliable. In fact, previous studies conducted using radiocarbon dating, have shown that the erosion process began later than about 5500 years ago and that the erosion process reached the silty deposits about 1200 years ago (Santilli *et al.*, 2002; Pelfini M. & Santilli M., 2003). Although the erosion process was probably inconstant over time, considering the mean erosion rate and the distance between the opposite escarpments at different points along the torrent, that is, the breadth of the canyon, within the range of 48 m (measured) and 240 m (estimated), it is possible to calculate the time required to reach the present-day situation starting from an originally flat valley floor. These intervals are consistent with the radiocarbon dating findings: 1040 years around the silty deposits and 5220 years in the lower part, where the process began.

The deepening of the bed also took place at the same time as the retreat of the escarpments and it is also possible to provide an approximate estimate of the rate at which this process took place. A rate of 1.0 to 1.4 cm/year for the deepening of the bed was obtained for various escarpments. This value was checked by comparing it with the data obtained for three recent stream terraces to the left side of the main torrent. The height of each terrace was measured (0.9, 2.1 and 5.5 m) and their minimum ages were determined on the basis of the maximum ages of the trees growing on them (60, 96 and 268 years, respectively). Thus the rate of the deepening of the bed was calculated (1.5, 2.2 and 2.1 cm/year, at an average rate of 1.9 mm/year), which proves to be slightly higher. Yet, it should be kept in mind that we are dealing with the "minimum ages" of the terraces and thus this rate can be considered to be in keeping with those obtained for the escarpments. Clearly, the estimates of the rates of the deepening and widening of the canyon are merely indicative, but it is very interesting that both rates seem to be in keeping with the escarpment retreat rate obtained through dendrochronological dating.

Lastly, all samples characterized by the presence of compression wood and found along the main torrent, are reported on a graph (fig. 5). The random distribution of the trees in the forest explains the pattern shown on the graph. In other words, it can be imagined that a certain number of trees fall into the escarpment each year (the lowest inclination in the oldest part - bar A in fig. 5 - being due to the low number of old samples). However, there are several years in which numerous trees started to develop compression wood. The years 1917 and 1951 are examples of this. On-going dendrogeomorphological studies of debris flow activity affecting the fans in the study area have demonstrated that widespread episodes took place precisely in those years. Therefore, we can conclude that the escarpment erosion process generally progresses slowly, with accelerated phases taking place during intense precipitation events.

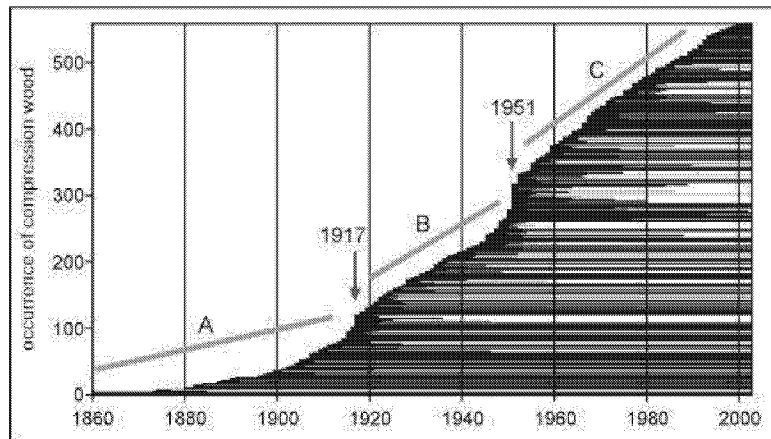


Figure 5: Temporal distribution of all the sequences of compression wood identified in the samples collected along the main torrent. The number of sequences exceeds the number of trees sampled, as many samples revealed more than one compression wood production cycle.

Acknowledgements

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SECTION 3

CLIMATOLOGY

A spatial high resolved climate reconstruction from recent and historical tree-ring data in the Rheinische Schiefergebirge since ad 1500

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Introduction

Tree- ring growth in Central Europe is affected by the interaction of many different climatological and non-climatological factors. In contrast to high-elevation tree sites, where temperature is the main limiting growth factor, temperature generally does not limit the growth of most of the main European tree species in the temperate Rheinische Schiefergebirge, with altitudes varying from 100 to 1000 m a.s.l.. From a synoptic point of view, the Rheinische Schiefergebirge represents an orographical barrier for air pressure masses moving from west to northeast. Hence, at specific ecological sites, precipitation seems to be the dominant growth-limiting factor.

By combining recent and historical oak ring width series, we intend to analyse the signals of temperature and precipitation on tree-ring growth, in order to reconstruct precipitation patterns in the Rheinische Schiefergebirge for the last 500 years.

Initial dendrochronological investigations in Windeck (Siegthal/NRW), a commune in the middle of the research area, document the strong influence of precipitation on the growing-patterns of the oaks at this site.

The analysis of historical oak wood of a half-timbered house first of all serves to define the year of construction of the building, and furthermore provides the material, which, in combination with recent data, makes the development of an oak chronology possible.

Thus, in this first study, a lot of interests on different scientific fields were set up:

- the year of house construction and further building periods
- the development of an oak chronology for this area
- the relationship between climatic forcing factors and tree-ring growth.

The prime aim was the analysis of the influence of precipitation and temperature on recent trees. These results point to the potential for climate reconstructions derived from trees of this site.

Material and Methods

The original dataset consists of cores taken from two buildings and recent trees. These trees are located on a slope close to the buildings in Windeck.

To set up the local chronology and anchor each core in time, we cross-dated the sampled cores among themselves and compared the dataset with different chronologies provided from B. Schmidt (Westerwald, Cologne, Germany) and S. Bonn (combination of sites in the northern German Mid Hills).

We were working with the programs TSAP and COFECHA by using the threshold $GLK > 60$, $t\text{-Wert} > 3,0$, Cross-Dating-Index > 100 (Rinn 1996) and $NET < 0,8$ (Esper et al., 2001) to assign the single cores.

B. Schmidt's site chronology Westerwald served as basis for the dating of two cores by calculating for each potential position in time the GLK (Schweingruber 1983), $t\text{-Wert}$ (Schmidt 1987) and the Datingindex (Schmidt 1987).

For further verification, the dataset was compared with other Central European chronologies. Therefore, the parameters mentioned above parameters were calculated between the indexed chronologies.

The meteorological data are taken from two climate stations: Bonn- Friesdorf (temperature and precipitation) and Windeck-Dattenfeld (precipitation). The combination of data from both stations guarantees the proximity to the sampling places, a dataset with high resolution in time and a long, comprehensive data base.

The time interval chosen for the analysis comprises the period 1900-1990.

Some cores which consist of less than 40 rings were eliminated from the chronology.

The study was focused on the analysis of the interannual relationships between the chronology and the meteorological dataset (monthly, summer periods, annual values). Therefore, the ratios of the 5-year moving average were set up and after indexation, correlation coefficients between the resulting chronology and climate data were calculated.

Results and Interpretation

Site chronology

From the selected 79 cores, a comprehensive local chronology spanning the time period AD 1491-2002 was developed. Due to the fact that 2-4 cores were sampled from one tree or beam, the chronology consist of 46 raw series, which characterize the dynamics of growth of one single tree or beam.

The mean segment-length is 99 years, with a dispersion between 44 to 187 years. The replication varies very strongly over time. The beginning of the chronology until 1500 is only occupied by two series, whereas the 20th century, consisting of the recent tree series, is defined by a number of 18. The time period 1500-1900 is characterized by a very strong variation in the number of replication. Finally, the chronology is comprehensive and useful for an analysis in this site, but further replenishment is necessary for representing a well defined chronology.

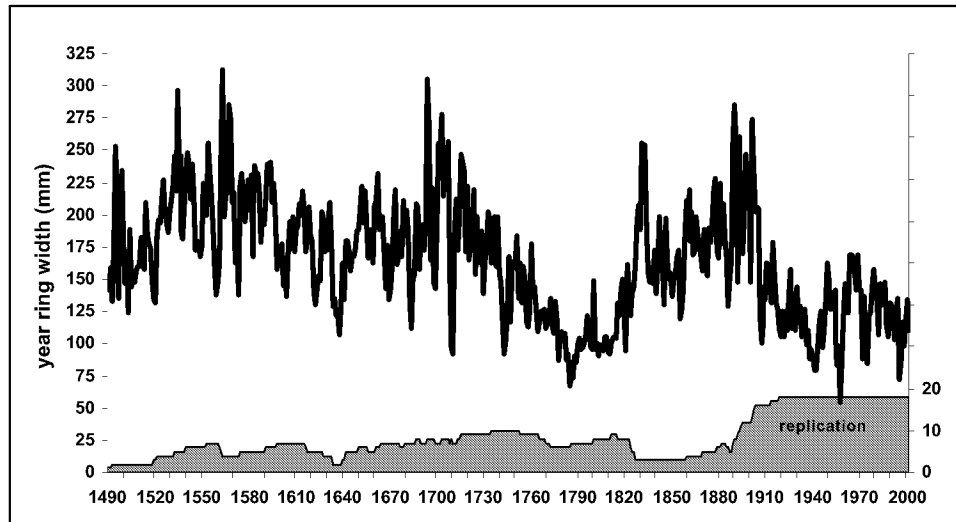


Figure 1: Local oak chronology Windeck AD 1491-2002

The comparison between the different regional chronologies demonstrates a high level of similarity. The calculated statistical parameters, as shown in Table 1, lie above the defined thresholds. From the comparison between the Bonn and the Windeck chronologies result higher values than between the Windeck and the Schmidt chronology, although the Schmidt chronology is closer to our research area. The analysis emphasizes an indication of teleconnective relationships in Central Europe.

Table 1: Statistical comparison between the chronologies; SCHMIDT chronology = Cologne (Königsforst), BONN chronology = Mittelgebirge (mean-curve of different sites)

Parameter	Windeck- BONN	Windeck- SCHMIDT	SCHMIDT-BONN
	1776-1972	1752-1994	1776-1972
t-value	46,0	41,9	34,2
GLK	91	90	87
CDI	3702	3349	2529
NET	0,30	0,27	0,25

Dating results of "Haus Lütz"

After generating the original dataset collected of "Haus Lütz", 81 cores were left for reconstructing the history of construction of this half-timbered house. 52 cores were successfully dated. The dating-rate is 64% and according to F. Schweingruber (1983:87), this

can be categorized as a good result. These 52 dated cores are sampled out of 32 beams part of three different housewalls. The cross-dating process yields to two separate sub-datasets, both consisting of 16 beams. Thus, at least two periods of construction can be identified for "Haus Lütz".

To define the year of construction and further building periods, the established method "year of felling = year of construction or rather year of felling +1 = year of construction" (Schmidt, 2000) was used for the interpretation of the dated beams.

In three beams of the first building period, the last developed tree ring is still preserved, which is necessary to define the year of felling. The last tree ring of the youngest beam is dated in 1679, while the other beams both end in 1677.

The three beams described above all end their last tree ring with latewood, which verifies the felling of the trees in autumn or winter. Thus, due to the fact that the beams are dated in 1677 and because of their position and function in the building, the construction of "Haus Lütz" began in the following year 1678, as usual in Central Europe (Hollstein 1980).

The third beam dated in 1679 has the function of a moulding. Mouldings are mainly fixed in the end of a building period or even separately (Großmann 1998). Taking this into consideration, the year 1680 could be interpreted as the end of the first construction period.

For the second building period, 5 beams which include the last developed tree ring were found. The construction timber was felled in a time interval: Two beams were felled in the year 1824, one in 1825, and two beams in 1827.

Based on these data, it is not possible to define the exact year of the beginning of the second period of construction. There are two different ways of interpretation.

First possible interpretation: sometimes timber of several years of felling are collected before the building period begins (Wrobel et al. 1993), which indicates the year 1827 as the beginning of the second building period (earlywood found).

Second interpretation: due to the different positions of the beams in the building, it is possible that the beams belong to different time intervals of the second period of construction. The period started in 1825 (1824 has latewood) in the ground floor and ended 1827 in the top floor, in which two dated beams belong. For further interpretation, a historian of construction is needed.

Dendroclimatological analyses

Figure 2 shows a significant relationship between climate and tree-ring growth for both precipitation and temperature. The analysed climatic parameters differ in the sort of influence: correlations between precipitation and growth are most extensively positive, while temperature and tree-ring growth show mainly negative relations. Precipitation has the strongest positive influence on ring width during the summer period (May-August), whereas temperature is negatively high correlated with tree growth during the vegetation period (April-October).

Apart from the influences of precipitation and temperature during the vegetation period, correlations to ring-width during the winter period, especially February, and the prior year were found.

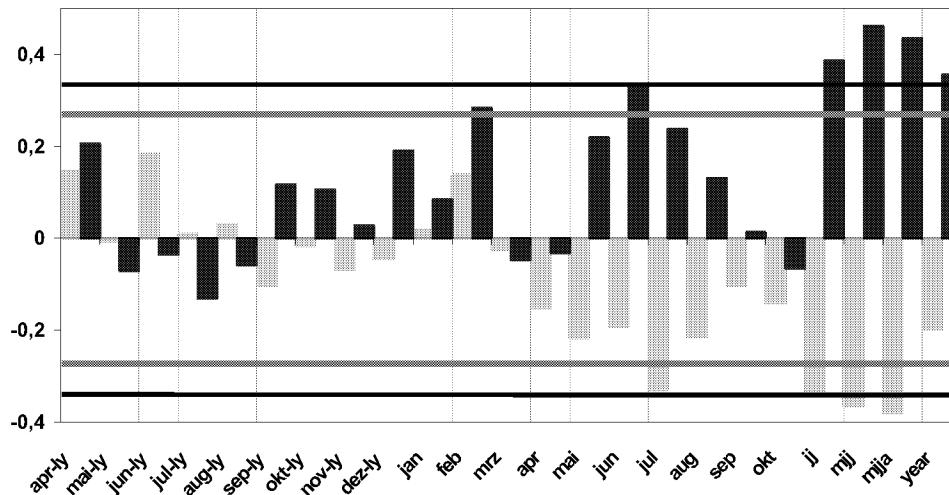


Figure 2: Correlation coefficient between indexed year-ring width and monthly means of temperature and precipitation. The time periods: from April of the year prior to growth until October of the year of growth, summer periods, annual; light beams = temperature correlation, dark beams = precipitation correlation; significant levels: grey = $p > 1\%$, $r^*_{99} = 0,27$; black = $p > 0,1\%$, $r^*_{99,9} = 0,34$

Precipitation in February falls in Windeck as snow. It has a strong positive correlation to growth due to the fact that snow can be regarded as a support of humidity at the beginning of the growing season.

The analysis confirms the influence of the climate conditions of the prior year on tree-ring growth (Spurk, 1997). The values calculated for correlations between the months of the prior year and growth are not highly significant, but correlations on a low significant level are provable. Especially oaks, which transport water only in the latest ring, have to build up a new ring every year, in order to guarantee sufficient water-supply. Thus, the climatic conditions of the prior year, in which nutrients for building up the next year-ring are collected and stored, are important for growth.

The annual sums of precipitation are highly significant positiv, as the several values for the summer periods, which emphasises the strong influence of this climate parameter on growth. Temperature has a high influence on growth as well, but the values are in general not as high as for precipitation, which is demonstrated by the lower influence on annual basis.

Thus, the correlations to climate parameters on a monthly, seasonal and annual basis emphasise that precipitation is the dominant growth-limiting factor for the planar collin oaks in this region.

Conclusion and outlook:

Our first results of dendroclimatological analyses in the Rheinische Schiefergebirge confirm the strong climatological influence (especially that of precipitation) on recent tree-ring growth. Furthermore, Schmidt & Gruhle (2003) found high precipitation signals in historical datasets in the West-German-regions. Therefore, the potential for climatic reconstructions can be assessed. The nature of the relationship allows to get information about precipitation by analysing tree-ring data.

In later investigations, the changing signal-strength due to changing climatological conditions over time (IPCC 2001) will be analysed in order to reconstruct the varying relationship between precipitation and tree-ring growth over the last 500 years. Taking this relationship into consideration, the precipitation reconstructions can be established.

Another factor which must be considered is the high spatial variability of precipitation. Due to this variability, a dense network of sites is necessary. Therefore, ring width data from recent trees and historical construction timber at multiple sites within the Rheinische Schiefergebirge will be used.

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Dendroclimatology of *Toona ciliata* in Australia

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Introduction

Tree-ring chronologies have been used to reconstruct the variability of past climate in many regions of the world, particularly in North America and Europe. Dendrochronology has rarely been applied in the Australian tropics due to the extreme shortage of species producing anatomically distinct annual growth rings. Only near the coast and its hinterland trees flourish but decrease in size along a rainfall gradient into the inland area. Dendroclimatological studies (e.g. Ash 1983; Rayner 1992) have been conducted with preliminary results indicating that some Australian tree species are suitable for reconstructing climate patterns. In neighbouring countries it has been demonstrated that dendroclimatological studies in the tropics can be successful (Berlage 1931; Jacoby and D'Arrigo 1990; Murphy 1994; Buckley *et al.* 1995; Stahle *et al.* 1998). Other sources for terrestrial proxy-data in Australia are rare and only in the semi-arid to humid zones can sources such as lake sediments, or other archives of vegetation change (Stocker 1971; Kershaw 1978; Hopkins *et al.* 1990, 1996; D'Costa and Kershaw 1995; De Deckker 2001; Bowler *et al.* 2003) and tree-rings (Ogden 1981; Schweingruber 1992) be expected. The inland zone is too dry to conserve any natural archives and adjacent savanna and dry eucalypt forest communities are prone to regular fires, and consequently cannot hold any long-term records (Bowman and Cook 2002). Additionally, trees do not have the chance to grow to old trees due to the damage by insects such as termites (Mucha 1979), thus no long-term annually resolved climate proxy tree-ring records do exist yet for mainland Australia.

Therefore, the objective was made to show that *Toona ciliata* M. Roemer (*Meliaceae*), Australian red cedar, can be used to build tree-ring chronologies and reconstruct climate along the east coast of Australia reaching into pre-instrumental periods. The study concentrates on *T. ciliata* because it is one of the few deciduous tree species in Australia experiencing a seasonal dormant period of the cambium, a general indicator that missing rings might not be a problem as in many other non-deciduous tropical tree species. In addition, it has a wide latitudinal range occurring from Cape York to just south of Sydney which enables the application of a sample strategy adjusted for the tropics, whereby starting in higher latitudes and, with more knowledge gained, approaching the lower latitudes (Stahle 1999).

Toona ciliata belongs to the *Meliaceae* family which is commonly known as the mahogany family and is part of the Indo-Malayan floristic element. The genus *Toona* is closely related to *Cedrela*, the neotropical counterpart, with which it has been repeatedly united and separated

(Boland *et al.* 2002). *Toona ciliata* is a tall deciduous often buttressed tree usually to about 40 m in height and with stem diameters up to 1-3 m. The species occurs in the remnants of warm temperate, subtropical and tropical rainforests between sea level and 1500 m above sea level where it grows in both primary and secondary rainforests. In Australia, *T. ciliata* grows best on rich alluvial or volcanic soils having a neutral to acid pH-range in wind-sheltered positions and is also common on krasnozems derived from basalt. It can tolerate a few frosts each year and prefers a mean annual rainfall of 1200-3800 mm.

This study consists of three parts: dendrometer band studies, growth experiments and dendroclimatology using tree core samples.

Methods

Growth experiments and pinning

Growth experiments consisting of different treatments, *i.e.*, restricting water, temperature, light, and fertilizer supplies were conducted in order to examine their effects on wood anatomy and tree growth. Two additional experiments attempted to induce false rings (density fluctuations of the fibre cells, tangential bands of vessels, extra parenchyma bands, *etc.*). In the first group, trees were defoliated in the middle of their active growth period, and in the second, trees were kept under very low light conditions, *i.e.*, 200 $\mu\text{mol/m}^2/\text{s}$ photosynthetic active radiation (PAR). The first experiment tried to imitate natural loss of foliage due to insect attack, cyclone or drought damage and the second one aimed to reproduce wet-season tropical conditions with a thick cloud cover and high temperatures prevailing during a major monsoonal depression or a cyclone.

In the past, the pinning method has been identified as a useful tool for studying the timing of annual wood formation (Mariaux 1967; Wolter 1968). Recently, the pinning method has also been used as an intra-seasonal marker system to measure and explore radial growth within one year. For the present study a small needle was inserted into the stem on a quarterly basis.

Dendrometer bands

Dendrometer bands have often been used to detect seasonal growth patterns of trees because they offer an easy way for measuring changes in the diameters of tree trunks. In contrast to dial gauge dendrometers they have the advantage of recording average circumferential increase which can be converted to average radial increase for the entire bole section (Bormann and Kozlowski 1962). Due to their sufficient accuracy and low-budget construction costs dendrometer bands were used in the current study. Two trees were banded and monitored at the Australian National Botanic Garden (ANBG) in Canberra and three trees each on private properties in Robertson and Upper Kangaroo Valley (UKV) during the growing period 2001-2002. The ANBG site is located outside of the species' natural distribution because winter temperatures and annual amounts of precipitation are too low. In Robertson, higher amounts of annual rainfall but occasional frosts are experienced, and hence, the site is situated near the limit of the natural distribution of the species. The third site UKV shows evenly distributed monthly amounts of rainfall and higher temperatures, and

therefore, is found within the natural range of the Australian red cedar. The increment data measured with dendrometer bands at the three sites are compared with temperature and rainfall data which have been averaged and summed, respectively, corresponding with the number of days of each measurement interval.

Preparation of samples for microscopy and digital imagery

For further microscopic analysis thin transverse sections of the pinning areas were cut in large quantities by applying a more time-efficient technique invented by Heady (1997).

The light microscopy analysis was done with a Zeiss Axioskop optical microscope equipped with a digital camera. First, the samples were examined for possible tree-ring boundaries that had occurred during the period of the experiment. These observations were then combined with phenology data. Secondly, the images of the pinning areas were imported to digital imagery software which facilitated the measurements of distances from each wound tissue to the cambium at four radii. Along the radii but outside the wound tissue zones numbers and sizes of vessels were noted and averaged for each quarterly pinning zone per tree. The diameter measurements were converted into values of area and then multiplied by the vessel counts. In addition, the measurements were divided by the corresponding values for growth increments represented by the length between the pinning wound tissue and the cambium.

Dendroclimatology

The dendrochronological methods applied in the current study follow the general routines described in Stokes and Smiley 1968, Fritts 1976, Schweingruber 1983, and Cook and Kairiukstis 1990. On the Atherton Tablelands and in Lamington National Park located in north and south Queensland, respectively, 57 dominant to subdominant trees were sampled. The surfaces of the core samples were smoothed according to routine sample preparations with a belt-sander using paper grit size of 240 (Bowers 1964) followed by an orbital sander treatment with paper of increasingly fine grit size up to 1200 (Pilcher 1990). The smooth surface of the cores allowed them to be scanned in high resolution mode and imported to the WinDENDRO program for further analysis (WinDENDRO 2003). Initial crossdating was achieved visually and graphically in WinDENDRO and the final quality control was aided by COFECHA software (Holmes 1994).

After the quality of the crossdating was verified the variance was stabilised using a power transformation. The overall age trend was removed by means of a cubic smoothing spline function with (Cook and Peters 1981). The resulting tree-ring indices were exposed to simple correlation analysis with monthly climate data to identify important forcing factors controlling tree growth. The monthly climate data available comprised precipitation, maximum, minimum and mean temperatures.

Results and discussion

The growth experiments helped to identify crucial aspects of the growth of *Toona ciliata*. They revealed that the treatments were successful in adjusting the phenological performance due to changed environmental conditions.

- It was found that tree growth is sensitive to low temperatures, poor soil and drought conditions.
- The general macroscopic wood anatomical features in terms of vessel size and numbers also changed when trees grew in different environments.
- When restrictions to the supply of water, temperature and soil nutrients applied trees at first reduced growth increments in the latewood zone and then reduced vessel size and increased vessel numbers.
- False rings occurred but only in younger trees or in adult specimens under very extreme conditions, such as total defoliation during a direct cyclone hit or a very extreme drought followed by a fire entering the rainforest, as suggested by Herwitz *et al.* (1998).

The current study illustrated that the home-made dendrometer bands were adequately accurate to monitor stem diameter growth on a weekly to monthly basis for one growing season. The specimens monitored shed all their leaves, stayed leafless for several weeks and entered a dormant period. Growth recorded by means of dendrometers was found to be related to either temperature or precipitation depending on the geographical location. While the tree increments in Canberra were correlated positively with temperature, growth in Robertson and Upper Kangaroo Valley showed more coherence with precipitation. The ANBG is located outside the natural distribution of the species and the continental climate often is extensively hot in summer and cold in winter for longer periods. This might explain the stronger relationship between tree growth and temperature in Canberra compared to the coastal sites where tree growth was mainly influenced by the more maritime climate.

In Upper Kangaroo Valley, diameter growth of *T. ciliata* decreased during both extremely dry and wet periods in December 2001 and February 2002, respectively. This result confirms similar results found for the same species by Bhattacharyya *et al.* (1992) in India that very humid conditions can also limit growth in *T. ciliata*. These humid conditions can be the result of heavy rainfall events or due to soils with poor drainage properties intensifying the problem of water-logging. The question of where is the upper limit for the rainfall values to start exerting a negative effect on tree growth in Upper Kangaroo Valley could not be answered due to the lack of suitable data. To solve this problem long-term dendrometer band studies are strongly recommended. At the beginning of the dendroclimatology section, tree-ring statistics for the two study sites derived from COFECHA and MS Excel outputs are listed in table 1. The trees grew 3.05 to 3.58 mm per year in average. The minimum and maximum values of the annual increments exhibit a wide range typical for tree growth in the humid tropics extending from 0.01 to more than 2 cm. The coefficients of variation expressed as percentages of the mean shows that the standardisation has reduced the variation around the mean immensely to approximately 20 % to 10 %.

Table 1: Summary statistics for the two site chronologies

	Atherton Tableland		Lamington National Park	
Chronology length	2001-1592		2001-1717	
Length (years)	410		285	
No. of trees	37		20	
No. of samples	53		38	
Mean (min./max.) annual increment (mm)	3.58 (0.1/20.55)		3.05 (0.1/21.49)	
Standard deviation (mm)	2.89		2.64	
Coefficient of variation before and after Standardisation (in %)	833.21	21.64	696.84	19.05
Mean sensitivity	0.597		0.588	
Mean autocorrelation before and after standardisation	0.427	0.254	0.316	0.012
1 st year EPS below 0.85	1920		1900	
Series intercorrelation	0.522		0.539	

The values for the mean sensitivity of the sites are large suggesting that they are suited for dendroclimatic research. The values for the series intercorrelation indicate common variance implying that tree growth is controlled by one main common factor. The values for the mean autocorrelation have decreased after the standardisation indicating that the low-frequency variance originating from non-randomness other than climate has been filtered out by the cubic smoothing spline.

The site chronologies from Atherton Tablelands and Lamington National Park are presented in figure 1. The site indices (dark grey graph) were only computed for a minimum of 5 samples. This limit was reached in Atherton Tablelands in 1861 and in Lamington National Park in 1856. The response plots in figures 2 and 3 illustrate that these site indices correlate with precipitation as well as temperature records.

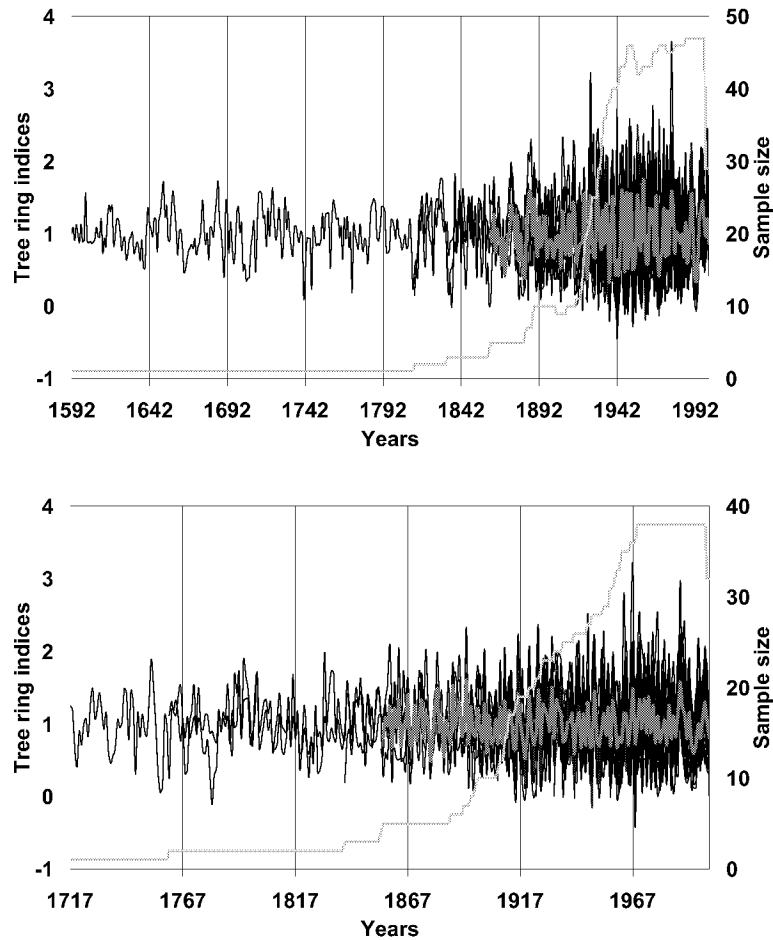


Figure 1: Tree-ring indices with averages (dark grey graph) and sample size (light grey graph) from Atherton Tablelands (top) and Lamington National Park (bottom)

The results of the correlation analysis for the Atherton Tablelands indicate that the precipitation of the months March to June of both the previous and the current season seem to be most important for tree growth (figure 2a). Tropical cyclones bringing torrential rains and other unfavourable tree growth conditions to the region might explain the insignificant correlation patterns during the first part of the current growing period between September and February. The temperature data of the previous year correlate mainly positively with tree growth (figure 2b). This suggests that the specimens from north Queensland seem to have a “temperature memory”, *i.e.*, high temperatures in the second half of the previous year influence tree growth of the present season positively.

In contrast, high maximum and mean temperatures during the current growing season seem to exert detrimental effects to tree growth. For example, during March of the previous and current growing season trees seem to grow best when humid conditions with high minimum but low maximum temperatures prevail.

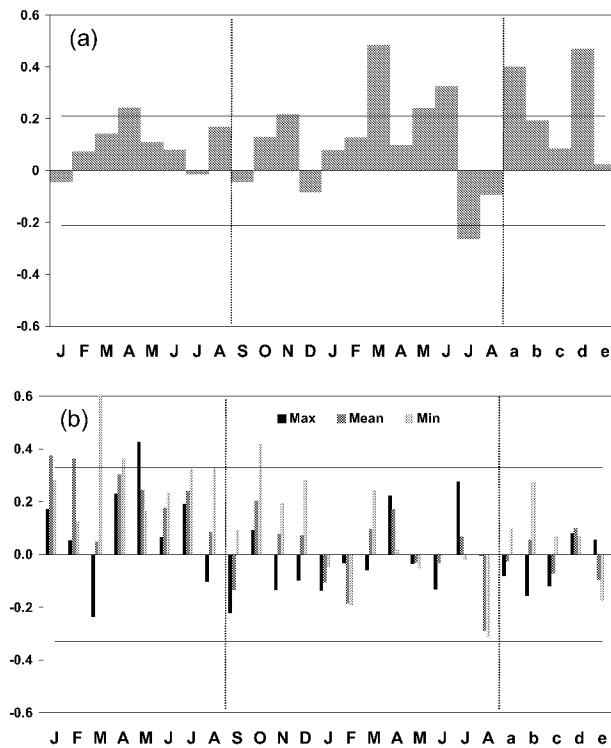


Figure 2: Climate response plots for the Atherton Tableland site with Kairi research station meteorological data: Monthly coefficients of correlation for precipitation (2a) and maximum, minimum and mean temperatures (2b). The left half of the diagram covers the period January to August before the current season the middle part stands for this season (September to August) and the small letters a to e stand for the annual value and the averages for the periods for September to November, December to February, March to May and June to August of the current season, respectively. (Source: Bureau of Meteorology, Canberra 2002)

Figure 3a illustrates that apart from precipitation in August none of the months of the previous year exert significant influence to this season's growth. From September to December of the current season no correlation is discernible. Subsequently, the correlation grows to a significant level in January and remains positive until the end of the season.

The response plot also shows a significant positive correlation value for annual precipitation (letter “a” in diagram 3a). Temperatures of the previous and at the beginning of the current season until November are positively related to tree growth (figure 3b). From December to the end of the growing season maximum temperatures correlate negatively.

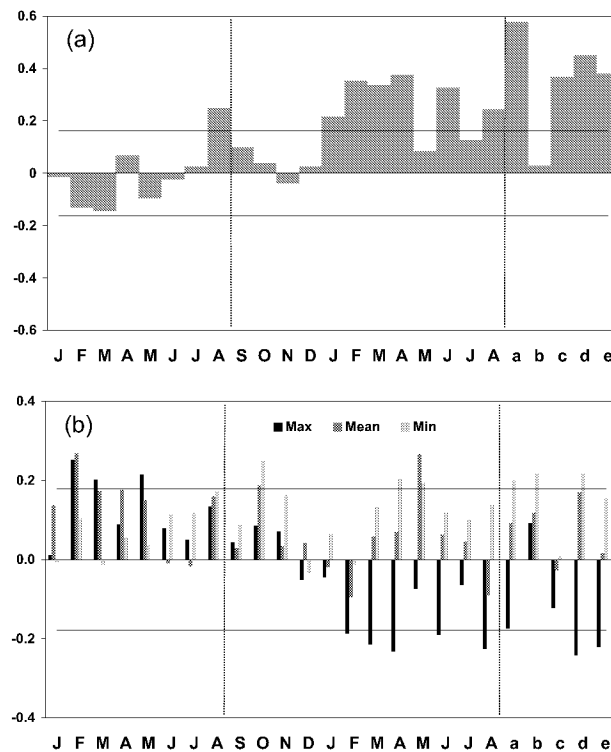


Figure 3: Climate response plots for the Lamington National Park site with Brisbane meteorological data: Monthly coefficients of correlation for precipitation (3a) and maximum, minimum and mean temperatures (3b). The left half of the diagram covers the period January to August before the current season the middle part stands for this season (September to August) and the small letters a to e stand for the annual value and the averages for the periods for September to November, December to February, March to May and June to August of the current season, respectively. (Source: Bureau of Meteorology, Canberra 2002)

The values for the minimum temperature show the reverse displaying significant positive correlations in April and May. This pattern can also be found with a weaker signal for the Atherton Tablelands. These correlations might be an indicator for the particular climate of the tropical highland rainforest which can experience cold nights at any time of the year during periods of clear skies. This is supported by the fact that in the Lamington National Park the cool temperate *Nothofagus* rain forest type can also be found adjacent to the tropical rain forest depending on the local micro-site conditions (Graham 2001).

Conclusions

This study has demonstrated for the first time that *Toona ciliata* can be used for dendroclimatological investigations in the tropics and subtropics of Australia. The site indices were found to be sensitive mainly to seasonal and annual precipitation and to smaller extent to temperature. Further analysis, not presented here, showed only weak correlation between site indices and the El Niño Southern Oscillation (ENSO). However, it was revealed that this relationship seems to be influenced by the state of the Inter-decadal Pacific Oscillation (IPO). Further tree-ring studies need to focus on both climate phenomena ENSO and IPO in order to ensure more reliable regional climate predictions of higher quality.

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Lateglacial tree-ring chronologies - A high resolution archive of the past

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Introduction

Lateral melt-water channels were formed along the margins of the Alpine glacier lobes on the Swiss plateau after the last glacial maximum (approx. 16 ka BP). As soon as these outlets became inactive, landslide, solifluction, and surface water processes started to fill the channels with loamy alluvia. Pioneer forests (birch, pine) established themselves in response to the abrupt warming at the beginning of the Lateglacial. While the pioneer vegetation was developing, continuous sedimentation processes led to the tree stumps being buried in sediments some 10 m thick. This process ended when the Boreal vegetation began to migrate to higher elevations, suppressing the Lateglacial and Preboreal pioneer forests and stopped weathering and alluvial downwash from the slopes.



Figure 1: Fossil pine stump (*Pinus sylvestris*)

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 approx. 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 Period (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), accompanied by a temperature dropping approx. 7°C relative to the early Bølling (Dansgaard et al. 1993, GRIP Members 1993).

Material and methods

Construction work for the highway tunnel through the Uetliberg near Zurich started in summer 2000. 144 fossil pine stumps have been recovered on the construction sites Gaenziloo and Landikon in the glacial melt-water channels on both slopes of Uetliberg. The valleys of Reppisch on the western slope and of Sihl on the eastern one (Schaub, 2003a).

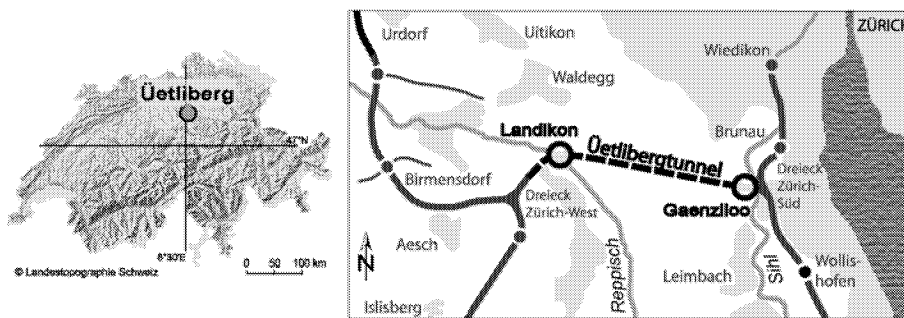


Figure 2: Site location

Mass movements, precipitation and melt-water filled the channels with material weathered from Upper Freshwater Molasse and glacial till deposits upon the slopes. These mainly loamy sediments developed with sedimentation rates of 2 to 6 mm/year to huge archives containing fossil pines, other plant remains, snail shells, other macro- and micro- remains. The pine trees have been buried continuously during their lifetime by loamy alluvia, which were washed down from the slopes; hence the wood is well preserved. Object of this study are the finds from Gaenziloo in combination with those from Daetttau (Friedrich et al. 2001; Friedrich et al. 1999; Kaiser 1993). The stumps recovered were cut into disks: A first one was taken at the level where the roots are spreading for the purpose of finding the germination age of each tree. Another or more disks were taken 30 to 100cm above to avoid the disturbances caused by the roots. The samples were dried and sandpapered. The disks were smoothed with razor-blades and contrasted with white chalk or water on hardly visible areas. To measure the tree-ring widths the program TSAP has been applied (Rinn, 1996). Thus the annual growth rings can be measured on 1/100 mm exactly. The radii are synchronized on the light-table, checked by statistical values by the TSAP program (t-values and Gleichläufigkeit), get averaged, and form a curve for each tree. Several tree curves may be combined to a chronology. The program Cofecha is used to do a data quality control as well as a check of the crossdating among the trees within chronologies. (Grissino-Mayer, 2001).

Results

Three independent chronologies at Gaenziloo have been developed (Schaub, 2003a):

1. ALLCH_A spanning 428 years, mid Allerød (ending approx. 11,400BP)
2. ALLCH_D spanning 544 years, end of Allerød (ending approx. 10,900BP)
3. YD_A spanning 205 years, Younger Dryas (ending approx. 10,500BP)

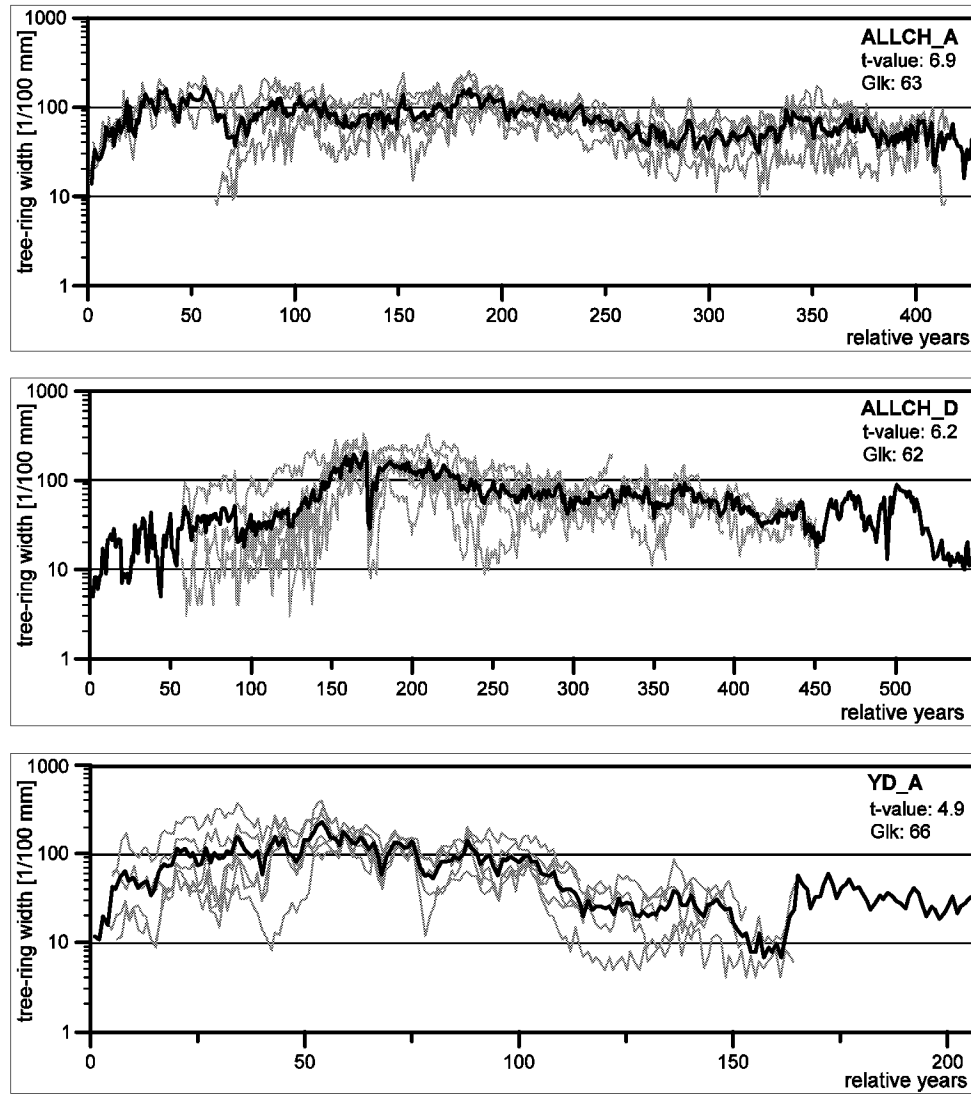


Figure 3: The different Gaenziloo chronologies (ALLCH_A, ALLCH_D and YD_A) in black and the tree-mean curves (grey) are displayed in relation to each other.

The position of floating chronologies on the absolute timescale is determined by ^{14}C datings. In Figure 4 the different chronologies are displayed in the correct position to each other. Moreover the dendromatches between different chronologies are shown by a vertical lines. ALLCH_A is crossdated with chronology Daealch_1 from Daetttau of early Allerød (totally 669 rings). ALLCH_D and Daealch_2 form also a chronology (544 rings) of late Allerød (Kaiser, 1993). Chronology KW_1 forms the oldest part of the absolute Hohenheim pine chronology (PPC) (Kaiser, 2003; Schaub 2003b; Friedrich, 2001).

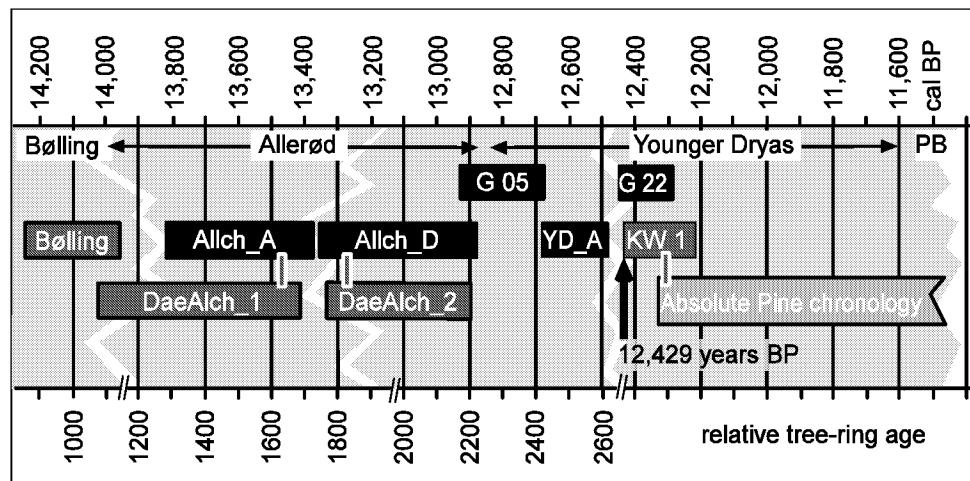


Figure 4: Dendromatches and positions of the different Gaenziloo chronologies in relation to existing ones

Discussion

In our study, crossdating in some cases was impeded by (a) the occurrence of extreme growth disturbances within the series, and (b) insufficient overlap between them. However, research in the area is still continuing, and the more samples we recover, the higher the chances are, to 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. By truncating the tree-ring series (i.e., by removing the first 50 to 100 annual values), the degree of crossdating improve. That's why the tree-ring sequences used in our study have not been standardized. 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 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.

Summary

At the construction sites of the A4-highway tunnel through Uetliberg near Zurich, more than 140 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 BP. The wood samples (cross sections of the trunks) were analyzed dendrochronologically. The radiocarbon method was used to determine their age. Three new floating chronologies were built and they were linked with chronologies from Daettgau produced by Kaiser (1993), termed DAEALCH_1 and DAEALCH_2. The newly built chronologies cover the main parts of the Allerød (ALLCH_A and ALLCH_D) and also a part of the Younger Dryas (YD_A). Student's t-values, percentages of parallel variation ('Gleichlaufigkeit') and radiocarbon wiggle matching (^{14}C age determinations on a decadal scale) support the validity of the resulting chronology.

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SECTION 4

ISOTOPES

New stable isotope and dendrochronological studies of the 1000 years pine (*Pinus sylvestris* L.) tree-ring chronology at the upper timberline in the Khibiny Low Mountains, Kola Peninsula, North-Western Russia

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Introduction

A millennium-long (1138 years) tree-ring chronology for the central part of Kola Peninsula, first presented in this paper, is a result of continuing our dendroclimatological investigations on Kola Peninsula (Hiller et al., 2001; Boettger et al., 2002, 2003a, 2003b). Climatic influence on growth of trees (tree-ring width, wood density, stable isotope) in this area is high due to the geographical position of Khibiny Mountains. Pines exist there at the northern latitudinal boundary of their range, also limited by the mountain relief in the altitudinal distribution. The presented tree-ring chronology is the longest for Kola Peninsula and unique for Khibiny Mountains.

Study areas

Khibiny low mountains are located in the central part of Kola Peninsula, 150 km North of Polar Circle and at an elevation as high as 1100-1200 m a.s.l.

The climate refers to the cold-temperate type with strong Arctic and Atlantic oceans impact, resulting in long, moderately cold winters and cool, wet summers. The modern mean January temperature at the south-western margin of the Khibiny Mountains is about - 12°C, while the mean July temperature is +13° C. Vegetative season lasts from May to September (60 - 80 days). The annual precipitation reaches 450 mm, 75-120 mm of which fall in the cold season within the study area (Jakovlev, 1961).

The Khibiny foothills are covered by northern taiga vegetation (spruce, pine and birch dominate). Forests grow up to 300-450 m a.s.l. depending on the slope exposure.

Geographical location of Khibiny Mountains makes a significant climatic effect on wood growth. On one hand, pines growing here are located near the northern latitudinal boundary of their distribution range, on the other hand, the mountain relief of Khibiny Mountains constitutes an altitudinal limitation for their growth.

Material

The collection of wood for constructing tree-ring chronologies consists mainly of Scots pine (*Pinus sylvestris* L.) samples. In total, 259 wood samples have been obtained, but only 19 of them refer to spruce (*Picea abies* L.). Samples were taken at different altitudes as well as along the perimeter of Khibiny mountains where pine forests grew in the past (Fig. 1). Only at site 1 and 2 we collected spruce wood due to the absence of pines there.

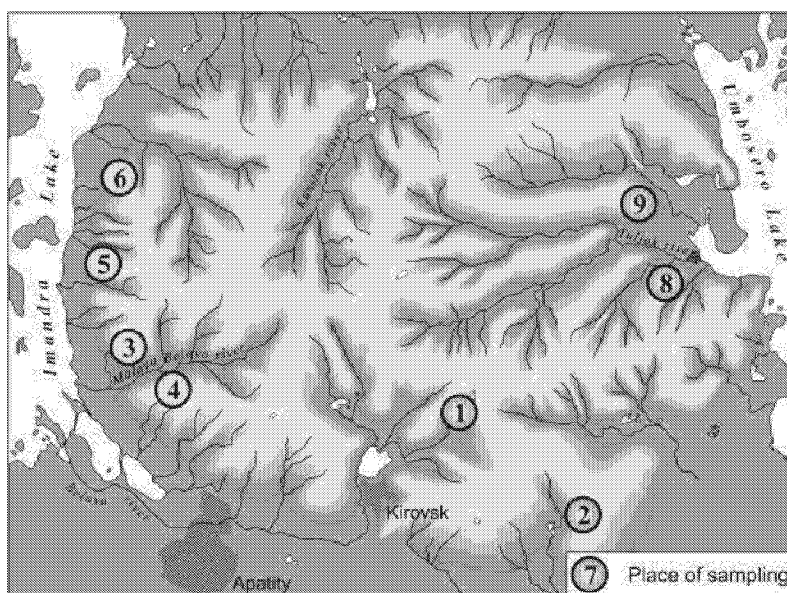


Figure 1: Map of Khibiny Mountains, showing the sampling sites.

Living trees

Three (minimum two) cores were taken from each living tree in different directions. The sample sites embraced foothills up to the upper timberline and were collected at 50 m altitudinal interval. Not less than 10-15 trees were studied in each location.

Dead trees

The samples from dead trees were taken in form of discs. Wood remains were found at an elevation of 250-450 m a.s.l. It is noteworthy that 49 samples were obtained from dead trees, found at an elevation of 100 -140 m above the present tree line.

Results and discussion

Construction of the chronology

All samples were exposed to a preliminary preparation in the laboratory. Cores from living trees were prepared using a razor along the horizontal axis of the trunk. Slabs from dead trees we cleaned by razor for three or four radii. We measured tree-ring widths to the nearest

0.01 mm, and the data were stored in computer files using TSAP standard tree-ring measurement software system. Obtained data were used for graphs of absolute tree-ring growth of every radius for each sample. Then all tree radii were averaged to produce an individual chronology for each sample. The next step was cross-dating of individual chronologies (Briffa *at al.*, 1990). To remove the age trend that can obscure the climatic influences on tree-ring growth, a special method known as standardization or indication of absolutely dated chronologies was used (Cook *at al.*, 1990). As a result a tree-ring chronology more than 1000 years long has been constructed (fig. 2).

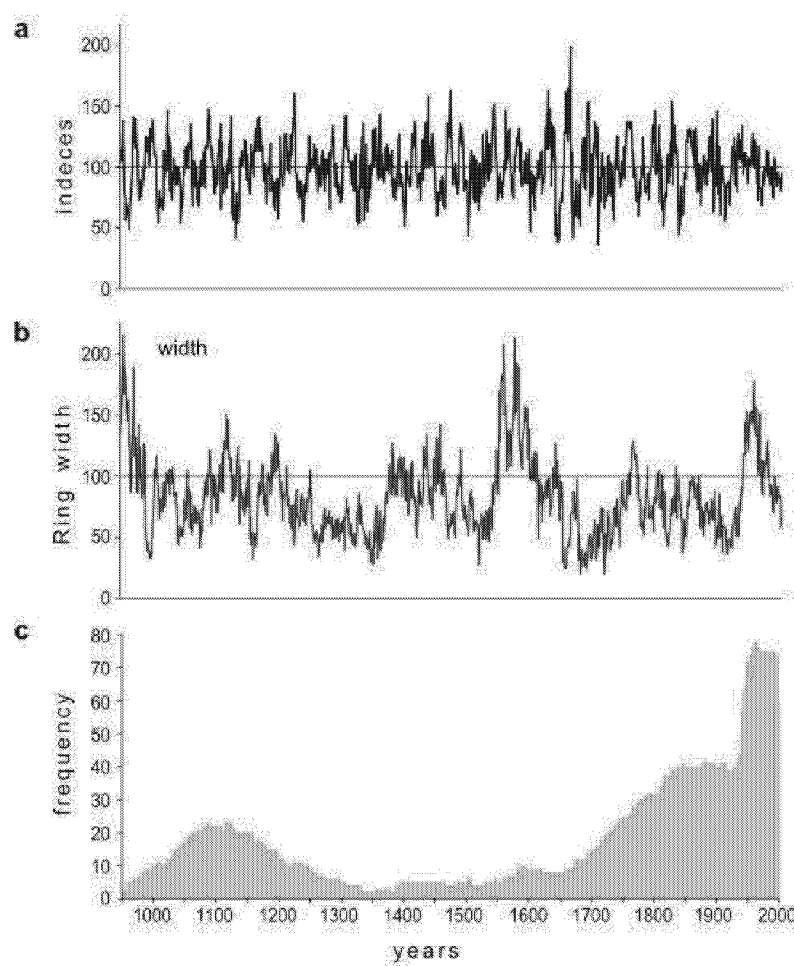


Figure 2: Tree-ring chronology for Khibiny Mountains. (a) Standardized data, (b) raw data, (c) sample depth.

Radiocarbon dating

The dendrochronological dating was supported by ^{14}C dating of selected wood fragments (Hiller et al., 2001). All the data are given in conventional ^{14}C years BP. Quoted errors (1s) include uncertainties in conventional ^{14}C dates and were calibrated using the INTCAL 98 calibration program (Stuiver et al., 1998). According to determinations, ^{14}C dates well correspond to the dendrochronological dating, though some samples lay out of the ideal position (fig. 3).

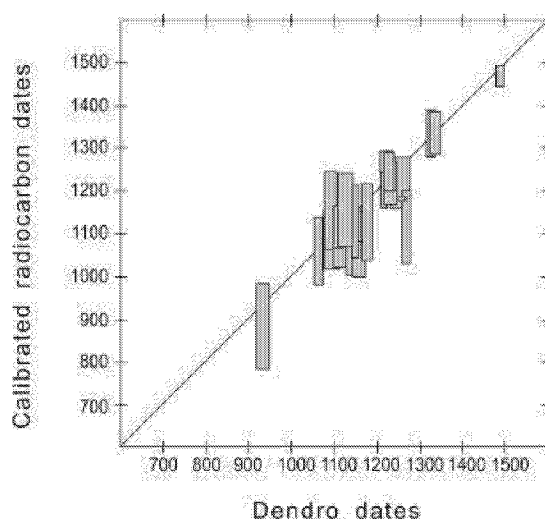


Figure 3: Comparison of dendrochronological age and corresponding calibrated ^{14}C age of the samples. Each box represents one sample. The width represents the number of rings in the sample, and the height represents the radiocarbon date of the sample.

Stable isotopes

10 increment cores of living pines were measured for stable isotope composition of carbon and oxygen in cellulose of their tree rings with annual resolution. The mean $\delta^{13}\text{C}$ values from three cores of young pine trees (where climatic signal is most pronounced) correlate significantly with the average temperatures of July and August ($r = 0.71$). Carbon isotopes and ring-width seem to have quite similar climatic information for this site (Fig. 4a,b). Much less pronounced correlation was found between the $\delta^{13}\text{C}$ values and the precipitation sums for summer months.

The carbon and oxygen isotope values from both living and fossil trees correlated positively with each other ($r = 0.78$; $n = 93$). Probably, the isotope ratios in the period of wood formation depend on varying humidity conditions (Saurer et al., 1997). Short summer in Khibiny is characterized by relatively low humidity.

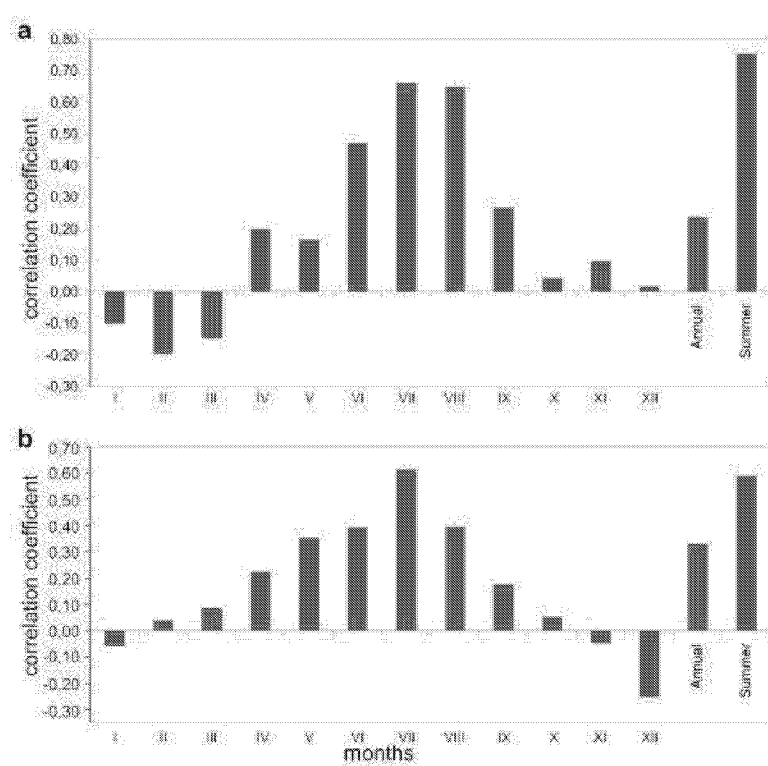


Figure 4: Relationship between air temperature and carbon isotopic composition (a) and tree-ring width (b)

Our results show that tree-ring width could increase and reduce within approximately 50 years. Only during 17th and first half of 18th centuries (about 150 years) the tree-ring growth was lower than its average value for the whole millennium. This longest period of tree "mortality" and low tree-ring growth rate can be identified as a main phase of Little Ice Age (LIA) in the study area. A considerable increase of tree-ring width occurred in the end of 9th and first decades of 10th centuries, the time interval can be attributed to the beginning of Medieval Warm Period (MWP). During the subsequent periods some oscillations of tree growth rate lasting several decades were recognized.

However, some insight into the MWP duration can be derived from the data about fluctuations of the tree-line in the given region. Samples of wood, discovered above the contemporary tree-line, serve as related proxies (Fig. 5). The highest location of this group of samples was 140 m higher than the modern pine-tree-line. This means that at that time the upper timber line was at least 140 m higher than now.

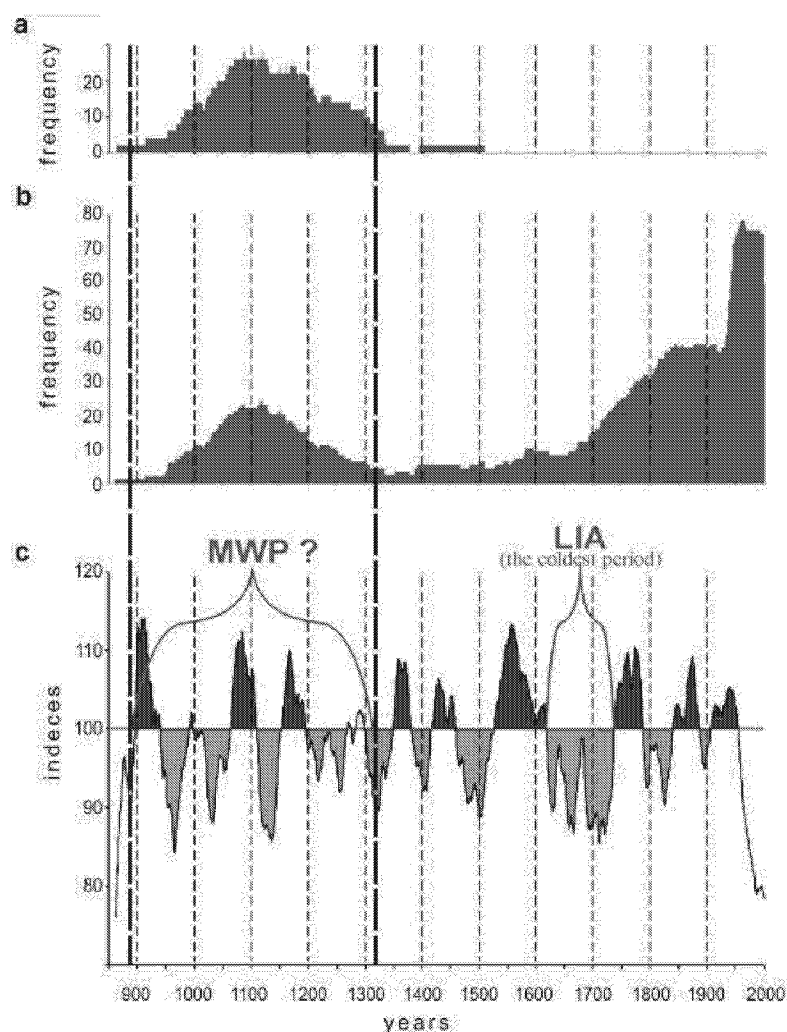


Figure 5: (a) Sample depth of samples above modern tree-line. (b) The same for all samples. (c) annual ring-width variability filtered with 50-year running mean.

Dendrochronological dating of the samples showed that they had grown there mainly from the end of 9th to the middle of 14th centuries that corresponds to the general assumption about timing of the MWP.

Important feature of the presented tree-ring chronology is a strongly pronounced trend to reduced tree-ring growth in the second part of the 20th century, characterized by the so called modern global warming. Furthermore, instrumental records from weather stations in Khibiny foothills with a long period of observation (from 1924) suggest a tendency to cooling since the end of 1930s.

Conclusions

- (1) The presented tree-ring chronology for Khibiny Mountains enables us to conclude that dynamics of carbon isotope content and tree-ring growth correlate with climate changes.
- (2) Climatic changes during the last millennium, influencing annual tree-ring growth, are identified as short-term (decadal scale) oscillations.
- (3) The main chronological subdivisions of Late Holocene in Khibiny area had specific regional features being rather smoothly pronounced in contrast to Central Europe.

Acknowledgements

We would like to thank U. Helmstedt for carrying out much of the laboratory work. Special thanks go to Dr. A. Hiller for the radiocarbon analysis.

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Stable isotope ratios in late wood of *Picea abies* from Engadine

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Introduction

Trees supply terrestrial records from pre-industrial period that are invaluable for climate change studies: to fully exploit the potential of tree-rings as archives of paleoclimate data, several tree-ring parameters should be examined in combination. In this on going project we aim to compare fluctuations of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in tree-rings, with tree-ring width and maximum density. A first set of results concerning the $\delta^{13}\text{C}$ isotopic ratios is presented here.

In this study, $\delta^{13}\text{C}$ variations in late wood cellulose of *Picea abies* Mill., growing at the upper timberline were calibrated with meteorological data. Two time windows of 50 years, covering periods of climatic interest were investigated, namely, the end of the 20th century (1946-2000 AD) as a warm period, and the beginning of the 19th century (1800-1850 AD) covering the Dalton minimum.

This research is part of a program investigating palaeoecological natural archives with annual resolution (lake varves, ice cores and tree rings) from the same geographic area (Central Alps) (NCCR Climate, project VITA).

Methods

Samples were taken in the Central Alps, Engadine Valley, Switzerland, at 1900 m a.s.l. Bedrock is acidic (gneiss) and soil type podzol, soil drainage was good, trees were growing at middle slope, with SW aspect, on a convex Topography. Sampled *Picea abies* trees grow in an open mixed conifer community with *Larix decidua* and *Pinus cembra* (40% cover). Forest understorey was dominated by *Calamagrostis villosa*, *Vaccinium myrtillus*, *Rhododendron ferrugineum* (80% herb layer, 10% shrub layer). Four to six cores from *Picea abies* (L.) Karsten dominant trees were taken. At the same time two cores were taken from 40 sub-dominant and suppressed spruce trees to develop a reliable chronology. Two cores from four selected dominant trees were used for isotopic analysis. The late wood and early wood from each ring was separated with a razor blade under a binocular, the boundary late/early wood was clearly visible making accurate separation possible.

The late wood of two cores from the four selected trees was pooled for each year to further analysis (Treydte, Schleser et al. 2001). Pooled late wood samples were then milled. Pooling and homogenizing the wood has shown to give a reliable mean isotope curve.

Cellulose was extracted from the wood through dissolution of the extractives with toluene and ethanol in a soxhlet apparatus, followed by lignin and hemicellulose extraction (with

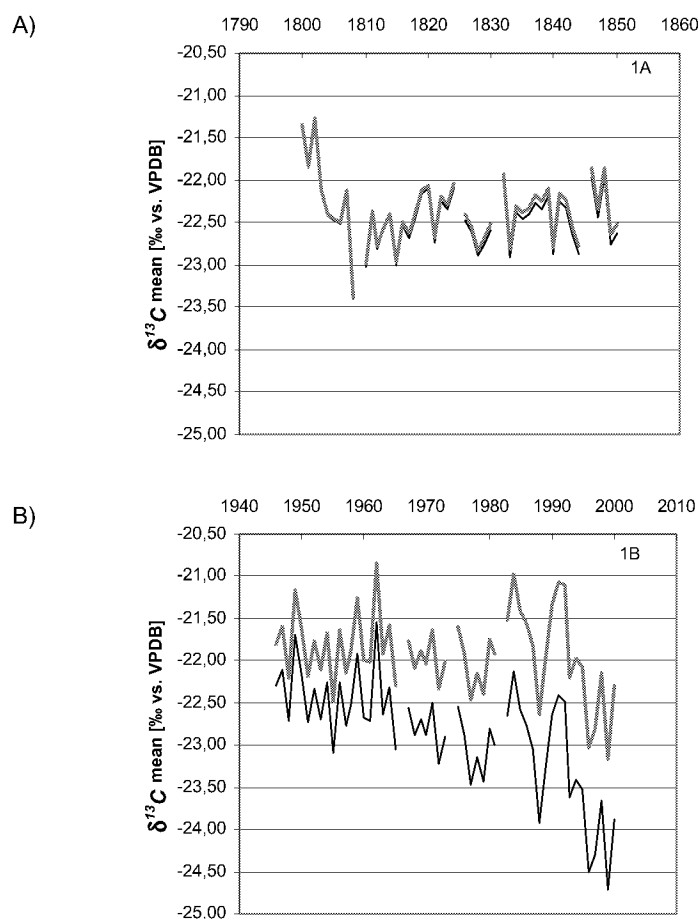


Figure 1: $\delta^{13}\text{C}$ mean [‰ vs. VPDB] in the two periods analysed (A: 1800-1850 AD; B: 1946-2000 AD); measured values in black, corrected values in grey.

NaClO_2 , acetic acid solution, and NaOH , respectively) and final cleaning of the α -cellulose in deionised water (Green 1963; Brenninkmeijer 1983). Isotopes were measured with a IRMS at the Physical Institute, Bern. Measured isotope data expressed as $\delta^{13}\text{C}$ vs PDB (‰) were detrended using residuals from a 5 –year Kernel filter to pronounce very high frequency variations.

Mean monthly homogenised temperature anomalies, homogenised precipitation, sunny hours and relative humidity were available from the nearby station of Davos for the years 1946-2000 AD. Mean monthly temperatures and precipitation dating back to 1800 AD were available from a meteorological station in Milan. Residuals of meteorological data, after filtering by a 5-year Kernel filter, were correlated with standardized isotopic variations to enhance the short term signal.

Results

The content of $\delta^{13}\text{C}$ in cellulose is influenced by the progressive decrease of atmospheric $\delta^{13}\text{C}$ due to the emission of CO_2 of plant fossil origin since the beginning of industrialisation. This long term effect has to be considered when investigating the relationship between meteorological data and tree ring $\delta^{13}\text{C}$. Ice core $\delta^{13}\text{C}$ values from Cape Grim were used for corrections of the tree ring isotopes (Francey, Allison et al. 1999) (Figure 1A, and 1B). In the text we refer from now to corrected values.

The records of $\delta^{13}\text{C}$ in the tree ring cellulose for the 1800-1850 AD interval (Figure 1A) show a strong decreasing trend in the first decade of the 19th century (1800-1808 AD) with values ranging from -21.84‰ to -23.39‰ . In contrast, from 1810 to 1850 AD, the isotopic ratios range only from -22.99‰ to -21.9‰ . The mean value for the whole 50 year period is -22.37‰ .

The whole record for the 1946-2000 AD period shows a decreasing trend, the mean of this 50 years interval being -21.90‰ . In the first 30 years of the 20th century the isotopic records range between -20.84‰ and -22.49‰ , but in the last 20 years of the century a minimum of -23.16‰ is reached.

Correlation coefficients between isotopic ratios and monthly values of temperature, precipitation, sunny hours and relative humidity were calculated. Table 1 shows the correlation to the summer season. Highest correlations were recorded for the combination of the months July and August for temperature; precipitation, sunny hours and relative humidity (see Figure 2A and 2B for temperature). Precipitation has a higher negative correlation when the whole growing season is considered (June, July and August).

Table 1: Correlation coefficients between corrected $\delta^{13}\text{C}$ and residuals of meteorological data for summer months (after standardization) for the two time periods analysed; (**= $p<0.01$; *= $p<0.05$).

	JJA	JJ	JA
1946-2000 AD, Davos			
PRECIPITATION TOTALS	-0.30*	-0.19	-0.21
TEMPERATURE ANOMALIES	0.27*	0.13	0.41**
SUNNY HOURS	0.38**	0.36**	0.46**
RELATIVE HUMIDITY	-0.34*	-0.40**	-0.37**
1800-1850 AD, Milan			
PRECIPITATION TOTALS	-0.16	-0.34*	-0.16
TEMPERATURE ANOMALIES	0.34*	0.29*	0.49**

Discussion and conclusions

Accurate calibration of isotopic signal with reliable meteorological data in different species and in the most diverse ecological settings are necessary. Currently only one study is available for the alpine regions (Treydte, Schleser et al. 2001).

The $\delta^{13}\text{C}$ late wood record in the two time windows shows a marked decrease, with a difference between the mean values of the two periods of 0.78‰. A longer continuous record would be necessary to assess the relevance of such a decreasing trend and to investigate its possible relations with the recorded global warming for the last century.

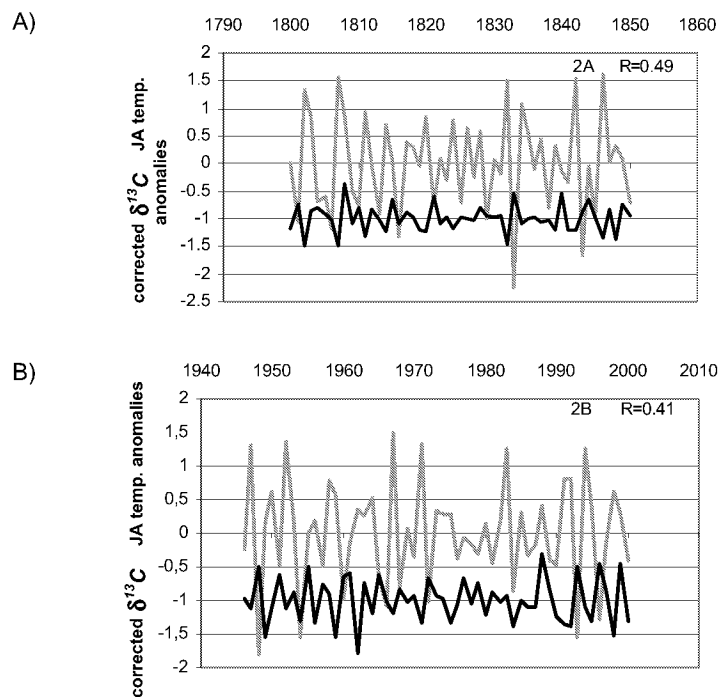


Figure 2: Variations of residuals of July-August temperature anomalies (grey) and $\delta^{13}\text{C}$ standardized values (black); (A: 1800-1850 AD; B: 1946-2000 AD).

Isotopic variations in late wood cellulose were calibrated with meteorological parameters. The number of sunny hours during the months of July and August showed to be the most relevant parameter to predict the variations in the cellulose isotopic record in the 20th century window ($r=0.46$). This parameter integrates tree growing conditions during the late growing season in which late wood is produced. For the 19th century window records of sunny hours were not available, but temperature seems to be even a stronger predictor ($R=0.49$). A stronger correlation with temperature for the years 1800-1850 AD suggests the climatic signal in the more recent isotopic records being dampened by the effect of the increase in atmospheric CO_2 concentration resulting from fossil fuel burning, deforestation and

expansion of agriculture. If this is the case, further corrections should be considered to take into account the plant responses to changed growing conditions (Treydte, Schleser et al. 2001, Treydte 2003).

Comparisons with other tree-ring parameters measured on the same samples should yield additional information to evaluate the potential of isotope variations for climate reconstruction.

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Isotope studies along a high-elevation transect on the Tibetan Plateau

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Introduction

Besides investigations on the variability of stable isotope ratios in ice-cores and sea-sediments, corresponding studies in tree rings have demonstrated a tremendous potential for high resolution paleoclimatic reconstructions on a millennial timescale (Anderson *et al.* 1998; 2002, Berninger *et al.* 2000, Saurer, M. & Siegenthaler, U. 1995, Schleser *et al.* 1999). During the last years, considerable progress has been made in the development of stable isotope techniques. Thus, measuring time for samples could drastically be reduced therewith enhancing the throughput of samples considerably (Treydte 2002).

Until today the number of tree-ring isotope studies for paleoclimatic investigations in the climatically sensitive region of the Tibetan Plateau is still scarce. This is very much in contrast to its key role for the regional circulation systems in Asia and Africa. By generating a distinctive low pressure system during the summer months due to the heating of the plateau, warm and moist air masses from the Indian and Pacific oceans are directed across the Indian subcontinent and southeast Asia. This causes heavy summer rainfall in the Himalayas and the mountain areas of western China, known as the Indian and the East Asian summer monsoons. When the Tibetan plateau cools in winter, a high pressure system is building up, resulting in the prevalence of cold and dry air masses (Webster *et al.* 1998). This pronounced cyclicity between summer and winter climate associated with the high altitude and the extreme high mountain topography leads to a distinct regional differentiation of climate and vegetation zones in the study area.

The aims of the study are:

- (i) to establish an annually resolved tree-ring based millennial dataset of stable carbon ($\delta^{13}\text{C}$) and oxygen isotopes ($\delta^{18}\text{O}$).
- (ii) to quantify the climatic significance of the datasets.
- (iii) to investigate additional wood parameters like ring width and maximum latewood density and to use the various proxy datasets for reconstructing the variability of the monsoon during the last millennium.
- (iv) To compare the annually resolved carbon isotope chronology from Qamdo to be established with an existing isotope chronology from the same site showing a pentad resolution (Zimmermann *et al.* 1997; Helle *et al.* 2002).

Material and Methods

Site description and study material

Within this project emphasis is based on high altitude forest sites situated along a gradient of decreasing influence of summer monsoon. Thus, a transect is considered, reaching from the humid eastern margins to the dry central part of the Tibetan Plateau (figure 1). We collected wood samples of juniper (*Juniperus tibetica*) from south-facing slopes and of spruce (*Picea balfouriana*) from north-facing slopes. The aim is to compare the effect of climatological forcing factors on various tree-ring parameters like ring width, maximum latewood density and stable isotope ratios.

The biological age trend of the ring width series was removed by dividing the original data with a fitted spline function that eliminated 50% of the variance at a length of 67% of each series using the program ARSTAN. The resulting standard juniper and spruce chronologies cover the past up to 1500 years and 400 years, respectively.

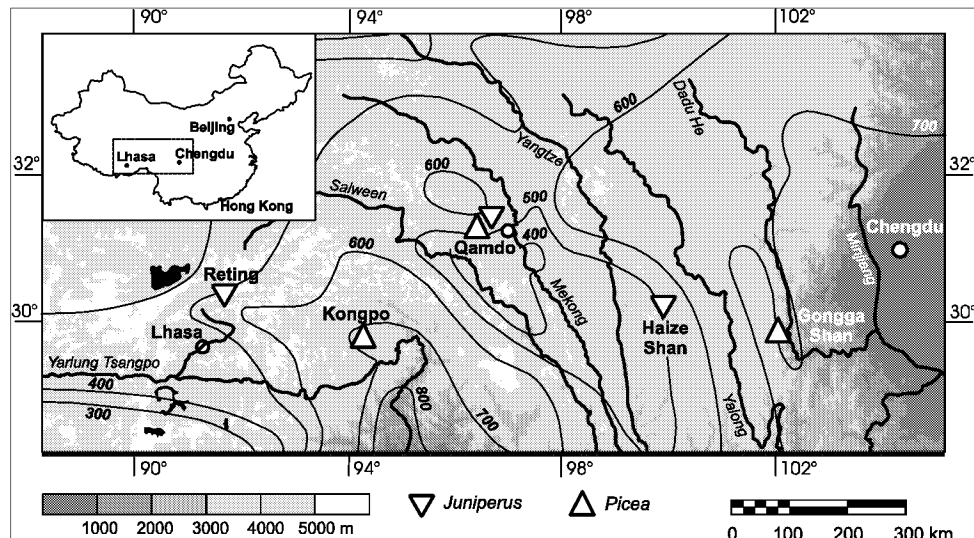


Figure 1: Overview of the investigation area and position of the sampling sites at the Tibetan Plateau. Isolines show mean annual precipitation in mm.

In table 1, several characteristics of the currently available ring width chronologies are summarized except for the site chronology 'Gongga Shan' which is still under investigation. Although exceptions occur, the signal-to-noise ratio (SNR; Wigley *et al.* 1984) and mean correlation between the trees ($\bar{r}$) generally increase in the direction from humid to dry sites, whereas first-order autocorrelation (AC1) shows a reverse trend.

Table 1: Characteristics of eastern Tibetan ARSTAN STD ring width chronologies. Relatively dry sites are marked in white columns, medium sites are highlighted in light grey, humid sites in dark grey.

Site	Reting	Qamdo	Haize Shan	Kongpo	Qamdo
Tree species	<i>Juniperus tibetica</i>	<i>Juniperus tibetica</i>	<i>Juniperus tibetica</i>	<i>Picea balfouriana</i>	<i>Picea balfouriana</i>
Site elevation	4300 m	4450 m	4400 m	ca. 4100 m	4500 m
Chronology	1082-1999	445-2003	1174-1993	1635-1998	1406-2003
Length (years)	918	1559	820	366	598
average tree age	475	597	558	281	278
max. tree age	917	1306	819	364	589
No. of trees	40	34	8	12	22
SNR	8.97	3.14	1.16	2.02	8.96
AC1	0.38	0.42	0.67	0.50	0.75
rbar	0.31	0.18	0.28	0.16	0.36

In a first phase, 4 cores and 6 tree disks from a Juniper stand (*Juniperus tibetica*) were analyzed. The samples were collected at a south-facing slope near the upper timberline (~ 4500m a.s.l.) in the south-eastern part of Tibet close to the city of Qamdo (compare fig. 1). Each tree sample was crossdated against an existing ring width chronology (Bräuning 2002) using the TSAP™ program. In order to develop a millennial scaled carbon isotope record from the Qamdo site, tree disks and core samples from living and dead trees were combined. After exact dating, the individual tree-rings were cut using a razorblade. Wood samples of corresponding age were then pooled to minimize the possible influence of outliers caused by potential ecological differences between the individual trees (Borella and Leuenberger 1998).

Cellulose extraction and mass spectrometry

Since wood material consists of different chemical components with rather different isotope signatures ($\delta^{13}\text{C}$), it is necessary to concentrate on one single chemical compound. It is usual practice to extract cellulose for carbon isotope analysis because it is easiest to obtain. To extract cellulose the separated samples were treated in small glass vials at 60°C using a water bath. The corresponding technique is described by Kürschner and Popik (1962). In a first step, lignin, resins and other components were removed with NaOH (treatment for about 4 hours). Then, hemicelluloses were extracted for 36 hours with slightly acidified NaClO₂. Between these two steps, the wood samples were washed several times with deionized water. After the cellulose extraction the samples were dried at 60°C for about 48h until they reached weight constancy. Subsequently, the pooled specimens were milled using a cryogenic mill to attain homogeneity between the constituents of the different trees. These annual cellulose samples were weighted to achieve aliquots of 200µg/sample and then packed into tin capsules for carbon isotope analysis. Samples were then combusted to CO₂ using an on-line method with an elemental analyzer (Carlo Erba) interfaced to a mass spectrometer (Micromass Optima) where the analyzed $\delta^{13}\text{C}$ values are automatically scaled against the Vienna standard of PDB (V_{PDB}).

Results

As a first result, an annually resolved 500-year $\delta^{13}\text{C}$ -isotope record from *Juniperus tibetica* trees originating from Qamdo was established. As Fig. 2 shows, clearly recognizable shifts in the values of $\delta^{13}\text{C}$ occurred during this period. Although statistical analyses have still to be carried out, several outstanding features like the double peak between 1550 and 1630 are obvious. Former analyses have shown a statistically significant response of ring width of juniper at the Qamdo site to winter temperature and summer rainfall (Bräuning 2002), whereas interannual $\delta^{13}\text{C}$ variations are positively correlated with summer temperature (Helle *et al.* 2002). To eliminate the anthropogenic "fossil fuel burning effect" of an increasing atmospheric CO_2 trend combined with a depletion of its ^{13}C fraction (Fig.2), a correction of the measured $\delta^{13}\text{C}$ values since 1850 had to be performed (Feng and Epstein 1995). We used two different CO_2 correction models (Fig. 2). The $\text{CO}_{2\text{ATM}}$ model corrects the measured $\delta^{13}\text{C}$ raw data by adding a variable factor derived from atmospheric $^{13}\text{CO}_2$ datasets of meteorological stations and ice cores. In addition, the model by Feng and Epstein ($\text{CO}_{2\text{FENG}}$) also allows for plantphysiological corrections of the carbon isotope signature which experiences a shift to more depleted values due to the atmospheric CO_2 increase. Fig.2 shows the generally observed declining trend in the curve of $\delta^{13}\text{C}_{\text{raw data}}$ which still remains for the $\delta^{13}\text{C}_{\text{ATM}}$ curve. A slightly increasing trend is seen for the $\delta^{13}\text{C}_{\text{FENG}}$ record. Which correction model finally will be applied is uncertain which makes the interpretation of the last part of the record difficult.

Due to the high tree ages of the juniper trees (Table 1), the final isotope series from Qamdo will reach back to 445 AD and thus will cover climatically important periods like the so-called "Little Ice Age" and the "Medieval Warm Period". The latter can be regarded as climatically equivalent to the temperature conditions that are predicted by global circulation model results for the near future (Ni 2000; Uchijima & Ohta 1996).

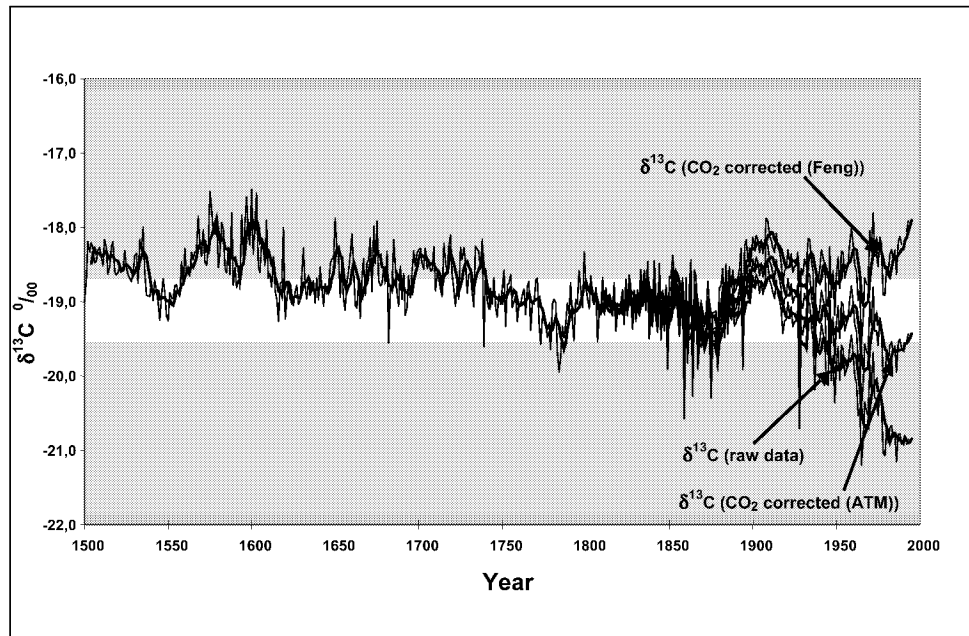


Figure 2: Yearly resolved ^{13}C -isotope record (against V_{PDB} standard) deduced from juniper trees originating from Qamdo, Tibet. The record is based on 5 pooled trees, each of them covering the whole study period. For further explanations of the shown CO_2 trends after 1850, see text.

Wood parameters, like maximum latewood density (MLD) and variations of $\delta^{18}\text{O}$ shall be analysed in the near future for all sites and compared to regional meteorological datasets. By using this multiproxy approach for ecologically contrasting tree species along a broad scale precipitation gradient we expect to gain new insights into the temporal and spatial patterns of climate variability in the marginal areas of the monsoon realm on the Tibetan Plateau.

Acknowledgements

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Stable isotope ratios in tree rings of living *Scots pine* near Reichwalde opencast mine in Lusatia (East Germany)

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Introduction

In front of the opencast mine of Reichwalde (Lusatia, East Germany) a late glacial pine (*Pinus sylvestris* L.) forest has been excavated. The fossil wood samples were analyzed dendrochronologically at the University Hohenheim and a floating tree-ring chronology match in the time of Allerød (more than 13'000 years BP) was produced. A collection of well preserved trees were chosen to build the isotope chronology ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$) covering c. 850 year of Allerød. This investigation offers a unique chance to reconstruct this key climate period with annual time resolution. For the reconstruction and interpretation of the proxy data comparable recent studies are needed. Usually, the functional correlation between stable isotope ratio and climate data has to be determined. With a transfer function it is possible to deduce to the climate condition in the past. Thereby the site dependence of the transfer function is often neglected. For this reason we chose for our recent investigation a location where over a short distance the site conditions varied from moist and swampy to dry and sandy. Thus, it should be possible to study the dependence of isotope data on ecological variations, behind the correlation to climate.

Material and Methods

Sampling Site

For our investigations we chose an area in the surroundings of the open cast mine Reichwalde which is situated in the Federal Forest of Daubitz (51°25' N und 14°50' E, ca. 25km north of Görlitz) near the village Rietschen. In this area inner dunes are found which emerged on the end of the last ice age and consist of poor sand. Dry sites are on the top of the dunes. Between the dunes small moors are located, with moist sites next to them. In the forest of Daubitz we took cores of pine trees from two transects ranging from the moor to the top of the dune. Those transects were divided into three sites (Figure 1).

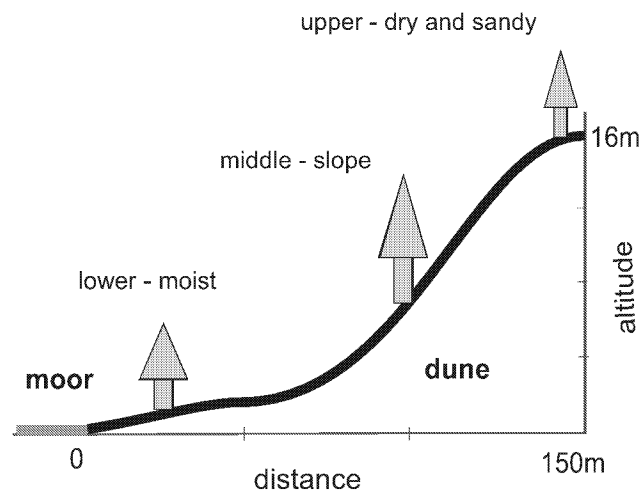


Figure 1: Schematic diagram of the topology of the sampling site in the forest of Daubitz.

Unfortunately, the intensity of human impact was strong. Therefore, we selected a second sampling site near Jena (Thuringia) for comparison. This sampling site is situated in the upper part of a south exposed limestone slope. The ecological conditions are dry and the vegetation on the slope is xerotherme phytocenosis.

On each site of both transect, 15 to 20 dominant pines were sampled by taking two cores per tree. Dendrochronological measurement (ring width) and data processing was carried out at the University of Hohenheim. After cross dating and measuring the ring width, we chose two pine trees from the upper and the middle site and one tree from the lower site for the isotope analysis. At the location near Jena we sampled cores from 45 pines and two pines were chosen for isotope measurement.

Stable isotope analysis

The annual isotope investigations on increment cores of the living trees were carried out on the cellulose of the wood. Each individual tree ring from increment cores was cut under a microscope with a scalpel. The cellulose was extracted using the methods described by Gray & Song (1984). The stable isotope analyses of fossil and living pine samples were carried out on the cellulose ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$). To measure $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values, the samples were pyrolysed to CO and both isotopes measured simultaneously (Knoeller et al., in press) online using the XLplus mass spectrometer (Finnigan MAT).

Results

Figure 2 shows the average isotope ratio curve of two pines from the upper dry site. One pine is 160 years old and the other 110 years. The older tree has very small rings between 1905 and 1940 and so we chose 5 year blocks for this period. We estimated the lower frequency variations using a 9-year running mean.

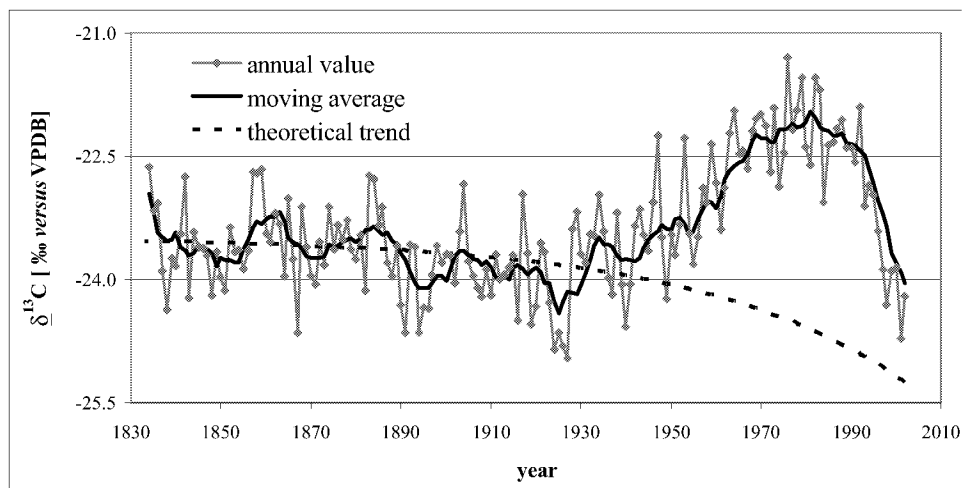


Figure 2: Mean $\delta^{13}\text{C}$ value of tree-ring cellulose and 9-years moving average for two living pines of the upper site. Anthropogenic caused decline in $\delta^{13}\text{C}$ of CO_2 in the atmosphere is shown as “theoretical trend”.

The long term trend due to the shift in the atmospheric isotope ratio is visible in the measured data until 1950. After 1950 the $\delta^{13}\text{C}$ value are heavier opposite to common findings (Francey *et al.* 1999, Treydte *et al.* 2001) and do not decrease before 1990. Thus we classified three periods: not influenced until 1950, then strongly influenced until 1990 (in this time GDR existed) and after 1990 – the time of regeneration. Notable is the fast decrease of $\delta^{13}\text{C}$ value and convergence to the theoretical trend after 1990. We also could observe the period of regeneration on the middle site. Now we are confronted with the question if this effect is only local or common in East Germany.

To answer this question we made a comparison with the results from the site near by Jena. The $\delta^{13}\text{C}$ value of pine also shows the period of regeneration, which, however, does not occur so fast. We interpret this result as a consequence of the burning of lignite for energy production in the former GDR and subsequent air pollution. In Lusatia some coal fired large-scale power plants were in operation that were not equipped with filter technology. Therefore, the shift of carbon isotope ratio ($\delta^{13}\text{C}_{\text{Cellulose}}$) to heavier values was probably caused by air pollution (SO_2 , dust etc.) and its influence on photosynthesis. Other publications (Saurer *et*

al. 2004, Hemmann 1993) also describe an increase of $\delta^{13}\text{C}$ values through influence of reactive air compounds.

One aim of our investigations was to describe the dependence of the isotope ratio on different site conditions. In comparison with the middle and the lower sites, the carbon isotope ratio of the upper (dry) site usually was approx. 1.4‰ heavier. The $\delta^{13}\text{C}$ values of the lower site compared to the middle site were heavier (mean 0.7‰) in the period 1940 to 1960 and lighter in the period 1980 to 2000 (mean -0.4‰).

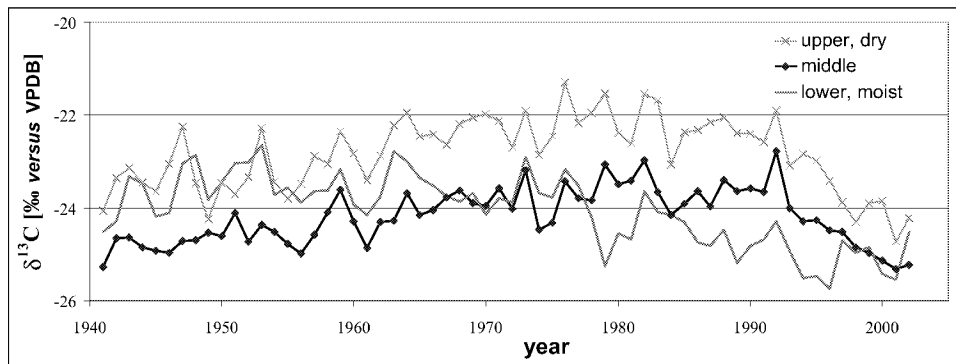


Figure 3: Mean $\delta^{13}\text{C}$ -value of tree-ring cellulose for living pine in upper, middle and moist habitat near the village Rietschen. Change in the characteristic between middle and lower site.

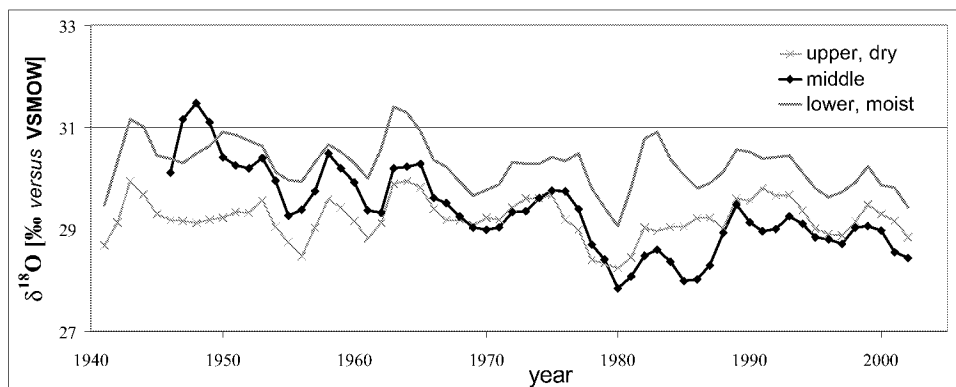


Figure 4: Mean $\delta^{18}\text{O}$ value of tree-ring cellulose for living pine in upper, middle and moist habitat near the village Rietschen. The values of the middle site decrease.

The oxygen isotope ratio values of the moist site were in average 1.1‰ heavier than the dry site (Figure 4). The middle site did not have a relation to the other sites. The $\delta^{18}\text{O}$ values decrease from a level which is equivalent to the moist site to values comparable to dry site. We interpreted this effect with a change in water availability for the investigated pines. As a

consequence of open cast mine activity the groundwater level decreased (information by Vattenfall AG). In our opinion, the shift of $\delta^{18}\text{O}$ values is caused by change in the source of water for the pines. So trees on the middle site lost the contact to the groundwater and were beginning to depend on precipitation. This result also explains the change in the relation of $\delta^{13}\text{C}$ values between the lower and the middle site.

Conclusion

The theoretical long term trend of $\delta^{13}\text{C}$ values in tree rings caused by changing composition of atmospheric CO_2 could be disabled through air pollution. We observed that the carbon isotope ratio shifts to heavier values compared to the theoretical trend. Additionally, a change in the long term trend can be affected by a change in the water availability. For the climate reconstruction of the late glacial chronology we need comparative studies on different recent locations. Maybe then it will be possible to find a better transfer function between instrumental climatic data and the isotope ratio.

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SECTION 5

METHODS

Quantification of sulphur in *Picea abies* by LA-ICPMS

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Introduction

Sulphur profiles in Swiss peat bogs have been studied in our working group before. While the profile of a Duedingen peat bog core (580 m a.s.l., Swiss Plateau) correlates with the sulphur dioxide emission profile of the 20th century in Switzerland (Jeker 2001), the profile of an alpine peat bog in Mauntschas near St. Moritz (1900 m a.s.l., Engadin) shows a different behaviour (Schreier et al. 2002). These results are to be compared and consolidated with data provided by measurement of trees growing nearby. *Picea abies* (L.) Karst. is widely spread and represents 48% of all forest trees in Switzerland. Therefore, it was chosen as the tree type representative for all of the regions and altitudes mentioned. Six trees were chosen in both regions, and additional six specimens in the forest of Frieswil (740 m a.s.l., Swiss Plateau) for comparison with the anthropogenic Duedingen site, which is situated next to a highway.

In 1987, 88% (150'000 kt) of the total emissions of sulphur dioxide were anthropogenic (Parlar & Angerhöfer 1995). In Switzerland, these emissions have decreased since, due to several measures such as the replacement of coal by oil and the desulphurisation of mineral oil. But in other countries such as China, SO₂ emissions are still increasing, which has also been seen in trees near the heavily polluted city of Chengdu (Gaoming 1996). Due to the extent of these emissions, sulphur dioxide became an additional source of S for plants.

Sulphur metabolism in trees is complex and not completely deciphered. Sulphur is one of the six macronutrients for plants, although it is only 3% to 5% as abundant as nitrogen (Leustek & Saito 1999). It is found in the two amino acids cysteine and methionine, and in a variety of metabolites like the tripeptide glutathione, which plays an important role as an anti-oxidiser. Plants cover their demand for sulphur by reduction of inorganic sulphate. Recent studies showed that sulphur metabolism is linked to carbon and nitrogen metabolism (Kopriva & Rennenberg 2004).

Sulphur dioxide enters the needles via stomata without regulatory control. It is rapidly fixed into cysteine by the cysteine biosynthetic pathway (Noji et.al. 2000). This is an important step in the detoxification of the sulphite ion, leading to an increase of sulphate and glutathione contents. In wood, the uptake of gaseous sulphur compounds is reflected by higher sulphate content in case of sulphur dioxide, or by a larger amount of organic sulphur compounds in presence of hydrogen sulphide (Rennenberg 2004), and reduces the uptake via roots substantially but not completely (Giesemann et.al. 2000).

Some physiological aspects of sulphur in wood are not fully understood yet. Examples are the diminution of total sulphur content in compression wood compared to normal wood, as well as the huge increase observed in case of fungal attack in the heartwood of old trees. These results were already obtained at our laboratory by analysis of drill core pieces from Frieswil (Barrelet et.al. 2003).

Aim of the present study is the assessment of the spatial distribution of sulphur in tree rings and the investigation of the suitability of this archive for non-metals. It should be tested if LASER ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) is an adequate technique for quantification of sulphur in *Picea abies* (Norway spruce) drill cores. The main advantages of LA-ICP-MS are its high spatial resolution and high sensitivity and the minimized risk of chemical contamination and sulphur losses due to sample digestion.

As a quasi non destructive method, LA-ICP-MS is mainly used in research applications on solids such as archaeological, metal and glass samples, or other solids (Devos et.al. 2000, Senn-Bischofberger 2004). The hyphenated technique was also applied to plant materials such as bark (Liebergeld et.al. 1996), wood (Prohaska et.al. 1998) or leaves (Hoffmann et.al. 2000), e.g. to investigate the variation of metals in tree rings. However, little is known about its application in dendroecology for quantifying non metals. The present work presents development and optimisation of LA-ICP-MS for sulphur analysis in wood, as well as first results.

Experimental

Sampling

At three sampling sites in Switzerland Frieswil, Duedingen and St. Moritz, six trees were sampled using a 5 mm increment borer (Suunto). The sampling procedure was optimised with special regards to minimised contamination. The use of gloves was necessary and furthermore, the cleaning and lubricating oil used for the preservation of the borer had to be free of sulphur. Previously, sulphur contents in different lubricants were determined using ICP-OES. PhEur grade paraffin (Hänseler) was chosen because of lowest contamination risk.

Determination of tree characteristics

Trees of different sizes were selected in order to assess ageing effects. Four drill cores per tree were taken at breast height in each direction. Additionally, two drill cores were taken 5 cm under the southern and western drill holes. Since in *Picea abies* there is no difference in colour between sapwood and heartwood (mature wood), the extent of the humid sapwood had to be measured immediately after sampling. The samples were pressed into weighted and previously cleaned plastic rails and dried in an oven at 40°C until weight constancy was reached. Water content of the drill cores was finally determined by difference weighing. The density and tree ring width of the two supplementary, parallel drill cores was measured at WSL by radiodensitometry on a DENDRO-2003 Densitometer (Walesch Electronic GmbH).

Instrumentation

An EMPA modified Nd:YAG LASER Perkin Elmer/Sciex sampler 320 (Wanner et.al. 1999, Bleiner et.al. 2003) was coupled to an ELEMENT 2 high resolution magnetic sector field ICP-MS (ThermoFinnigan). The LASER was operated at a wavelength of 266 nm in Q-switch mode using a Q-switch delay of 300 ns. The formed craters show diameters of about 100 μm . The ablated particles were transported by 5.0 grade helium at an average flow of 1.5 l/min. An additional argon gas flow was added after sampling cell to keep the plasma stable. The ICP was operated under hot plasma conditions using RF power 1250 W, 1.3 l/min Ar sample gas, 15 l/min cool gas and 0.8 l/min auxiliary gas.

Sample preparation for LA-ICP-MS

For LA-ICP-MS, drill core pieces of 3 cm length were cut using a scalpel and inserted into plastic rail pieces of corresponding size. After counting of the tree rings, a mark was applied onto the rail every 5 year rings. Two samples in rails were placed onto a small aluminium holder in a cavity of the sampling cell designed by the EMPA.

Standardisation for LA-ICP-MS

A precondition for quantification using LA-ICP-MS is the availability of suitable solid standards such as commercial reference materials. For sulphur in wood however, no appropriate calibration standards procurable. Self-made doped cellulose powders had been used by other authors (Hoffmann et.al. 1996). Also in this study standards had been produced in the laboratory. Two different base materials were tested:

- cellulose powder (20 microns, Aldrich) with 5 % activated charcoal (p.A., Merck),
- homogenised wood powder characterised at EMPA.

Both standards were prepared as follows: 2 g portions of powder were put into six Teflon vials and doped with 0, 40, 200, 500, 1000 and 2000 μl of a solution containing 200 $\mu\text{g/ml}$ sulphur (1:5 dilution of S ICP standard solution, 1000 $\mu\text{g/ml}$ S in water, Alfa Aesar). 650 μl of a 100 ppm Scandium solution (1:5 dilution of Sc ICP standard solution, 1000 $\mu\text{g/ml}$ Sc in 5 % HNO_3 , Alfa Aesar) was added as an internal standard. Six millilitres of ultrapure water were then poured into the vials while mixing thoroughly with a plastic stick until a homogeneous paste was obtained. The paste was dried in an oven at 80°C until weight constancy. Subsequent to the drying, the content of the vials was crushed in an agate mortar. The homogeneity of the obtained powder and the appropriateness for calibration was verified by analysis of two aliquots with ICP-OES. Afterwards, 300 mg of powder were transformed into pellets.

Results and Discussion

For each sampled tree, sapwood width, circumference and wood water content were determined. Knowledge of the sapwood extent is important due to the physiological processes of heartwood formation. Some authors describe soluble mineral compounds

containing P, K and S which migrate to the sapwood through the rays (Bamber 1976, Ziegler 1968). While sapwood contains living parenchyma cells, heartwood is inactive and has no water-conducting functions anymore.

Furthermore, density and cambial age of two drill cores per tree were measured by radiodensitometry. The averages of six trees at each site are presented in the table below, as well as the individual characteristics of the drill cores D1W and D5W, which were investigated by LA-ICP-MS so far. Further studies will be presented soon.

Table 1: Characteristics of the sampled trees.

	Measured circumference [cm]	Determined cambial age [y]	Measured sapwood width [cm]	Sapwood zone [y]	Determined wood water content [%]
Duedingen 580 m a.s.l.	167.5 +/- 26.3	95.7 +/- 3.4	5.9 +/-1.3	31 +/- 8	46 +/- 7
D1W	128	101	4.3	43	39.8
D5W	165	99	7.5	34	44.5
Frieswil 740 m a.s.l.	208.2 +/- 39.4	141.8 +/- 6	5.2 +/-1.4	29 +/- 4	41.1 +/- 8
St. Moritz 1900 m a.s.l.	150.2 +/- 21.9	155.2 +/- 19.5	5.4 +/-1.4	62 +/- 16	60.5 +/- 8.3

After instrument optimisation and mass calibration using multi-element solutions, the LASER had been coupled to the ICP-MS using a self-designed adapter. The LASER parameters such as aperture, pulse energy and repetition rate were optimised and resulted in the final settings of 30 mJ for pulse output energy and 10 Hz for pulse repetition rate.

Before the development of the method for transient signal acquisition, the sulphur signals were optimised to maximum intensities on all three stable sulphur isotopes ^{32}S (95.02% relative abundance), ^{33}S (0.75%) and ^{34}S (4.21%). The transport gas flow rate through the cell had major influence and was finally set to 1.5 l/min. Validation was performed using wood and cellulose standards as well as selected samples.

A major problem was the high sulphur background level, which is of important concern considering the low concentration in wood. Consequent elimination of plasticine as fixation material for samples and sample holder finally led to lower background. Additionally, the use of 5.0 instead of 4.6 quality helium as transport gas lowered the background as well. Another positive effect resulted from careful cleaning of the sample cell before each sample change. After careful method development and validation first measurements were performed on two drill cores from Duedingen, labelled D1W and D5W. These drill cores originate from two forest trees of different age, both located in a distance of 500 and 450 m to the highway A12, respectively. The peat bog is situated about 1 km away. Tree D1 has a cambial age of 101 years, while tree D5 has an age of 96 years. Details can be found in table 1. Both drill cores were sampled from western direction.

Test spots every 5 years as well as in the cambial zone and bark were selected in this preliminary study. All data were normalised using ^{13}C as internal standard. Figure 1 presents the obtained profiles for ^{32}S for the drill cores DW1 and DW5. The data present averages of multiple determinations.

From 1915 to 1970, the sulphur profile of D1W varies slightly between 0.1 and 0.2, while the profile of D5W ranges on a marginal higher level between 0.15 and 0.25. From 1970 on a significant sulphur increase was observed in both trees, with maxima in the particular tree rings corresponding to 1985. A similar peak was also found for the neighbouring Duedingen peat bog which reaches back to the year 1920 (Jeker 2001). The peak corresponds also to the SO_2 emissions in Switzerland acquired by the Swiss Agency for the Environment, Forests and Landscape. The main sulphur source in the rural Duedingen area is likely to be mainly traffic (diesel fuel and tyre abrasion). This hypothesis is supported by the fact that the A12 highway in this area has been inaugurated in parts between 1971 and 1973. Even if the mobility of sulphur in wood cannot be neglected (Bamber 1976, Ziegler 1968), the anthropogenic origin of the peak described above is very likely. After the maximum, a significant signal decrease was observed, presumably due to the sulphur reduction in fuel.

The rise of the concentrations after 1995 is likely to be of physiological origin, since the decay of xylem cells, which begins shortly after the cambium, is accompanied by the decay of proteins. This leads to the presence of a ring-like zone with higher amino acid concentration in the tree (Sandermann et.al. 1967). Furthermore, there is a bidirectional exchange between phloem and xylem during long-distance transport along the stem, which has been described for sulphate, glutathione and cysteine (Gessler et.al. 2003). Thus, the observation that sulphur content is rising again in the years preceding the cambium is not surprising.

Due to the excellent spatial resolution of LA-ICP-MS, the cambial zone could be sampled separately, revealing higher sulphur content compared to xylem. This is consistent to protein contents of the cambium reported elsewhere, which range between 0.42 - 0.56 %, and fall shortly afterwards to 0.2 – 0.3 % (Schmid-Vogt et.al. 1977). From a previous study using microwave digestions of 5-year drill core segments determined by ICP-OES, the sulphur concentrations of Norway spruces from Frieswil are known to range between 20 and 80 mg/kg (Barrelet et.al. 2003). Bark showed higher concentrations of about 200 mg/kg sulphur. LA-ICP-MS results gave higher sulphur concentrations in bark, too. A similar pattern was found for total sulphur in the presented D1W and D5W investigations.

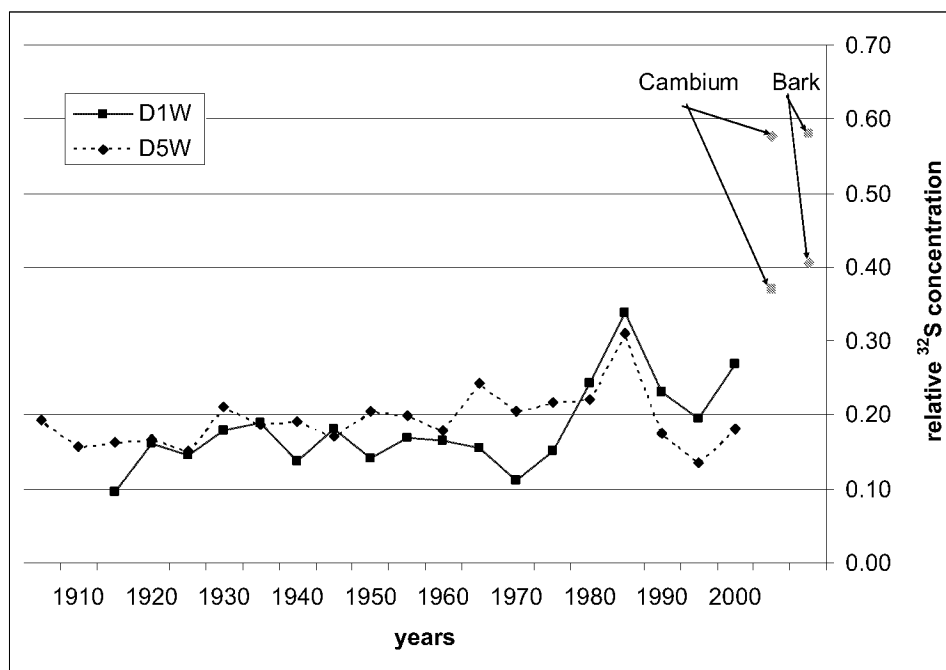


Figure 1: Relative total sulphur concentrations in the drill cores D1W and D5W

Outlook

Further steps are the optimization of an appropriate calibration strategy to get a reliable quantification. Since ICP-MS enables to perform simultaneous multi-element determination, it is planned to investigate additional information about metal distribution in spruce wood. A closer look at selected metal concentrations such as Al, K, Ca, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Cd, Ba and Pb might give further information about possible correlations of sulphur with these metals. Metal doped cellulose or wood pellets will be used for calibration.

A reliable validation of the LA-ICP-MS multi element method is planned by comparison to an independent digestion based procedure, where digested 5-years drill core segments will be quantified by inductively coupled plasma optical emission spectrometry (ICP-OES) as well as ICP-MS.

Conclusion

The two investigated trees gave similar sulphur profiles, which show several analogies with the profile found in the Duedingen peat bog. This leads to the assumption that *Picea abies* is an appropriate environmental archive for sulphur.

The excellent spatial resolution of LA-ICP-MS allows the determination of sulphur in each tree ring, whereas digestion-based procedures usually require 5 to 10 year segments for adequate determination. For this reason, only LA-ICP-MS enables to distinguish the cambial

zone from bark. Even discrete analysis of earlywood and latewood would be possible by high spatial resolution of LASER Ablation with maximum spot sizes of about 100 µm. Therefore LA-ICP-MS is a suitable technique to determine sulphur in tree rings. The trees from St. Moritz and Frieswil will be investigated next.

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Dendroindication of synchronous trends in productivity (middle-taiga of Arkhangelsk region, Russia)

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Introduction

Interaction of landscape components, i.e. relief and rock, local climate, water, soils and vegetation, determines the structure and dynamics of the landscapes.

Principles of structure creation are best understood through the study of their functioning, i.e. the process of component interaction. The structure can be looked at in terms of different hierarchical levels.

Evolution and external factors of landscape dynamics are equally important aspects understood through the study of landscape functioning.

Spatial-temporal synchronous processes in landscapes is one of the central issues in the modern studies of landscape functioning. One approach to understanding the processes is searching for natural registering means that reflect both variability of external and internal landscape conditions and spatial distribution of landscape functioning processes. Tree-rings found in abundance in most boreal zone landscapes are a good example of such means.

Therefore, we suggest the dendrochronological method, which allows describing biological productivity, the key indicator of variability. This method can be used as the main tool in studying the in-centennial rhythms of functioning of local-scale landscapes.

We rely on theory and methods of both landscape studies and dendrochronology. Accordingly, we apply both geographical and dendrochronological scientific principles. Hence, we suggest the name "Landscape dendrochronology" to define this new area in physical geography (Beliakov, 2003).

Materials and Methods

The materials were collected along the line of local landscape transect located in the middle-taiga subzone in the South of the Arkhangelsk region, Russia. The study region is characterized by temperate climate (no growth-limiting factor), young (under 100 years old) forests, and sizeable anthropogenic influence (timber industry). The sampling process was standard as described in the literature (Josza, 1988). It included getting cores by increment borer and stem disks by chain saw.

Nearly 300 increment cores and stem disks of *Pinus sylvestris* L., *Picea abies* L. (Karst) and *Picea obovata* Ledeb. were collected along the line of an 8125 m transect. The transect passes through a diverse range of sites: different types of forest, oligotrophic and mesotrophic bogs, valleys of small rivers and creeks. The transect is representative of the spatial structure of the region.

The measurements followed the standard procedure: cores and stem disks were scanned and the tree-rings were digitized by an image editor; the ring-widths were calculated semi-automatically. All the samples collected from one site were crossdated and verified to exclude the false rings and find the missing rings. The data that could not be crossdated were excluded from further computation of site chronologies. The age-related trends in each series were minimized by applying two statistical methods: cubic spline (length of wave - 32 years) with further site chronology computation by a biweight robust mean estimation using ARSTAN program developed by Cook (Cook, 1985), and five-year moving averages smoothing with chronology computation using arithmetic mean value function.

The correlations and similarities (Gleichläufigkeit) (Eckstein, Bauch, 1969) between tree-ring chronologies of each site were then calculated. The same coefficients were also calculated separately for series covering periods 1960-1970, 1970-1980, 1980-1990, 1990-2000 to evaluate short trends in productivity.

Results

Analysis of correlation between tree-ring chronologies of landscapes showed their synchronous reaction to external factors.

The five-year moving averages smoothing method resulted in average correlation coefficient of 0.83 for chronology series. The 0.97 maximum correlation coefficient was observed for two chronologies of neighboring forest landscapes on the local watershed. Two border zones of bogs (local ecotones) also react quite synchronously, but correlation between them and other landscapes varies between 0.3 and 0.8.

High correlations were also observed in series processed with the ARSTAN program.

Similarity (Gleichläufigkeit) varies greatly. At different time periods the trees demonstrated great variability in productivity synchrony, although they were clustered relatively close to one another. The most synchronous were the sites on level drained watersheds with zonal vegetation and soils. Since 1970s the productivity in different sites has been getting more and more asynchronous. Least synchrony was observed in droughty and warm 1990s. Nevertheless, in 1980s and 1990s the increments at a wide oligotrophic bog and a wooded hollow were quite synchronous. Thus, we considered them functionally related.

The process of functioning (productivity) studied by applying the dendrochronological method allowed us to identify different geographical systems. For instance, the 1970s synchronous increments in landscapes of the valley of the main river of the region, Zayachya and its local inflows clearly showed the domination of basin-type landscape organization. In 1990s wide oligotrophic bogs and their border zones (local ecotones) and even a few landscapes located close to them were quite synchronous in productivity showing the nuclear type (Reteyum, 1988) of landscape organization (i.e. the central part of the bog being the nucleus). The influence of the nucleus on the border systems was found to be loosening as the distance increases, providing a great example of the famous "decrement law".

At other time periods these types of landscape organization at the same sites were significantly less clearly pronounced. Application of the dendrochronological method allowed

us to find out the periods of stronger spatial relationships. Visibility of the specific types of landscape organizations was found to depend on changes in global and local climate.

Traditionally, the Russian school would expect the actual landscape borders to match geomorphological borders derived based on landforms and their genesis. Our study showed that the borders of geographical systems defined by productivity do not consistently demonstrate such match. Therefore we added new evidence supporting the argument of continuity of landscapes.

Conclusions

Global climatic factors affecting all landscapes of the transect at same times are the basics of spatial-temporal synchrony. Each in-centennial rhythm of increments (productivity) is characterized by its own level of synchrony. In young forest communities, the discovered asynchrony is a product of community-specific trends. It was also caused by anthropogenic factors and the overall absence of common limiting factor. We identified three mechanisms forming landscape structure organization: "geostationary" (related to stable site-specific geomorphologic base), "biocircular" (continuous rhythmic activity of vegetation ignoring genesis-based borders), and "geocircular" (matter and energy transfer, e.g. processes in basin-type and nuclear-type geographical systems), that place our findings conceptually close to those outlined by Solntsev (1981, 2001) in his "geostructure" theory.

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The effect of power transformation on RCS – evidence from three millennial-length alpine chronologies

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Introduction

Tree-ring standardization in dendrochronology since its introduction by Douglass (1928), is often discussed and debated, especially when extracting different wavelengths from the resulting chronologies (e.g., Briffa et al. 1992, 2001; Cook et al. 1995; Esper et al. 2004; Fritts 1976). Individual series standardization techniques are commonly used to eliminate decreasing values with increasing tree age, the so-called age-trend (Fritts 1976). However, the traditional, individual series detrending precludes the reconstruction of variations longer than the samples individual segment length (Cook et al. 1995). Recently, effort has been made to reconstruct low frequency variations from long tree-ring chronologies, using age-related composite standardization techniques (e.g., Briffa et al. 1992, 2001; Cook et al. 2004; Esper et al. 2002). When tree-ring chronologies act as a proxy for climatic and/or environmental reconstruction, proper detrending is critical and the method should preserve high to low frequency variations.

For detrending, the Regional Curve Standardization (RCS, Becker et al. 1995; Briffa et al. 1992, 1996; Esper et al. 2003; Mitchell 1967) method is applied. This method can avoid the “segment length curse” (Cook et al. 1995) and allows the preservation of variations longer than the segment length of individual series. The three independently developed datasets discussed herein, possess reasonable sample size and sample distribution characteristics for age-related composite standardization techniques to be justifiably applied. Two different manners of calculating tree-ring indices within RCS are used.

In this manuscript, the tree-ring data and the detrending methods applied are first introduced. Second, differences and similarities of the Regional Curves (RC) are described. And third, the effect of calculating ratios or residuals plus variance stabilization on the growth levels, trends and variance of the resulting RCS chronologies is discussed.

Data and methods

Three independent ring width datasets from the Alps are compiled (Tab. 1). Data include 229 spruce (*Picea abies* K.) and 1110 larch (*Larix deciduas* Mill.) samples from Switzerland, and 418 stone pine (*Pinus cembra* L.) samples from Austria (Büntgen et al. 2004a, 2005; Nicolussi and Schießling 2002), covering the western-central Alpine arc from 46°28'–47°00'N and 7°49'–11°30'E.

Table 1: Chronology characteristics.

	Species	Series #	Period AD	Chronology AD	MSL	AGR	Location	Source
spruce	PCAB	229	1108-2003	1163-2002	145	1.13	Valais/Engadin	Schmidhalter/ Neuwirth/Seifert
pine	PICE	418	645-1997	786-1997	198	0.99	Western Austria	Nicolussi
larch	LADE	1110	505-2003	738-2003	165	1.00	Valais/Engadin	Büntgen/ Schmidhalter/Seifert
total		1757	505-2003	738-2003	170	1.01	Central Alps	

Chronologies truncated at $n < 5$ series. MSL = mean segment length (years). AGR = average growth rate (mm).

Samples include wood from living trees, historical buildings (Büntgen et al. 2004b) and dry-dead and subfossil logs (Nicolussi and Patzelt 2000), all from elevations $>1,500$ m a.s.l. The composite records show a reasonable replication and fairly even distribution of samples during the past millennium (Fig. 1). Individual segment lengths range from 23-775 years, with a mean of 170 rings.

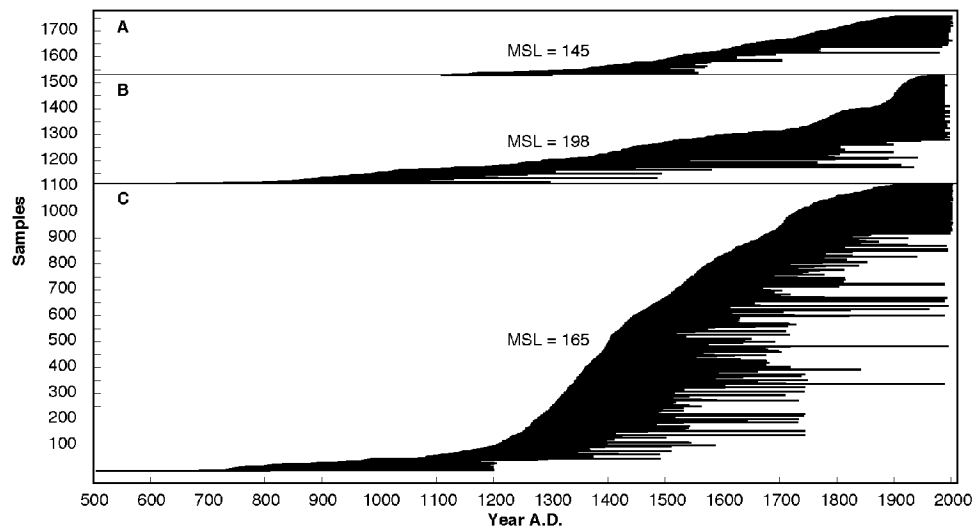


Figure 1: Sample replication and distribution of the three Alpine A spruce, B pine and C larch datasets used. The mean segment length (MSL, average number of rings per core or disc) is indicated.

Prior to detrending, all measurements were checked for missing rings and dating errors on a site-by-site basis using the program COFECHA (Holmes 1983). For RCS detrending, the program ARSTAN (Cook 1985) was used. RCS begins by aligning all individual tree-ring series by their innermost ring. In so doing, all series are set to the biological (cambial) age of one. Note that the innermost measured ring of a sample, and the actual first year of tree growth do not necessarily agree. In the pith offset (PO), the number of years estimated to the pith based on the growth rate after the missing segment can be used to estimate the offset

between the innermost measured ring and the pith (Bräker 1981). The influence of the PO and its uncertainty on RCS is discussed by Esper et al. (2003). The age-aligned series collectively describe the age-related, biological growth trend, typical for the given species, site and region. A single growth function, or regional curve (RC, smoothed using a cubic spline (Cook and Peters 1981) of 10% the series length) is calculated as the mean of all age-aligned series (Fig. 3A-C). Anomalies of the raw measurements from the RC are interpreted as non-biological signals, and result from, for example climatic and/or ecological forcings (Briffa et al. 1996). The anomalies from the RC are taken, using two different methods for index calculation:

- (i) ratios of the actual-to-biologically expected ring width for each year and
- (ii) residuals of the actual-to-biologically expected ring width, after applying an adaptive power transformation (PT, Cook and Peters 1997). The PT is employed to series of original ring width prior to growth trend removal.

This transformation (in method *ii*) is necessary due to the heteroscedastic nature of raw ring width series, when residuals are applied. PT results in homoscedastic time series, with the yearly spread being independent of the growth level (Fig. 2B). Calculating ratios (in method *i*) also results in nearly homoscedastic time series.

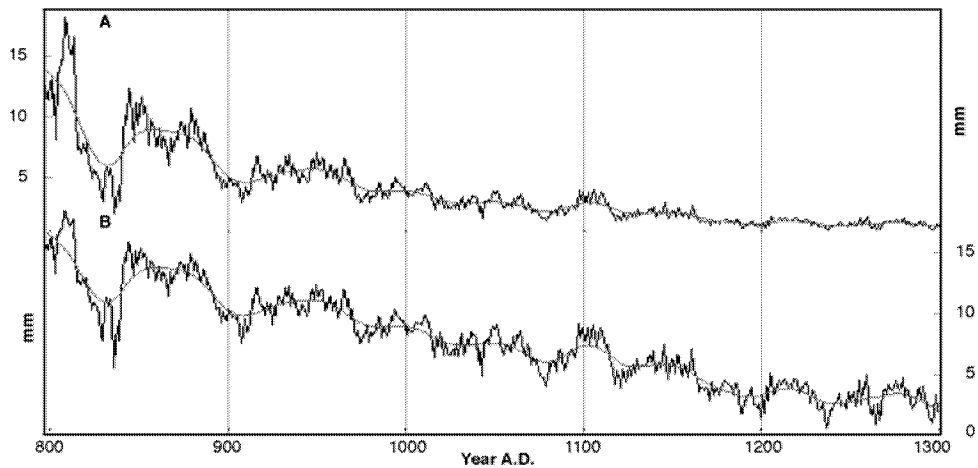


Figure 2: Variance stabilization by using adaptive power transformation. A Raw measurements from a subfossil, high elevation stone pine sample (gli 38_m) from western Austria. Decreasing growth level and variance with increasing age explains the heteroscedastic variance of raw ring width series (spread vs level relation), commonly eliminated by calculating ratios. The last 100 years of the sample have low values, potentially resulting in the "end-effect" problem, when computing ratios with individual detrending methods (Cook and Peters 1997; Cook et al. 1995). B Tree-ring width measurements of the same series after power transformation ($p=0.15$). The variance stabilization results in nearly homoscedastic time series that can be standardized by calculating residuals.

The deviations from the growth function are then re-aligned by their calendar year and the mean RCS chronology is calculated, using the robust, biweight mean (Cook 1985). The individual, RCS detrended measurements are dimensionless indices, without a defined mean, and thus allow low frequency variability to be preserved. For variance stabilization of the chronology, a technique that considers the number of samples per year and the average correlation coefficient between the single measurements is applied (Osborn et al. 1997). The chronologies shown, are truncated at a sample size <5 series. To minimize end-effect problems of smoothed chronologies (Fig. 4A), we applied a padding procedure of 10 years with the mean value from the 10 endmost years, representing half of the filter length (Mann 2004).

Results

Three datasets from the Alps indicate sensitivity and/or robustness with respect to the different ways of calculating RCS chronologies. The mean growth function (RC) for each species and calculation method is illustrated in figure 3. Their decline is an expected, reasonably systematic and fairly simple function of time (Bräker 1981). This mean age-related decrease is the basis for the RCS method (Briffa et al. 1992, 1996). RC for raw and PT measurements show notable level differences, but reflect similar growth functions. The erratic ends at the higher cambial ages are caused by decreasing numbers of measurements per year (Fig. 3A-C). Due to higher replication of the larch and pine data at all age classes (Fig. 1), erratic ends are most significant for the spruce series. After PT, yearly mean growth values increase from 1.13 to 1.39, 0.99 to 1.26 and 1.00 to 1.31 for the spruce, pine and the larch data, and the series from the three chronologies are raised by the mean power (p) of 0.44, 0.35 and 0.54, respectively.

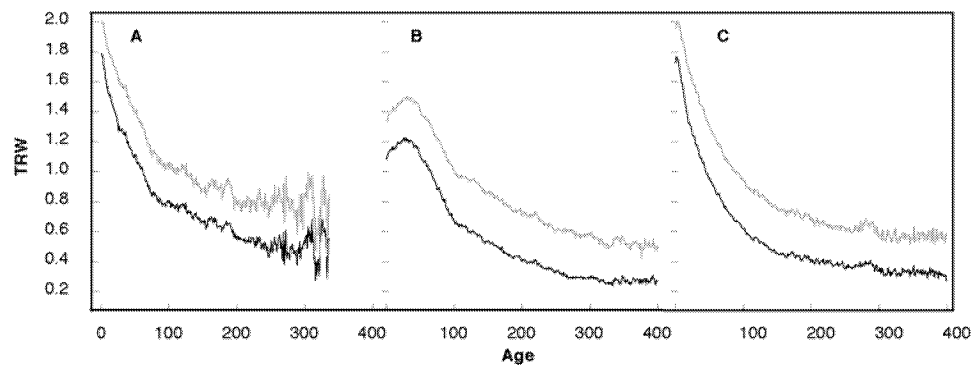


Figure 3: Arithmetic mean of the age-aligned data calculated from the raw (black) and power transformed (grey) for A spruce, B pine and C larch measurements. A general level increase is obtained after PT. RC would be 10-year cubic splines fit to these series.

The three composite data collections reflect substantial low frequency variation over the past millennium however the trend and amplitude differ slightly within the same species and more significantly between species. The chronologies possess common long-term growth behavior, e.g., high values prior ~1300 (except pine), a depression from around 1350-1820 and increasing values since ~1820 (Fig. 4A). Discrepancies depend on the data used, varying sample depth, the ecological variations, potential site disturbances and the signal preserved.

When calculating ratios, the chronologies obtain similar results with unreasonably high values if the RC reaches the “danger-zone” <0.5 mm (Fig. 3), and has a time-axis intercept near either end of the series. Further, a significant lack-of-fit between the ring width values and the RC can cause inflation. Nevertheless, the advantage of ratios is the correction for heteroscedasticity in raw ring width series (Fig. 2A). As alternative, the calculation of residuals plus PT is proposed (Fig. 2B).

Depending on calculations with ratios, or residuals plus PT, the RCS chronologies show greatest differences toward their ends, and similarities within the record’s middle sections (Fig. 4A, B). If reconstructions are based on ratios, rather than residuals, significant influence occurs in the earlier portion of the larch, slight for the spruce and none for the pine record. The recent trend since ~1820 seems to depend the species used. This rising trend is lower for the spruce and higher for the pine and larch data and likely expresses the “end-effect” problem described by Cook and Peters (1997) for individual series detrending. Besides long-term deviations, differences occur on annual scale. In particular, the larch chronology contains years with anomalously high discrepancies. These outliers mainly reflect larch budmoth events (e.g., Rolland et al. 2001; Weber 1997). To avoid low frequency deviations and annual outliers, caused by growth levels <0.5 mm, we suggest calculating with residuals plus PT.

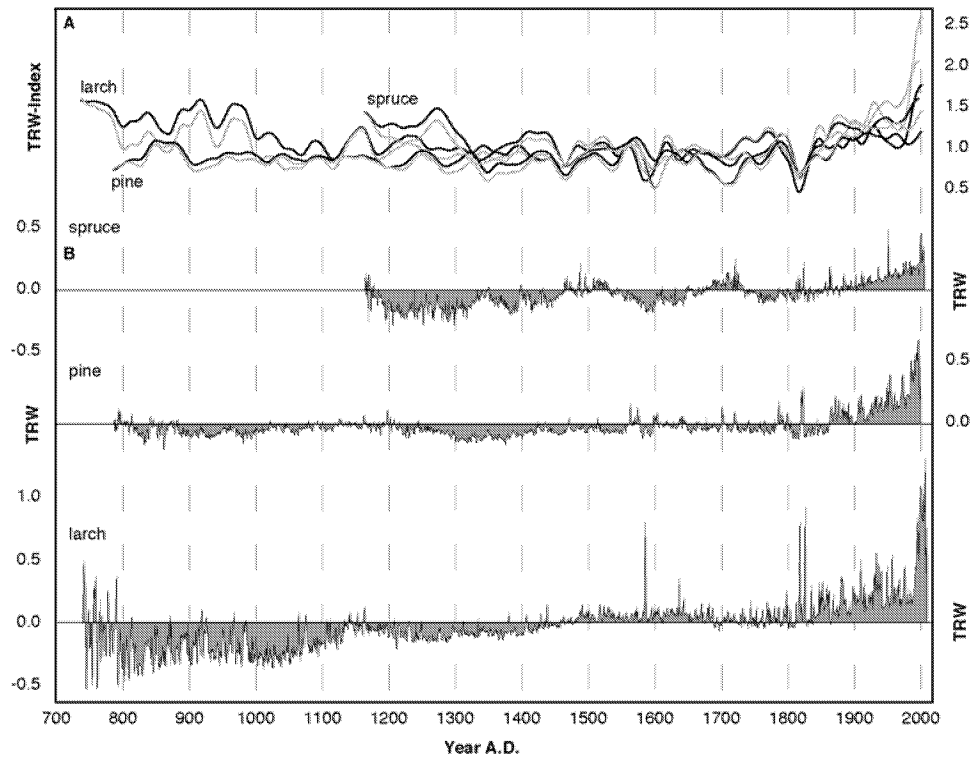


Figure 4: A Common multi-decadal trends and deviations of the 40-year smoothed RCS chronologies after using ratios (grey) and residuals plus PT (black), and B annual differences and long-term discord. In all cases ratios result in increased values in the 20th century relative to the earlier portion of the record.

Discussion

The RCS method contains a variety of uncertainties, e.g., index calculation, sample size, the influence of pith offset and species and site composition (Esper et al. 2003). Here we particularly focus on the bias of computing anomalies from a fitted growth curve function (RC). As explained by Cook and Peters (1997), bias in tree-ring indices obtained from calculating ratios can occur when (i) the fitted growth curve or RC decrease towards zero and (ii) the standardization curve diverges negatively from the local ring width near either end of the series. The problems described (Cook and Peters 1997), refer to individual series standardization. The degree of misfit between a series and its detrending function, is generally much greater in the RCS method.

The three RCS chronologies indicate a significant dependence on methodology, specifically whether ratios or residuals plus PT are used for detrending, and particularly towards the series modern ends. Here more level offset of early vs. late periods is revealed. We show that differing methods of calculating RCS can cause bias from annual to centennial scales

(Fig. 4), however, with more minor effects on high frequency and more major effects on low frequency scales.

Datasets with high sample replication, even sample distribution and homogeneous growth levels allow the application of RCS. Samples without the pith and pith offset estimation (not shown) are still usable (Esper et al. 2003). The choice of either using ratios or residuals plus adequate variance stabilization is related to the dataset, thus a general recommendation is not given. Esper et al. 2003 showed similar results and proposed to always compare RCS chronologies after using ratios and residuals plus PT. A tendency for valid RCS results, based on ratios is indicated by generally higher growth levels (>0.5 mm), within the entire series. RCS runs with different species verify these results (Fig. 4A, B). We show a significant “end-effect” problem for the pine and larch chronologies, with adult wood centered towards the records recent end. Smaller “end-effect” bias of the spruce chronology is likely related to younger samples within the 20th century and generally higher growth values of the spruce trees. The positive deviations in the 20th century, seemingly caused by the “end-effect” problem, can have a significant impact at the beginning of the chronologies, when centering the resulting RCS chronologies ~ 1.0 (Fig. 4A). Hereby the end-effect is “distributed” to both ends of the records. To better understand this bias, further analyses on a single series basis are necessary.

Differing values during the records earlier portion can also be related to a reduction in sample size and inadequate truncation (e.g., $n=5$ series). Due to the use of the most recent portion of a seven thousand year pine chronology with adequate sample size during the past millennia (Nicolussi & Schießling 2002), lesser uncertainty exists for the Austrian data (Fig. 4B).

The importance of either, using ratios or residuals plus PT is expressed in Late Medieval temperatures, either above or below these of the 20th century (Fig. 4A). Substantial trend deviations late in the chronologies are predominantly caused by the index calculation method applied within RCS. A method individually adapted to the common growth level of the dataset used, is essential for placing the recent warming trend in the context of past climate variability.

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Compression wood formation and pith eccentricity in *Picea abies* L. depending on selected site-related factors: Detection of compression wood by its spectral properties in reflected light

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Introduction

Studies have shown that the formation of compression wood is a negative gravitropic reaction of the coniferous tree. It is interpreted as serving the tree in recovering from a displacement in order to regain its original orientation in space. For the stem this would be the vertical orientation which it can hardly regain. The observed correction is often limited to the apical meristem leading to the appearance of a sweep. Therefore, compression wood formation can be considered as being a reaction to an external stress which is putting a strain on the tree. A profound knowledge of compression wood distribution could lead to a better understanding of the interaction of ecological factors and the growth or reaction of trees in response to them.

In this study the effects of potential external factors on displacement and consequently compression wood formation are investigated. Trees from sites with different slopes and exposure to the prevailing wind directions are examined for their compression wood distribution and eccentric radial increment using a new hyperspectral image analysis method. The compression wood distribution in stems of Norway spruce is described and the detection of an inter-annual time series in the formation of compression wood is analysed.

Material

One of the objectives of this study is to describe the distribution of the compression wood in the stem of Norway spruce (*Picea abies* [L.] Karst.) and to examine the possible impacts of slope and exposure to the prevailing wind direction on the compression wood formation. Therefore the sites were selected to be as similar as possible, differing only in slope and exposure. In total, trees from five sites were sampled, all of which are located in south-western Germany in the growth region "Black Forest" and "Baar-Wutach". The sites belong to the submontane to highmontane altitudinal, there climate is suitable for Norway spruce.

One of the sites is almost level with a slope of 1°. Two sites could be said to be strongly inclined with slopes of 10° and 17°, whereas the last two sites with 25° and 29° are considered steep. Of the two pairs of sites on the inclined slopes, one site on each is exposed to the south-west, against the prevailing wind direction, and the other to the north-east. Summarised data for the description of the five different sites are listed in Table 1. The wind data are taken from measurement stations of the DWD - German Weather Service and

the LfU - Landesanstalt für Umweltschutz Baden-Württemberg named in Table 1. Note that the indicated wind directions are where the wind is blowing from in contrast to the aspect of the slope. "Feldberg" is the closest station to the site at Titisee-Neustadt, but due to its exposed situation in the landscape on top of the highest mountain of the Black Forest, the mean wind speed is presumably much higher than that at the site located at an elevation 400 m further down.

Altogether 56 Norway spruce trees were sampled from the stands on the five different sites. All the stands were mature and at least dominated by Norway spruce. The trees belong to the social classes I to III according to KRAFT (pre-dominant to co-dominant). From every sample tree, on average 8.57 cross sectional discs were cut for compression wood analysis, with the north direction marked. The minimum number of discs per sample tree was 5, the maximum 13, from defined heights along the stem. The total number of sample discs taken is over 500 including those for age analysis at a height of 0.3 m.

Table 1: Summarized data for the description of the five sample sites.

Forest district	Waldkirch	Titisee-Neustadt	Bonndorf	Elzach	St. Märgen
Growth region	Black Forest		Baar-Wutach	Black Forest	
Location (Lat./Long.)	48°4' / 8°2'	47°54' / 8°4'	47°49' / 8°16'	48°10' / 8°7'	48°2' / 7°59'
Elevation [m]	1100	1100	960	760	540
Slope [°]	10	17	1	29	25
Aspect	north-east (45°)	south-west (243°)	east (68°)	west (234°)	north-east (27°)
Soil type	humous Cambisol	Cambisol	Cambisol, partly Planosols	Cambisol and Spodo-Dystric Cambisol	Cambisol
Mean annual temperature [°C]	6.9	5.6	6.1	7	6.9
Mean annual precipitation [mm]	1736	1406	1306	1741	1736
Prevailing-/ mean wind-/ mean storm direction [°] (station)	240 / 251 / 237 Schauinsland	240 / 230 / 223 Feldberg	270 / 293 / 273 Höchenschwand	240 / 247 / 240 Elzach	120 / 162 / 270 Glottertal
Mean annual wind speed [m/sec.]	3.0	7.8	2.1	3.5	2.0

Method

Detection of Compression Wood by its Spectral Properties in Reflected Light

One of the most, if not the most, important issues when describing compression wood distribution is the method used to detect this tissue and to discriminate it from other wood features occurring on stem cross sections. After having tested different approaches to identify a suitable method for the detection of compression wood in dried stem discs from Norway spruce, and to classify it against other wood tissues, it was decided to use hyperspectral image analysis. For the assessment of the cross sections from the stems a method has been developed using the reflected light in the wavelength range 400 – 1000 nm, integrated to 121 bands with a spatial resolution of 0.1 mm, to distinguish

compression wood from other wood tissues by its spectral properties. These properties are given by the chemical composition and the scene geometry of the hyperspectral scanner developed for analysis. Hyperspectral image analysis allows for the comparison of the obtained spectra from the cross sections with reference spectra obtained from reference areas. Seven stem cross sections from previously sampled Norway spruce material are classified by cellular properties using light microscopy into the agreed classification system of compression wood severity grades “severe” and “mild” which serve as reference material. The criteria for the grading of compression wood tracheids to normal wood tracheids in the middle of tree rings have been chosen according to Yumoto, M. et al. (1983) but have been slightly modified (Table 2). The tracheids have to exhibit a very thick cell wall, a nearly circular boundary between S1 and S2 and the presence of intercellular spaces to be classified as “severe compression wood”. For “mild compression wood” the cell wall thickness has to be relatively thick, the boundary has to be round but was allowed to be variable depending on the presence or absence of intercellular spaces.

Table 2: Criteria of tracheid classification in cross sections. Criteria of gradation of compression wood tracheids to normal tracheids in the middle of tree rings modified according to YUMOTO, M. et al. (1983).

Criterion (cellular level)	Compression Wood severe	Compression Wood moderate	Normal Wood
Spiral grooves	distinct	poorly developed to absent	absent
Cell wall thickness	very thick	thicker than normal	normal
Cell outline between S1 and S2(L)	round, almost circular	round but variable depending on the presence of intercellular spaces	“rounded rectangles”
Intercellular spaces	generally present	incidentally present	absent
Color appearance	“reddish”	“darker brownish”	“brownish”

The classified areas from these seven discs were used as reference material to calibrate the classification model in order to facilitate the semi-automatic assessment of compression wood content in sample discs using hyperspectral image analysis. These regions were hyperspectrally scanned and 74 mean standardised reference spectra were recorded. These reference spectra, stored in a spectral library, serve in the classification model to discriminate between different wood features based on their spectral properties in reflected light using the “Spectral Angle Mapper” (SAM) classification algorithm (Kruse, F.A. et al. 1993). The algorithm determines the similarity between two spectra by calculating the “spectral angle” between them, treating them as vectors in a space with dimensionality equal to the number of bands. The result is a classification image which shows the best match at each pixel. For breaking down the classification information to the compression wood content of a single growth ring, an extracted grey scale image from the calibrated hyperspectral image, representing a spatial x/y-scanning in a specific wavelength band (435 nm) in the blue part of the Visible Light, is to be read into the growth ring analysis programme previously developed

at the Institute for Forest Growth. The semi-automatic measurement of the annual radial increment is adjusted to the spatial resolution of the hyperspectral images and the growth ring boundaries are located. Furthermore, the classification image is interpreted and the two compression wood classes and a third “non-compression wood” class are distinguished. Knowing the growth ring boundaries, it is now possible to break down the overall classification result of a radius into single year patterns of compression wood content by counting the corresponding pixels within a sampling kernel. Aside from recording the compression wood distribution, the annual radial increment is measured in eight radii oriented to the compass directions. An extensive description of the method is given in an submitted article to the IAWA-Journal.

Modelling the Compression Wood Distribution and the Pith Eccentricity

Every stem cross section was scanned in eight radii oriented from the pith to the bark according to the main and auxiliary compass directions. Within each radius the annual increment was measured and the annual compression wood recorded. This sampling design allows the compression wood distribution in the stem cross section in two dimensions (radial and tangential) to be described and, by interpolating the values between the different discs taken from the stem, the third axial dimension can be added. Furthermore, an inter-annual time series of the compression wood formation can be analysed. The classification results and the data from the measurements of the radial annual increment are used to calculate a vector ($\theta|r$) for the compression wood and growth ring structure of every tree ring. These vectors indicate by their angle (θ) the compass direction of the compression wood distribution or the pith eccentricity. The value for the length (r) gives a gauge to judge the amount of compression wood or the deviation of the pith eccentricity from a concentric circle. These “tree ring vectors” arise from adding the results, which could also be regarded as vectors, of a given tree ring from the eight individual radii scanned from a stem cross section. Adding up the “tree ring vectors” of one stem cross section results in a “disc vector” indicating accurately the amount and the mean direction ($\bar{\theta}$) of compression wood and pith eccentricity. If the resultant vector length (r) is divided by the number of vectors contributing to it, the mean resultant length ($\bar{r}$) results, which is associated with the mean direction ($\bar{\theta}$). The mean resultant length lies in the range (0,1) with interesting properties at the extremes. Further corresponding statistical methods for summary description and analysis of circular data are described by Fisher, N.I. (1993). The Rayleigh test is used to test randomness against an unimodal distribution of the directions for compression wood and pith eccentricity.

Results

Classification of Compression Wood

The method developed to detect compression wood in the reflected light by hyperspectral image analysis was validated by scanning a randomly selected test radius which had not been used for building up the spectral library. A confusion matrix for microscopically identified test areas was calculated and revealed an overall accuracy of >91%. This accuracy was achieved after applying the spatial filter "Majority Analysis" to the classification image thereby homogenizing spurious pixels within a large single class. As can be seen in Figure 1, some errors in the automatic detection occurred in the pith and on the inner side walls of cracks which are judged in part to belong to severe (CWs) or moderate (CWm) compression wood. Such clear misclassifications can be corrected manually in the data files. It is obvious that this would further improve the error statements leading to an overall accuracy of about 96%.

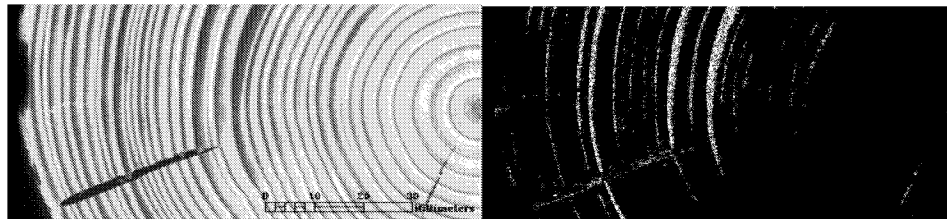


Figure 1: Cross section of a randomly chosen Norway spruce test radius and the corresponding classification result. The radius is extracted from an image cube giving spatial information at wavelength 435 nm in the left part of the image. The right part gives the corresponding classification result in a grey scale image: "Compression Wood severe"--white, "Compression Wood moderate"--grey, "Normal Wood" and "Background/Crack"--black.

Compression Wood Distribution and Pith Eccentricity

At first glance the occurrence of compression wood appears to form half-moon like patterns within tree rings in stem cross sections. The frequency of the compression wood formation is recorded and the extent to which the compression wood extends in the tangential direction within a tree ring is assessed. This is analyzed in the discs from all sample trees of the absolute tree height 1.3 m. The tree rings are subdivided into cambial age classes of 20 years, whereby the innermost tree ring comprising of the pith is excluded. First, it is observed whether compression wood occurs in a tree ring with a certainty of 99%, then it is recorded in how many radii, up to a maximum of eight, the compression wood is formed. On the stem cross sectional level it has been found that the frequency of compression wood formation in a tree ring increases from juvenile to adult wood. The observed frequency distribution of the compression wood formation in the cross sections from a height of 1.3 m for cambial age classes each comprising of 20 years is for class I – 27 %; III – 54 %, V – 57 %; VII – 59 %, VIII – 59 %.

IX – 64 %, XI – 61 % and for class XIII – 68 %. For cambial age class I, 87.93% of the segments containing compression wood are limited to a maximum of 135°, whereas in class XIII only 51.99% are limited to this maximum tangential spread. However, the sector containing compression wood can exceed 315° in some tree rings. In the cambial age class XIII this is the case in almost 4% of the tree rings in which compression wood is formed.

A very close relationship is observed between the direction of the compression wood sector in a ring and the direction of its eccentric growth. In 62% of the observations the difference between both directions is within a maximum of 45°. As is shown in Figure 2, both the sectors are oriented towards the north-eastern half of the circle in 79% of the growth rings.

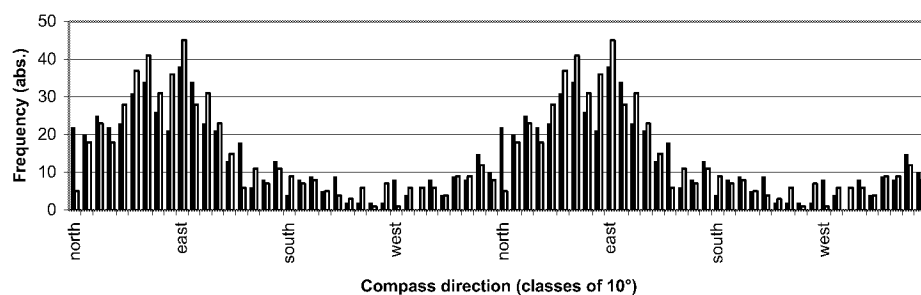


Figure 2: Frequency of the direction of compression wood formation and pith eccentricity in stem cross sections. Compression wood – black columns; pith eccentricity – white columns.

The results of the Rayleigh test of randomness compared to an unimodal distribution reveal highly significant differences in uniformity in the directions of compression wood formation and pith eccentricity at all sites except St. Märgen. The mean directions ($\bar{\theta}$) and the resultant length ($\bar{r}$) for compression wood and pith eccentricity are summarized in Table 3. Almost all mean directions are located in the north (0°) - eastern (90°) part of the circle. They do not follow the direction of the slope of the site, but in most sites the leeward direction of the prevailing wind is within the 95 % confidence interval of the mean directions (CW and IR). This finding is in contradiction to the hypothesis that the exposure of the slope has a decisive effect on the direction of the compression wood formation.

In order to examine the possible effect of exposure to the prevailing wind direction of the site on the formation of compression wood, inter-annual time series of the compression wood formation for the five stands were analysed for identical one year trends in their curves between the sites. The relative mean amount of compression wood formed in the five sites is shown over the calendar year in Figure 3. The bold curve high up indicates how many sites show a simultaneous deviation in the formation of compression wood compared to the previous year.

Table 3: Summary statistics of the directions for compression wood (CW) and pith eccentricity (IR) of stem cross sections. **Prevailing wind direction_(lee) within confident interval; *prevailing wind direction_(lee) less then 20° away from the mean direction.

Summary statistic	Waldkirch	Titisee-Neustadt	Bonndorf	Elzach	St. Märgen
Mean direction ($\bar{\theta}$) CW	66,7°	78,2°	100,0°	48,3°	3,5°
Mean resultant length ($\bar{r}$) CW	0,63	0,79	0,82	0,84	0,14
Confidence interval _(0,95) [°]	52,7 – 80,8**	68,0 – 88,5*	93,2 – 106,7*	41,1 – 55,6*	303,0 – 63,9
Mean direction ($\bar{\theta}$) IR	40,9°	69,3°	88,1°	60,4°	237,5°
Mean resultant length ($\bar{r}$) IR	0,72	0,91	0,85	0,80	0,21
Confidence interval _(0,95) [°]	29,5 – 52,4*	62,4 – 76,1**	81,9 – 94,4**	53,3 – 67,5**	193,8 – 281,1

It is remarkable that in several years all curves of the mean amount of annual compression wood show an increase compared to the previous year. Where the data are limited to only four sites due to the younger age of the trees in St. Märgen the bold curve is in grey. Hartig, R. (1896) was presumably one of the first to mention that compression wood is formed under the influence of wind. Pillow, M.Y. (1931) relates the sudden increase in the amount of compression wood formed in pine trees in Florida to the occurrence of a hurricane. In the consecutive years he reports a declining amount of compression wood. For the south-western part of Germany, Abetz, P. & Künstle, E. (1982) were able to identify a correlation between the occurrence of compression wood and the amount of incidental harvested wood due to storm and snow damage. In Figure 3 events with an extremely high wind speed are indicated by black columns (Dec. 1927, Nov. 1930, Mar. 1940, Jan. 1955, Mar. 1966, spring 1967, Mar. 1990, Dec. 1999), the grey columns mark major snow damage events (Apr. 1936, Feb. 1958, Apr. 1973); source: a.o. (Volk K. 1968). All these events lead to an increase in the annual mean relative amount of compression wood in the following vegetation period compared to the previous. There is only one exception, the storm in Jan. 1955, after which the amount did not increase before 1956. If the level of the different curves is examined, it is apparent that the trees from the nearly level site at Bonndorf formed the highest mounts of compression wood, followed by those from the steep site exposed to the west in Elzach. The levels of the trees from the sites located in the high montane range close to Waldkirch and Titisee-Neustadt are very similar to each other at a relative low level. The smallest amounts of compression wood are formed in the steep submontane site, exposed to the north-east close to St. Märgen.

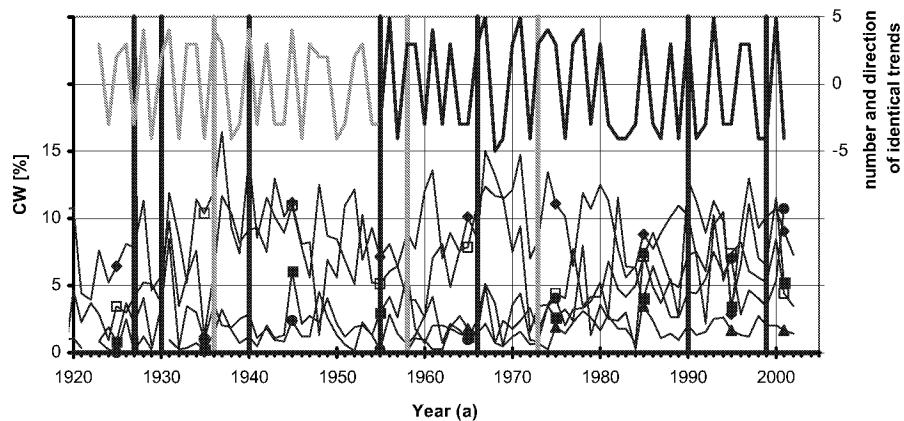


Figure 3: The relative amount of compression wood formation in the calendar years for the five different sites. The black columns indicate years with extremely high wind speed events, the grey ones indicate years with major snow damages. The curve high up shows how many sites display a identical deviation in the amount of compression wood compared to that of the previous year (— 4, — 5 observations). ♦ Bonndorf; □ Elzach; ▲ St. Märgen; ● Titisee-Neustadt; ■ Waldkirch.

Discussion

The description of the compression wood distribution allows for relationships of its formation with environmental factors to be analysed. The inter-annual time series of the mean relative amount of Compression wood revealed several years in which in all five sites an increase in relation to the amount of the previous year is observed. These years correlate very well with events of high wind speeds or major damages due to heavy snow loads. A comparison of the mean direction of the compression wood formation with the eccentric radial growths indicates that the prevailing wind direction and the direction where the storms came from explain well the direction of the displacement of the trees and resulting compression wood formation. In contrast, the slope is not able to serve as an explanatory factor. This statement has to be limited to the examined sites. In other altitudinal ranges with higher snow cover and corresponding snow movement processes when melting, it is to be expected that the trees would show pistol butted growth and corresponding compression wood formation. This has not been the case with the sampled trees. High amounts of compression wood occur in the almost level as well as in the steep western exposed sites, whereas the trees of the steep northeast exposed site have the smallest amounts. However, if the exposure to the prevailing wind direction is taken into account, it fits well that the trees at the lower part of the steep northeast exposed site, which are protected from the wind, hardly form compression wood. The trees of the strongly inclined highmontane sites have presumably well adapted over time to the higher wind speeds. Consequently, they form less compression wood after storm events. There still remains the question why the trees from the almost level site have formed

the highest amounts of compression wood. The explanation might possibly be found in the ground. The soil consists partly of sandy loam which holds the moisture well and reduces the anchorage of the trees after high precipitations thereby increasing their susceptibility to displacements.

Conclusions

The examination of stem cross sections with the new developed method to detect compression wood in the reflected light by hyperspectral image analysis allows for a three-dimensional description of the compression wood distribution in stems. Together with the compression wood assessment, the annual radial increment was measured, enabling the tree ring structure for eccentric growth to be analysed. The time series analysis of the mean relative amount of compression wood revealed a distinct effect of extremely high wind speed events and heavy wet snow loads on the formation of compression wood. This caused, within several years, the trees of all five sites to increase the amount of compression wood in relation to the year previous to the event. It was not possible to prove that the slope had an effect on the formation of compression wood nor on pith eccentricity, neither with regard to the amount nor to the direction. The directions are in fact dominated by the exposure of the site to the prevailing wind direction.

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New multivariate cross-correlation analysis

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Introduction

In various archaeological excavations small wooden samples were found. For the dating of wooden samples univariate standard methods are available until now. Often this method can not be applied, because the samples do not include the necessary number of 50 or more tree-rings to achieve a high statistical confidence of the dating result. The following paper gives information about a new approach using a multivariate cross-correlation analysis. The method based on data obtained from x-ray images made from the wood samples.

The cell wall thickness of xylem cells is typical and representative of the climatic conditions during the vegetation periods (cf. Larson 1994). Such time specific tissues are able to be described by "Tracheidograms" (Terskov et al. 1981). The idea was to improve the cross dating effectively by measuring and using more than the total ring width parameter and hence increasing the degrees of freedom. The dating of small Spruce (*Picea abies* [L.] Karst.) wood samples is as a result now possible.

Material and methods

Development of a regional multivariate chronology (master-chronology)

Xylem structures of Spruce are more regionally pronounced than such e.g. of Fir (*Abies alba*). That's why regional standards are necessary for dating. Recent samples were collected on 20 different sites in Saxony (Fig.1) at altitudes ranging from 260 to 1070 m a.s.l. (cf. Neumann 2001). Four radii from each of 123 recent Spruce logs were investigated to develop site-specific standard-chronologies by averaging. In addition 45 older samples (mostly cores) from historical buildings in Saxony were researched to compile, among others, a multivariate standard-chronology with 438 included years.

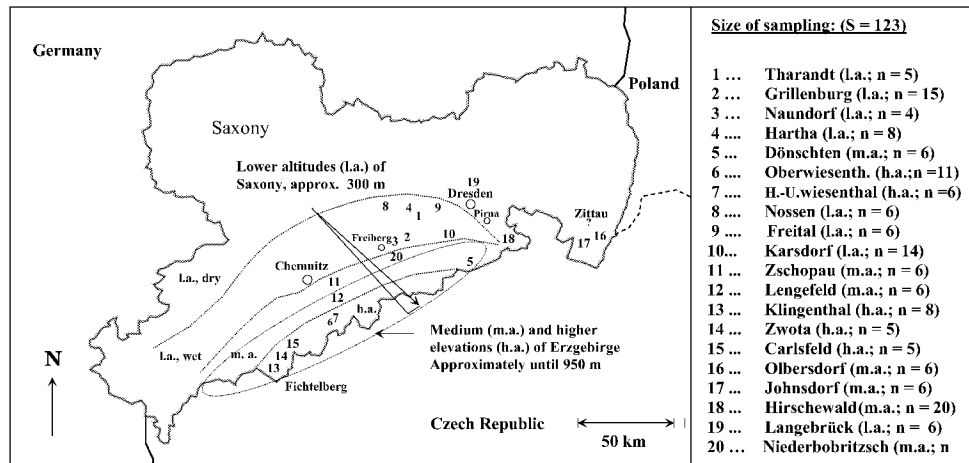


Figure 1: Map of sampling on sites of different altitudes in Saxony with indication of the number of investigated samples.

After air conditioning the extracted cross-cut samples were exposed over x-ray films (AGFA-Microvision Ci) and x-rayed under controlled conditions, using the facility "BALTOGRAPHE". The quantifications of year-specific grey values on the developed x-ray films by the tree-ring structure were done with the optometric unit "DENDRO 2003" (Walesch-Elektronik). The basic principles of the x-ray densitometry are explained in detail in Polge (1970b) and Cook & Kairiukstis (1990).

Quantification of late wood portion

The early wood/late wood percentage in a tree ring is an important parameter for the interpretation of climatic influences on the tree growth (Schweingruber 1980). To elaborate and quantify the late wood percentage in every single tree ring, the tracheid cell wall thickness was measured for 303 prepared tree-rings for 19,214 single tracheids on certain radii according to Mork's definition (1928). For x-ray densitometry data the early wood/late wood boundary was defined by mean wood density within each single tree-ring (mean value between minimum and maximum density). Both results were compared with each other.

Selection of tree-ring variables suitable for multivariate cross-correlation method

There is no variation in the real sense in case of time series by extreme values. But rather such extreme values (e.g. minima and maxima of late wood density) are indicators for late frost periods or extreme dry summers. The dispersion of values was adjusted by using statistical methods (e.g. low-pass filter). Some of these densitometrical tree-ring parameters are highly correlated (e.g. tree-ring width and early wood percentage). That's why the set of available parameters was reduced via principal component analysis to a set of independent

variables. Type and number of selected variables are dependent on the aim of the investigation.

Development of novel computer program

Univariate cross-correlations are calculable by the well known TSAP-program (RINN 1996, 2003). To realize the multivariate cross-correlations a novel software program (TreeRing-Analyser - TRA) was developed. The multivariate crossdating analysis of time series complexes can now be performed on the base of 10 independent variables (respectively of representatives) and several statistical indices used by program.

Final crossdating and verification of the new method

Finally the possibility and efficiency of dating shorter time series (with less than 50 tree-rings) were examined with a generated master-chronology (1566-2004).

Results and interpretation

Quantification of late wood portion

The histological investigations of microscopic cross-cuts by microtome, associated with x-ray analysis led to a practicable possibility of determining late wood cells. The annual tree-ring profiles showed that late wood cells are detectable by densitometry. The variation between both methods (MORK vs. x-ray densitometry) amounts to approximately $\pm 1\%$.

Selection of tree-ring variables suitable for multivariate cross-correlation method

Twenty tree-ring features were measured by x-ray densitometry. The investigated tree-ring features are:

- Maximum late wood density
- Mean late wood density
- Minimal early wood density
- Mean early wood density
- Wood density contrast
- Early wood percentage
- Late wood percentage
- Tree-ring width
- Early wood mass equivalent
- Late wood mass equivalent
- and the according ratios of measured data and the following value of the tree-ring parameter in the time series

The absolute values of tree-ring width of one stand varied up to 17%, but the comparability of several time series was maintained. Some of these parameters are highly correlated (e.g. mean and minimum early wood density; $r = 0.91$).

The principal component analysis was used to reduce the number of generated time series to some independent variables (e.g. maximal late wood density, wood density contrast, early wood percentage, mean early wood density, wood mass equivalent and total tree-ring width). Thereby the negative influences by multicollinearity were minimised. The investigations showed that type and number of variables are dependent on the target of the investigation and the region of origin of samples. Ten independent variables were extracted, which are able to include 97% of the input information. These variables were allocated to the sample and standard-complexes. On this basis the multivariate dendrochronological investigations for dating were possible by the bivariate cross-correlation.

Final crossdating and verification of the new method

The interactive early and late wood determination and the generation of several ring specific time series including dating itself are possible with the developed software. Extracted and synchronised time series of tree-ring features for the sample and standard complexes were used. The multivariate cross-correlation and dating can be controlled on the basis of calculation tables and interactive diagrams. The internal structure of the standard-chronologies is documented year after year with the number and direction vector of included values (corresponding with the "Gleichläufigkeit"). The degrees of freedom increase by measuring more than one tree-ring parameter using the extracted variables for crossdating. That's why the statistical confidence of cross dated true positions increases as well. The program works with dendrochronological statistics such as t-values, "Gleichläufigkeit" and a newly developed multivariate dating index (MDI). The MDI is a cumulative sum of similarity values of all cross dated variables.

Figure 2 illustrates the principle of multivariate cross-correlation with three selected tree-ring parameters (early wood mass equivalent, maximal late wood density and total tree-ring width).

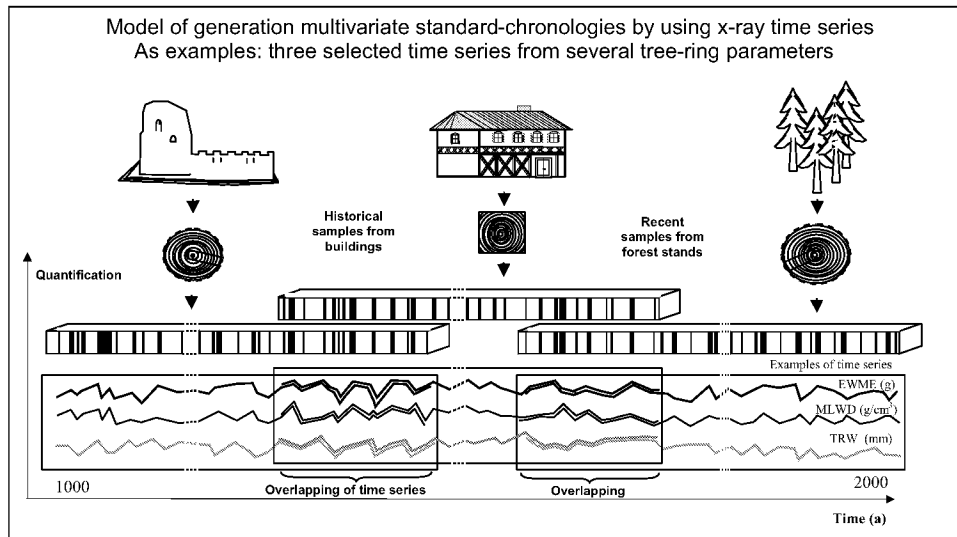


Figure 2: Principle of multivariate cross-correlation on the basis of several ring features, e. g. early wood mass equivalent (EWME), maximal late wood density (MLWD) and tree-ring width (TRW) – as a selection. Generation of regional standard-chronologies on the basis of analysing recent and historical material (cf. Schweingruber 1988).

The generation of multivariate standard-chronologies (e.g. 1566 - 2004, *Picea abies*, Tharandt, Saxony) is based on the synchronisation of single time series. Furthermore 20 site-specific standard-chronologies were generated by averaging the values of tree-ring parameters. The dating referred to generated site-specific regional standards of Spruce regarding the lower, medium and higher elevations in Erzgebirge Mountains.

As a final step the possibility of dating shorter time series with less than 50 tree-rings was proved. The cross-correlation analysis on the basis of generated multivariate standard-chronologies for the different regions in Saxony allowed for calculating the efficiency of dating. Step by step a given time series complex (e.g. a sample from forestry district: Altenberg / Dönschten, section: 758b², 600m o.s.l., Fig.3) was curtailed concerning shortened tree-ring sequences from the direction of the cambium layer. This was done in each case to include the more problematic tree-rings with more density fluctuations in the centre of the cross-section.

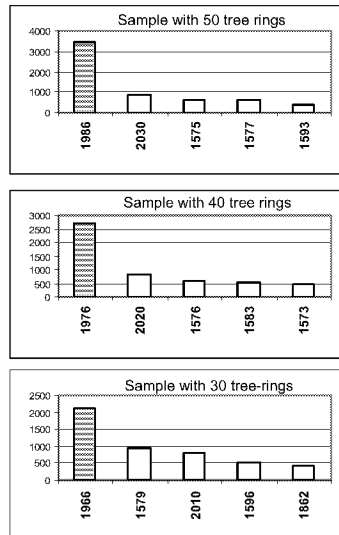


Figure 3: Results of statistical qualification (displacement) during cross-dating analysis, true solution (left) differs from four wrong solutions (right).

During the investigations the true results were well qualifiable as against the next wrong solution with positive differences of the MDI-values in dependence on the altitude of sites. Time series with 40 till 30 tree-rings were datable over a master-chronology of 438 years with a high statistical confidence level on the basis of the MDI-values. The difference between the true solution and the next wrong solution was quantified with approx. +40%. In case of dating by tree-ring width, the difference was 60% lower than with the multivariate method. Hence, the density features contributed considerably to the cross-correlation analysis (with 49 % at higher mountainous elevations). Samples from such higher (more temperature influenced) elevation with approximately 20 tree-rings were datable during the investigations (Fig.4). Samples from the lower sites with 30 tree-rings showed the comparable results and were datable, even though they show a higher variability of the tree-ring parameter values.

Such differences of MDI-values are indications of a higher quality of dating with increased statistical confidence by using the multivariate method. The acceptance of wrong solutions during the multivariate dating process of Spruce samples will become more improbable.

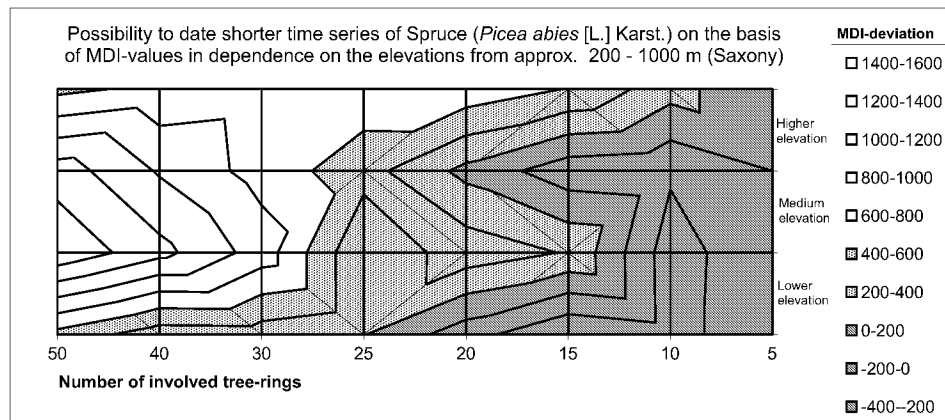


Figure 4: Differences between the true solution and wrong solutions of dating on the basis of distinction of the MDI-values: MDI-deviation from 1600-600 (white) and 600-200 (light grey): the true solution is significant qualifiable; 200 until -400 (dark grey): the qualification of the true solution under the wrong correlations is not significant in dependence from the elevation (lower elevations: from 200 m; medium: approx. 500-700 m; higher elevations: approx. 1000m).

Discussion and conclusion

Dendrochronological dating of softwoods is possible by using univariate and multivariate methods. On the one hand, the acceptance of wrong correlations may happen during the univariate cross-correlation on the basis of only one tree-ring feature (e.g. tree-ring width). On the other hand, the multivariate cross-correlation leads to a higher value of efficiency during the dating of Spruce samples by a more detailed characterisation of xylem. X-ray densitometry produces several tree-ring parameters for crossdating. Features of ring widths, wood densities and wood mass equivalents were involved during the investigations. Smaller Spruce samples are dateable with the developed multivariate analysing procedure by using the software "TRA". The target of the investigations, to develop a multivariate dating method for smaller Spruce samples with less than 50 tree-rings, was achieved.

An improved qualification of the true solution and wrong solutions by objective calculated numbers become possible by the explained procedure. Samples from higher elevations in the Erzgebirge Mountains (with stronger temperature influence) were more successfully cross dated than samples from the surrounding low-lying areas (with stronger precipitation influence). Not datable samples with abnormalities in the xylem structure will appear also regarding the multivariate method. The samples have to meet the demands of dendrochronological dating. The xylem structures have to be physically stable and regularly grown. Samples with secondary damage need special accuracy during the treatment.

Outlook

The developed multivariate analysis method is an innovative completion in comparison with the actual software for dendrochronological analysis. This method is applicable especially to complex problems. The multivariate analysis method seems to be useful for the cross-correlation of problematic time series (e.g. softwood structures with very uniform and smaller tree-rings from Scandinavia). A discussion based on wide interests is desired. The target for the near future is the adaptation of the method to the demands of analysing European (Richter *et al.* 2004) and tropical hardwoods. In doing so, the information content of the input variables should be retained basically during the selection of main factors. Sometimes weakly correlated variables were also used together in several investigations. For instance the height/diameter ratio (h/d) is used for the characterisation of specific tree growth features in the silviculture science. Using of special time series in the complex matters is beneficial for specific investigations. For instance the time series of early and late wood mass are useable for calculations of seasonal yield in forest stands.

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Tree rings as a calibration tool for dynamic forest models

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Introduction

Most forest gap models have been calibrated so that trees perform well in the centre of their altitudinal or latitudinal distribution. Model curves for growth response to climatic factors, such as temperature, are therefore not always optimized to realistically simulate the effect of limiting resources (e.g. cold or drought extremes).

ForClim (Bugmann 1994) and its derived model TreeMig (Lischke *et al.* in prep.) use the traditional parabolic representation of growth response to degree-day sum. This curve has been improved for the warm boundary of species' ranges in more recent versions of ForClim (Bugmann & Solomon 2000), by replacing it with an asymptotic function. In this paper, the focus is on the other extreme, namely growth in alpine or boreal tree-line conditions, with a view to improving the growth response to degree-day sum at its lower limit in the TreeMig model. This is achieved by comparing measured tree-ring width with degree-day sum, calculated from daily minimum and maximum temperature measurements, at various locations and for different species in the Swiss Alps.

Material and methods

Ring-width measurements were collected from the literature for 3 tree-line species - *Picea abies* (Heiri 2002; Hitz 2003; Meyer 2000), *Pinus cembra* (Müterthies 2002; Niederer 2003) and *Larix decidua* (Müterthies 2002) - at various sites in the Swiss Alps (Fig. 1). Daily minimum and maximum temperature data from 12 nearby climate stations (2-3 per site) were used to calculate the daily minimum and maximum temperatures at each site by linear regression.

Degree-day sum

For each of the study sites, the degree-day sum was calculated using a slightly modified version of Allen's double sine wave method (Allen 1976), with a lower threshold set at 5.5°C and no upper threshold.

Measured growth curves

All ring-width values were assigned their corresponding yearly degree-day sum. For each study site and each species, the ring-widths were then rearranged by degree-day sum, rather than in chronological order, and grouped into 25 degree-day "windows". Within each window, the mean of the 5% largest ring-width values was calculated. Only the largest values were considered in order to minimise the influence of other factors, such as tree age, precipitation

insect attacks, etc. Thus, the measurements should reflect the maximum growth which can be attained when temperature is the only limiting factor.

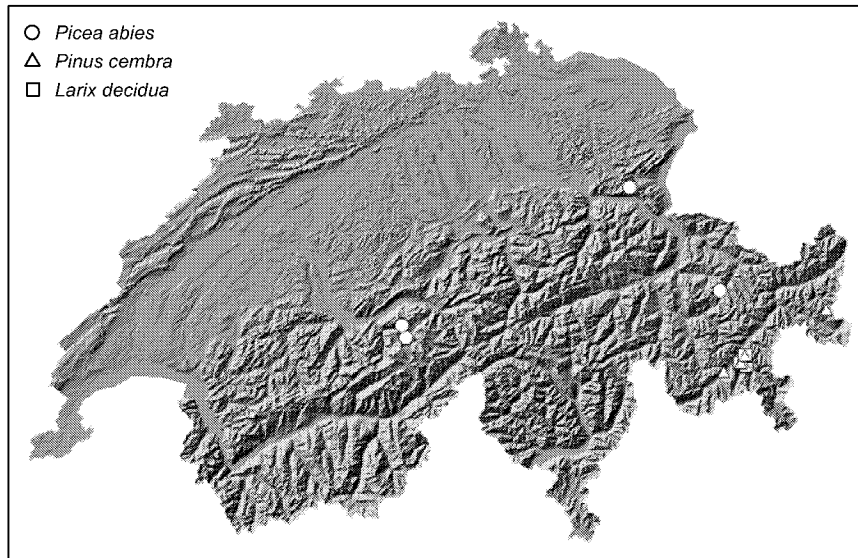


Figure 1: Location of the tree-ring width sample sites for 3 tree-line species: *Picea abies*, *Pinus cembra* and *Larix decidua*.

Theoretical growth curves

The measured growth curves were compared to two different theoretical curves: 1) the traditional parabolic curve used in many forest gap models, including early versions of ForClim (Bugmann 1994) and TreeMig (Lischke *et al.* in prep.); 2) the asymptotic curve used in ForClim 2.9 and later versions (Bugmann & Solomon 2000). The former is defined by the species-specific minimum and maximum degree-day sums, i.e. the temperature limits for growth, the maximum of the curve (where growth is maximal given the species' potential) being situated mid-way between the two. The second curve is defined by the species-specific minimum degree-day sum and tends towards the species' potential maximum growth. The shape of the asymptote is defined by a factor a , set so that growth is 75% of potential maximum when degree-day sum is equal to minimum degree-day sum + 1000 (Bugmann & Solomon 2000).

The asymptotic curve was then modified in order to improve its correspondence with the values of the measured ring-width data. The modifications concerned: 1) the minimum degree-day sum for each of the three species considered; 2) the shape of the asymptote, factor a being set so that growth is 75% of potential maximum when degree-day sum is equal to minimum degree-day sum + 250 (i.e. the slope of the curve is steeper).

Results and discussion

All three species showed growth at lower degree-day sums than the specific minimum in the original model curves (Fig. 2), which means the model would place the tree-line too low in altitude. The minimum degree-day sum for each species was therefore adjusted in the new curve, which better reflects the temperature limit for growth at tree-line.

Measured ring-widths increased rapidly with degree-day sum and the theoretical curves were all too flat, except for the parabolic curve for *Pinus cembra* (Fig. 2b). In the case of the asymptotic curve from ForClim V 2.9, this may be due to the fact that the slope was adjusted for the Pacific Northwest of the USA (Bugmann & Solomon 2000), where species' distributions seem to cover a broader range of degree-day sums. After adjustment of its parameters, the new asymptotic curve fits the shape of the maximum observed growth more closely.

In some locations, measured growth remains constantly low. This reflects the influence of other site factors, such as water availability, soil conditions, light, competition, etc. These factors are more likely to become the main cause for depressed growth as degree-day sums draw away from the lower limit.

For *Larix decidua* (Fig. 2c), the decrease in growth which appears when degree-day sum is further increased must be viewed with caution because of the smaller quantity of data used. Larch is subject to much growth fluctuation due to cyclic attacks by the Larch bud moth (*Zeiraphera diniana*). If the year with the highest degree-day sum also happens to be a "moth year", the effects of the two cannot be separated. The effects of other factors such as drought or tree age are also more difficult to separate if the dataset is small. Finally, the potential maximum growth of *Larix decidua* also seems to be underestimated, i.e. the value towards which the asymptote tends is too low.

Conclusions

This study has helped improve the theoretical growth curves used in the model, by adjusting their minimum values as well as their shape. This should enable the model to reflect reality better. Further investigation of age- and size-related growth is necessary to adjust potential maximum growth, particularly in the case of *Larix decidua*, for which more data must also be included. For all three species, this means extending the analysis of tree-ring growth beyond tree-line locations, thus including lower altitude sites, which have higher annual temperatures. Finally, the study will be extended to include other species, such as *Pinus sylvestris*, as the model is also to be used for the boreal tree-line.

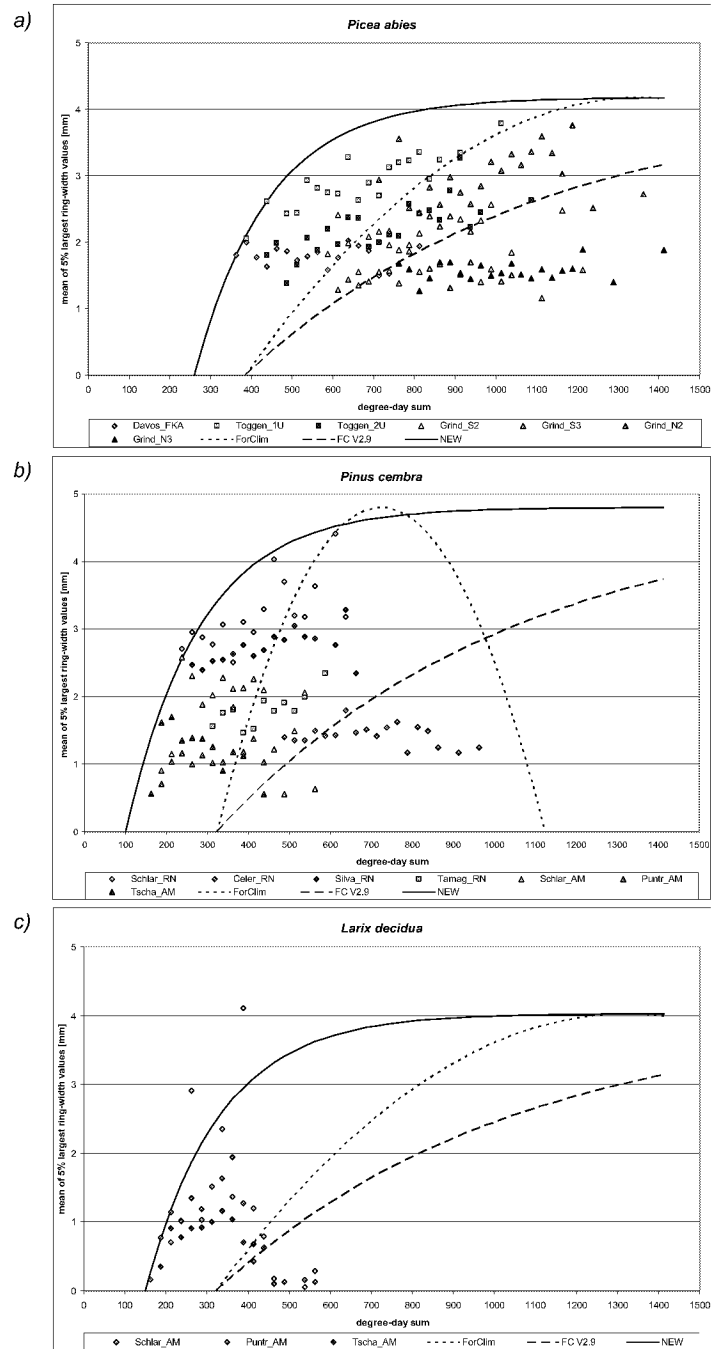


Figure 2: Means of maximum growth (ring-width) per site in each 25 degree-day window, for the 3 species: a) *P. abies*, b) *P. cembra* and c) *L. decidua*. The theoretical curves represented are ForClim/TreeMig (parabolic - dotted line), ForClim V 2.9 (asymptotic - dashed line) and modified asymptote (full line).

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Holger Gärtner

Dr. Holger Gärtner was born in 1965 in Heidelberg, Germany. He studied Geography and Geology at the University of Heidelberg. At the end of the year 2000 Dr. Gärtner established the Laboratory of Dendrogeomorphology at the Department of Geosciences, Geography, University of Fribourg in Switzerland. In 2001 he finished his PhD on variations in annual growth rings of roots caused by exposure due to various geomorphic processes. Since 2002 he is working as a Dendrogeomorphologist at the Swiss Federal Research Institute WSL, Birmensdorf, Switzerland. He currently is the treasurer of the Association of Tree-Ring Research.



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Jan Esper is head of the dendroclimatology group at the Swiss Federal Research Institute WSL in Birmensdorf, Switzerland (<http://www.wsl.ch/staff/jan.esper>). He studied geography at the University of Bonn, Germany, where he also completed his PhD thesis in 1998 on long-term climate variations in the Karakorum and Tien Shan mountains (Central Asia), and established the tree-ring group at the Department of Geography. He then moved on to the LDEO of Columbia University (New York), where he worked as a postdoc researcher. In 2001 he took his current position at the WSL. Jan is authoring numerous papers on global climate change, palaeoclimatology, and vegetation dynamics. He is involved in a variety of research projects supported by national and European funding agencies.



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G. H. Schleser works at Research Centre Jülich and is presently head of the Institute for Sedimentary Systems (ICG-V), which is part of the Department of Chemistry and Dynamics of the Geosphere. Current research at ICG-V deals with the inherent structure of climate change, which is critical for humanity today. Its focus is based on abrupt climate shifts, extreme climate events, ecological developments and catastrophic thresholds in regional- to global-scale biogeochemical systems.

He studied physics at the Universities of Cologne and Kiel and graduated in neutron physics. After three years with the Atomic Energy Establishment at Winfrith Heath, Dorchester, UK, he returned to Germany. He received his PhD with distinction from RWTH Aachen. He has over 25 years experience in the application of stable isotopes in various fields. This includes stable isotope work in tree rings, lacustrine sediments, as well as isotope investigations in peat bogs and soils. He has participated in numerous projects funded by the EU and the German Science Foundation (DFG). Since 1977 he has lectured at various universities. He has published almost 100 scientific papers, is Prof. at the University of Cologne and is currently Vice President of the Association of Tree-Ring Research.

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