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ASSOCIATION FOR TREE-RING RESEARCH

GESELLSCHAFT FÜR JAHRRINGFORSCHUNG

Edited by:
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Umwelt
Environment

Esther Jansma

Esther Jansma studied philosophy (BA, 1982) and ecological archaeology (MA, 1985) at Amsterdam University. In 1984-1985 she established a dendrochronological laboratory at the Archaeological Institute (IPP) of this university. Her MA-thesis concerned the dendrochronological dating of the harbour of a Roman fortress at Velsen (NL). Between 1987 and 1991 she worked on a grant of the National Science Foundation, which resulted in her PhD-thesis in 1995. She received her doctorate with honours and was awarded the W.A. van Es Award for Dutch archaeology. Part of her PhD-research was performed at the Laboratory of Tree-Ring Research, University of Arizona (1989 – 1990).

Since 1991 Esther has been working as a researcher at the National Service for Archaeological Heritage Management (ROB) in the Netherlands. The last two years she has been directing the research department of Environmental Archaeology and Conservation at the ROB. In addition, since 1993 she has been the director of science of the Netherlands Centre for Dendrochronology, a separate foundation with ties to the ROB.

Esther has another side, which is literature. She has published five collections of poetry and one short novel, and is considered a major Dutch poet. She thinks there are many similarities between writing and (tree-ring) research. Both require a sense of logic and structure. Both require patience and precision. And both use tiny elements (the alphabet, ring widths) to create something large and breath-taking.

Achim Bräuning

Dr. Achim Bräuning was born 1964 in Stuttgart, Germany. He studied Geography and Biology with emphasis on Botany, Zoology, Soil sciences and Biophysics. He finished his PhD in 1999 on dendroclimatology on the Tibetan Plateau. His main research areas are High Asia, Iran, Ecuador and Germany.

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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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Preface

This volume is the result of the conference *Tree Rings in Archaeology, Climatology and Ecology (TRACE) 2003*, which took place from May 1st – 3rd 2003 at the Museum Catherijneconvent in Utrecht (NL) and was organized by Dr. E. Jansma of the Association for Tree-Ring Research (ATR).

With the annual TRACE conference, the ATR intends to present the state of the art as well as new research perspectives in the field of dendrochronology, to actively stimulate further investigations and closer collaboration between different research groups, and to strengthen dendrochronological sciences in central European research.

About 70 scientists and students from Austria, Belgium, England, Germany, the Netherlands, Poland, Spain and Switzerland attended the meeting. In total, 24 talks and 12 posters were presented, covering the topics (1) Geomorphology, (2) Ecology, (3) Climatology, (4) Palaeo-environment, (5) Cultural Heritage, (6) Isotopes and Climate, and (7) New Applications. This volume contains 21 extended abstracts based on these presentations.

We sincerely thank the participants of the meeting, who contributed to a lively and enthusiastic exchange of ideas, and Marjolein Mullen (Utrecht University), Elsemiek Anraets and Tamara Vernimmen (RING) for their practical help.

TRACE 2003 was sponsored by (1) the National Service for Archaeological Heritage in the Netherlands (ROB, Amersfoort); (2) the Laboratory of Palaeobotany and Palynology (Department of Biology, Utrecht University), (3) Forschungszentrum Juelich GmbH (Juelich) and (4) the Netherlands Centre for Dendrochronology (RING Foundation; Amersfoort).

Dr. Esther Jansma
Dr. Achim Bräuning
Dr. Holger Gärtner
Prof. Dr. Gerhard H. Schleser

CONTENTS

SECTION 1

ECOLOGY

Tree-ring studies in the Dolpo-Himalya (western Nepal)

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Introduction

The central Himalaya in the state of Nepal comprises a broad variety of regional climates and mountain-forest types. More than 80% of the annual precipitation is brought by the Indian Summer Monsoon (ISM) between June and September. However, there is a pronounced gradient of decreasing ISM intensity from Southeast to Northwest. In western Nepal, the influence of westerly disturbances in winter is increasing. This general trend is strongly modified by the complex topography. Jumla (2.344 m a.s.l.), Southwest of the main Himalayan crest formed by the Kanjiroba (6883 m) in western Nepal, receives 935 mm of annual rainfall, whereas Mugu, North of the main crest, receives only 583 mm (Donner 1996). In humid areas, the upper treeline is formed by *Abies spectabilis* and *Betula utilis*. In dry regions of the inner Himalaya, *Pinus wallichiana* is found in higher elevations up to 3900 m a.s.l.

The present state of the dendrochronological exploration of the central Himalaya is still fragmentary. Initial collections made in the late 1970s by Rudolf Zuber and other chronologies were first published by Bhattacharyya *et al.* (1992). In a recent study, Cook *et al.* (2003) greatly improve the coverage of tree-ring sites across Nepal. In the frame of a long-term archaeological project in upper Mustang (central Nepal), several chronologies of *Pinus wallichiana* were developed which were supplemented by several hundred wood samples from historic buildings to form a regional master chronology spanning the period 1324-1997 (Schmidt et al. 1999). It could be shown that historic wood samples cross-date well with overlapping chronologies from living trees (Schmidt 1992) and that it is possible to reconstruct periods of house-construction activities and settlement patterns.

Methods

Increment cores from birch, pine and juniper trees were smoothed with razor blades and contrasted with white chalk. Cross-dating was accomplished using TSAP software (Rinn 1996). Standardisation of the chronologies was carried out with the help of the program ARSTAN. Due to the general lack of meteorological data in the region, correlation coefficients between the resulting index chronologies and climate data from Jumla (1957-1990) and the Indian Summer Monsoon Index (calculated as a regional mean over northern India; Pant & Rupa Kumar 1997) were calculated.

Results

Relationships between tree-ring chronologies and climate

Three local chronologies from different tree species from sites close to the upper treeline could be established (Table 1, Fig. 1). Apart from ring width (RW), maximum latewood density (MLD) was measured at the site of Rara at the WSL laboratory at Birmensdorf, Switzerland. The birches at Tschagö La were difficult to crossdate due to missing rings and the occurrence of micro-rings. It is the first chronology derived from this species. The chronologies shown in Figure 1 contain a remarkable common low-frequency signal, especially during the well-known northern-hemispheric cold phases during the 19th century (Briffa et al. 1998).

Table 1: Tree-ring standard chronologies from the Mugu and Dolpo regions

site name	Lat.	Long.	Elev. m. asl	species	no. of trees	length	Chronology	AC1	SNR
Rara RW Rara MLD	29°27'N	82°07'E	3500	*Abies spectabilis*	15	334	1665-1998	0.72 0.72	5.34 2.22
Tschagö La	29°40'N	82°36'E	4020	*Betula utilis*	10	344	1655-1998	0.23	1.26
Samling Gompa	29°26'N	82°54'E	3850	*Pinus wallichiana*	12	324	1675-1998	0.62	5.57

The chronologies have a sufficient replication over the last 300 years. Initial results evaluating their climatological potential are shown in Table 2, where the highest correlation coefficient between the tree-ring series and climatic variables are listed.

Table 2: Highest correlation coefficients between tree-ring series and meteorological data from Jumla and the Indian Summer Monsoon Index (ISM after Pant & Rupa Kumar 1997)

chronology	species	correlation coefficient with climatic variable (Jumla station)	correlation coefficient with ISM
Rara MLD	*Abies spectabilis*	$T_{Sep-Nov}$: 0.77**	0.34*
Rara RW	*Abies spectabilis*	$T_{Nov/py-Jan}$: 0.77**	0.41**
Tschagö La	*Betula utilis*	$T_{Jul/py+Sep/py}$: 0.88**	0.47**
Samling Gompa	*Pinus wallichiana*	$N_{Apr-Sep}$: 0.42*	-0.01

* significant (p<0.05), ** significant (p<0.01)

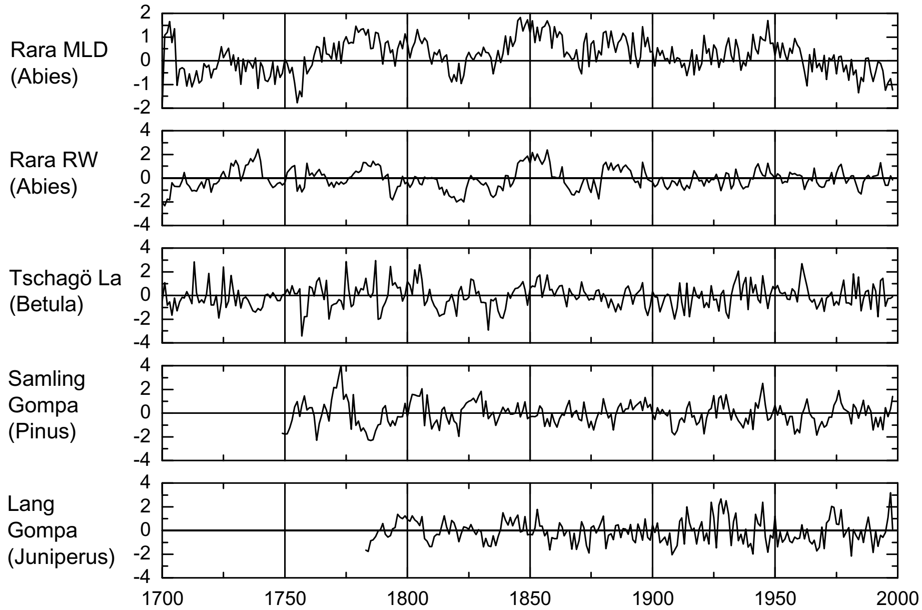

Figure 1: Tree-ring chronologies from high-elevation sites in western Nepal.

However, it must be noted that the temperature data from Jumla only span the period 1977-1986, whereas rainfall data are available from 1957-1990. The Indian Summer Monsoon index represents a regional mean of summer rainfall over northern India.

Ring width of birch is highly correlated with summer temperature of the summer prior to growth (Table 1), whereas ring width of fir is strongly correlated with temperature during the winter before the growing season. This behaviour of the frost-sensitive genus *Abies* has also been found at subalpine sites in southern and eastern Tibet (Bräuning 1999). The interpretation of the statistically highly significant correlation between the Rara MLD chronology and autumn temperature has to be verified physiologically and should be interpreted with some caution. Normally, summer temperature has a significant impact on MLD of fir (Bräuning 1994), but it seems possible that cell-wall thickening can still occur after the monsoon season, when cambial cell division has already ceased. In contrast, the chronology of *Pinus wallichiana* from the dry site in Upper Dolpo is significantly correlated to the local summer rainfall at Jumla, but not to the regional ISM. Nevertheless, as indicated in Table 1, monsoon rainfall has a significant influence on tree growth in the region.

Dating of historic timber

With the help of the Samling Gompa (gompa = monastery, Tibetan) pine chronology, it was possible to date wood samples from historic buildings. One example is shown from the abandoned village “ancient Pö”, located about 15 km Northwest of Samling Gompa. The sample originates from a former farm house or stable that is probably still used periodically as a shelter. Pith and waney edge were preserved and revealed the dates 1775-1946. The position compared to the chronology and the t-values and Gleichläufigkeit (the latter being the coefficient of parallel variation between series) are shown in Fig. 2

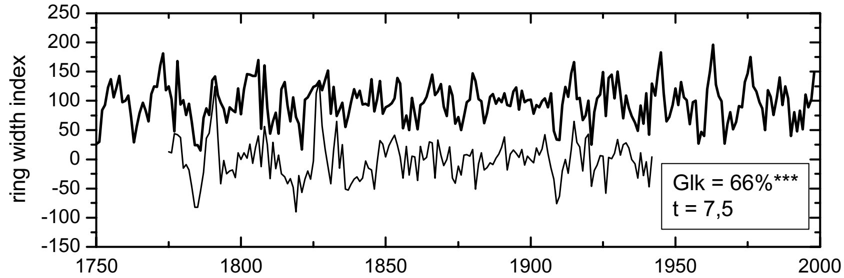

Figure 2: Synchronous position of sample "ancient Pö" and the Samling Gompa pine chronology.

In addition, 15 historic wood samples collected in monasteries within a distance of 20 km could be dated. The chronology for *Pinus wallichiana* for the Upper Dolpo region presently spans the period 1556-1998 (443 years) and could contribute significantly not only to the reconstruction of regional precipitation variations but also to the reconstruction of the regional settlement history, which is unknown to a large extent.

Conclusions

Tree-ring chronologies of different species from high-elevation sites in western Nepal have a great potential for the reconstruction of past climate conditions. Especially drought-sensitive relict stands of the widespread species *Pinus wallichiana* offer the possibility to analyse summer rainfall at the western border region of the Indian Summer Monsoon. The pine chronologies from living trees can be significantly extended by the use of historic timber, since the species has been used for construction purposes in ancient monasteries and civil houses.

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Roots - the hidden key players in estimating the potential of Swiss forests to act as carbon sinks.

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Introduction

The role of root systems in the CO_2 budget of forests is still largely unknown. One of the reasons is doubtlessly the extraordinary effort involved in gathering information about the size and spread of a complete root system of a tree.

In recent years, multifaceted modeling approaches have been developed based on existing data to assess the root spread of different tree species (Adiku *et al.* 1996; Brown *et al.* 1997; Lynch 1997). More recently, models have been developed to estimate root biomass (Cairns *et al.* 1997; Laclau 2002; Vogt *et al.* 1998). The results are ambiguous: they show widely differing percentages of calculated root biomass vs. above-ground biomass. These differences also apply to existing conversion factors that include root biomass into the computation of total biomass.

Possible reasons for these differences are the difficult accessibility of the roots and, more importantly, the varying environmental factors affecting root growth. According to Schmid-Haas & Bachofen (1991), who investigated root systems of uprooted Norway spruce saplings, the radii of these roots depend basically on:

(i) Tree size (positive correlation to breast-height diameter)
(ii) Soil type (negative correlation to soil porosity)
(iii) Stand density (negative correlation to stand density)

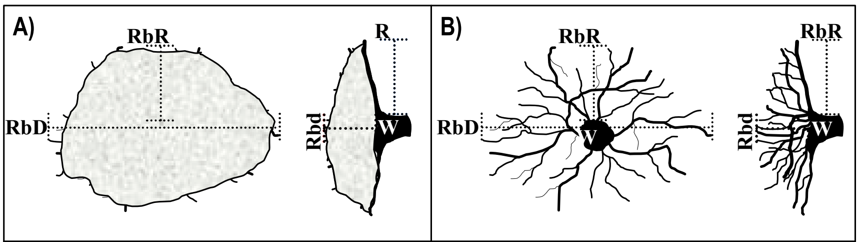
According to this investigation, the variability of the size of root systems (of for example Norway spruce) is very high. However, it should be noted that this investigation did not take into account the coarse roots which remained in the soil. Furthermore, the pH-value of the soil influences the longitudinal growth of roots. The root growth of *Pinus pinaster* showed a reduced longitudinal growth at a pH-value of 3.5 (higher values at pH 6.5), whereas biomass values according to an increased secondary growth are high (Arduini et al. 1996).

The ROOKEY-project (Roots – the hidden key players) at the Swiss Federal Research Institute WSL aims to analyze root systems of wind-thrown European beech (*Fagus sylvatica L.*) and Norway spruce (*Picea abies (L.) Karst.*) saplings, to enable the computation of site-dependant correlations between above-ground and below-ground biomass. There are two main questions to be answered in this project: (i) which role do roots play related to above ground biomass; (ii) is the presently increased growth of trees based on a shift in the relation between above-ground and below-ground biomass? This report concentrates on the role of roots related to above ground biomass.

Material and methods

In the first phase of the project, existing data (root-ball dimensions) of 128 European beech and 129 Norway spruce saplings thrown by the “Lothar” storm-event in the winter of 1999 were analyzed. Next, correlations were calculated between the different root-ball parameters (radius, diameter, depth) and the respective breast-height diameter (dbh) of the stem. In order to enable accurate calculations, all above ground parameters of the trees (height of stem and crown, dbh, age and growth rates) were taken into account.

The disadvantage of this approach is that root-ball data represent the volume of the whole root ball, instead of the volume of the real root system (figure 1). Consequently, the soil has to be removed to analyze the real biomass of the root system. For this reason, the root system of a 120 year old Norway spruce, also thrown in 1999, was exposed to get an impression of the real amount of roots. Unfortunately, all fine roots were decayed and bigger parts of the coarse roots were rotten. The coarse roots could nevertheless be sampled for analysis of the relationship between longitudinal and radial growth of the vertical and horizontal roots.



W = Root collar;: **RbR** = Root-ball radius, **RbD** = root-ball diameter, **Rbd** = root-ball depth

Figure 1: ***A)*** *Measured root-ball data. Root distribution and biomass can only be estimated.* ***B)*** *Real biomass determination can only be done after the removal of the soil*

Additionally, the root systems of 15 naturally-grown European beech and 28 Norway spruce saplings (age: 5 – 10 years) were excavated, and their spread, volume and weight were measured.

In August 2002, a thunderstorm threw a 150-year old European beech in the area of Zürich, Switzerland. The fracture points at the coarse roots around the root ball were rather small, so about 95% of the whole root system was covered in the root ball. The topicality of the event ensured the possibility to expose the coarse as well as the fine roots for biomass calculation. After exposing the whole root system it was cut off and transported in peaces to the lab. Further analyses were based on a 3D grid dividing it into sectors of 30cm (see figure 2 and 3). Currently, roots belonging to each sector are being cut out and their volume and weight are being measured.

Figure 2: Root ball of a 150 year-old beech (A) before and (B) after removing the soil. The root system was cut off (C) to analyze distribution and biomass (D & E) in the lab.

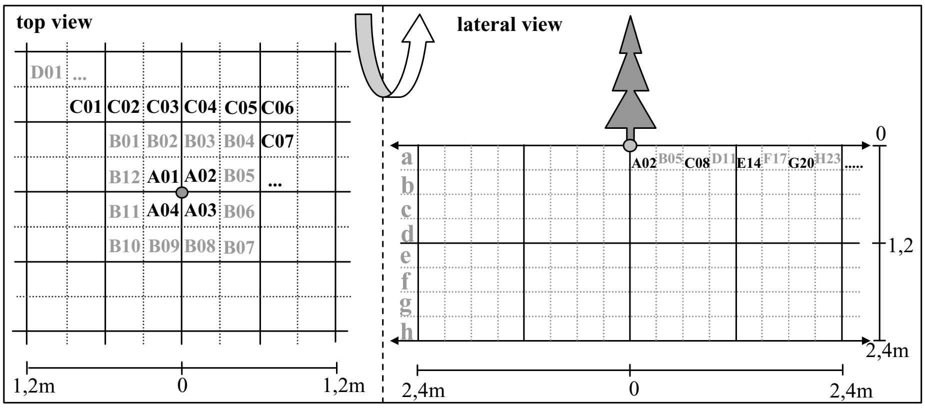


Figure 3: Schematic view of the 3-dimensional grid that is used to document the distribution of the root system in the soil.

Correlations for all trees (no site differentiation) were calculated for the diameter D, the radius R (? D/2, compare figure 1) and the depth of the root balls in relation to two values of dbh. These were measured perpendicular to each other (dbh1 and dbh2), due to unevenly shaped stems.

First results and future work

First analysis of root-ball data in relation to dbh showed highest correlations between dbh and root-ball diameter for all trees of all sites. This is valid for both species, although European Beech showed similar correlations between root-ball radius and dbh (table 1). These differences might be caused by the different shape of the root systems of the two species.

Table 1: Correlation coefficients between different values of dbh and the respective root-ball parameters of Norway spruce and European Beech (no site differentiation). Shaded cells: significance level p < 1% (compare significance levels to the right of the table); bold: highest values; dbh1 and dbh2 are two values of diameter at breast height measured perpendicular to each other for each stem; dbh represents the average of dbh1 and dbh2

SPRUCE	*Th*	*RbD*	*Rbd*	*RbR*	*dbh1*	*dbh2*	*dbh*	
Th	1.00							
RbD	0.12	1.00						
Rbd	0.42	0.02	1.00					
RbR	0.12	0.46	0.09	1.00				n=124
dbh1	0.52	**0.46**	0.30	0.38	1.00			r*95=0.17
dbh2	0.52	**0.44**	0.30	0.34	0.95	1.00		r*99=0.23
dbh	0.53	**0.46**	0.30	0.36	0.99	0.99	1.00	r*99.9=0.3

BEECH	*Th*	*RbD*	*Rbd*	*RbR*	*dbh1*	*dbh2*	*dbh*	
Th	1.00							
RbD	0.24	1.00						
Rbd	0.14	0.14	1.00					
RbR	0.16	0.61	0.15	1.00				n=120
dbh1	0.32	**0.61**	0.34	**0.65**	1.00			r*95=0.17
dbh2	0.33	**0.58**	0.32	**0.63**	0.95	1.00		r*99=0.23
dbh	0.33	**0.60**	0.33	**0.65**	0.99	0.99	1.00	r*99.9=0.3

Th: height of tree; **RbD**: root-ball diameter; **Rbd**: root-ball depth; **RbR**: root-ball radius; **dbh**: diameter at breast height

Correlations are in some cases stronger if they are calculated for single sites, but contrary to the analysis of all sites they are highly variable. The correlation values vary between the different parameters RbD, Rbd and RbR. Furthermore the correlation values are even negative at some sites, which is a strong contrast to the analysis of the values of all sites (table 2).

An additional effect occurred for single site analysis - although the differences in the two dbh-values of each stem were in most cases very low (1 – 2 cm), the resulting correlations were highly variable (table 2). The reason for this variation has to be further analyzed. It could be caused by the differences in age and stem size rather than by inter-site conditions.

Table 2: Examples for variable, site-specific correlation coefficients between different values of dbh (five trees) and the respective root-ball parameters. Variation of dbh1-dbh2 represents the max. difference between the two values for each of the five trees of a site. Shaded cells: explained variance r^2 > 25% (r > 0,5); bold values: significance level p < 5%; italic values: negative values

	Diameter	Depth	Radius	Variation dbh1-dbh2	Species	No.of trees	Site
dbh 1	0.59	0.44	0.78	0 – 1 cm	Norway spruce	5	A
dbh 2	0.59	0.38	0.79				
dbh 1	0.56	0.08	*-0.57*	1 – 2 cm		5	C
dbh 2	0.35	*-0.17*	*-0.70*				
dbh 1	*-0.69*	0.46	0.78	< 2 cm		5	E
dbh 2	*-0.28*	0.01	0.39				
dbh 1	0.22	**0.91**	0.88	0 – 1 cm	European beech	5	B
dbh 2	0.09	**0.92**	0.86				
dbh 1	0.82	*-0.19*	0.07	1 – 2 cm		5	D
dbh 2	0.85	*-0.33*	0				
dbh 1	**0.89**	0.05	*-0.52*	< 2 cm		5	F
dbh 2	0.34	0.65	0.18				

Coherence between root-ball parameters and the value of dbh seems to be obvious, but not strong enough to be used for further calculations. As a consequence, more above ground parameters have to be taken into account and, most importantly, the root system has to be exposed and measured.

Age determination of single horizontal and vertical roots of exposed root systems showed clear differences in the longitudinal growth of the roots, independent of site quality. The necessity to stabilize and support the tree with nutrients causes an increased growth of the horizontal roots in the first years of root system development.

The analysis of the exposed root system of the 150 year-old European beech will be finished in December 2003. The resulting data will be compared to the existing data of root balls measured on the basis of trees thrown by the “Lothar”-event of 1999. In addition, root systems of trees aged 20 – 50 years will be analyzed in 2004 to close the gap between trees aged 10 and 100 - 150 years. Besides for pure biomass determination, these data will be used to verify the assumption that the biomass of whole root system is more strongly related to the age and size of a tree than to (differing) site conditions.

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Dendroecological analysis of vegetation dynamics on abandoned heath lands in the Svabian Jura, southern Germany

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Introduction

The preservation of floristically rich vegetation types of heath landscapes (*Gentiano-Koelerietum*) that evolved during centuries of formerly practised extensive land use as pasture is presently a tremendous problem for nature conservation (Beinlich & Plachter 1995; Schreiber 1997). After abandonment due to economic changes during the last decades, succession processes take place that include the re-immigration of woody species and the gradual displacement of rare herbs. However, the dynamic of these processes can not be satisfactorily documented and analysed by means of plant sociological investigations, since species of former pasture lands mix with invading woody species. Long-term observations or repetitive mapping are not practicable and cost-effective. Furthermore, it has to be considered that the spatial pattern of shrub distribution largely depends on the different distribution strategies of the invading species. The dendroecological analysis of shrubs does not only allow the exact age determination and hence the establishment of all individuals during the process of invasion, but also enables the reconstruction of species-specific propagation patterns.

Material and Methods

The immigration patterns of invasive woody species were analysed on 4 study plots in the valley of the "Grosse Lauter" in the jurrassic limestone mountain area of the Svabian Alb. All study plots have comparable ecological conditions concerning soil conditions (rendzic leptosols) and former land use as pasture. The exact locations of all individuals on the sampling plots were determined and mapped with the help of a Geographic Information System (ARC View). Stem discs of all individuals on each plot were gained by cutting the shrubs at their base. Larger individuals were cored obliquely at a height of 30 cm to reach the oldest annual rings at the base. After drying, the surfaces of the cross sections were smoothed by sanding or by cutting with razor blades and the numbers of annual rings were counted. Additionally, microtome slices were prepared for selected samples (Schweingruber 2001). In total, 719 individuals of 18 woody species (among them 13 tree species) were examined.

Results and interpretation

Species abundancy

To illustrate the differences of spatio-temporal immigration patterns of woody species in relation to the propagation strategy we show the results of two study plots which were primarily dominated by one species. Fig. 1 shows the portion of species contributing to the shrub population on plots A and B, respectively. Plot A is dominated by the zoochorous species juniper (*Juniperus communis*), whereas on plot B blackthorn (*Prunus spinosa*), which is able to propagate by the formation of vegetative runners, dominates.

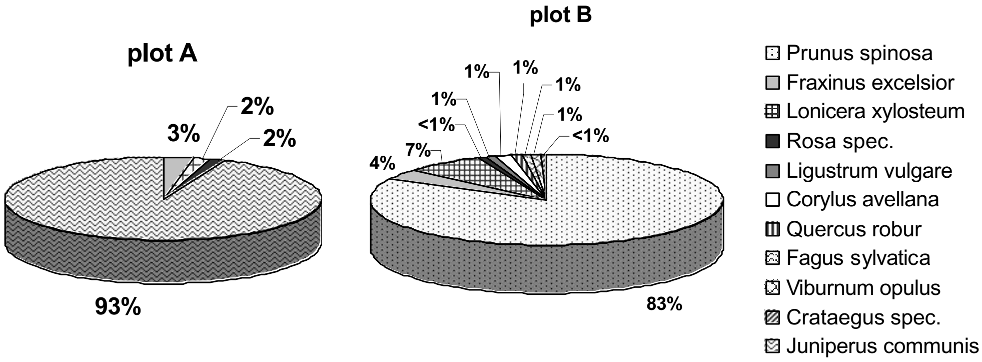

Figure 1: Percentage of different woody species on the shrub population on sampling plots A and B

Plant age and average growth rates

In many cases, the age of a shrub or a tree sapling is only estimated from its height or its diameter. However, the amount of light that a sapling of a light-demanding species receives largely determines the amount of bioproduction and thus the growth rate of the trunk (Table 1). With the exception of *Prunus spinosa* which usually does not occur under extremely shady conditions, the averages of all other species show growth rates of suppressed individuals that amount to between 35 % (juniper) and 18.6 % (ash) of dominant individuals that savour the full sunlight. Fig. 2 shows an example of two young ashes (*Fraxinus excelsior*) of similar size that grew on the open pasture and in the shadow of older trees. As can clearly be seen from Table 1 and Figure 1, the diameter of a trunk can not be used as a reliable estimator of the age of the plant. Careful determination of the real plant age by analyses of the number of annual rings is thus inevitable and the dynamics of vegetation-succession processes are to be studied.

Table 1: Average growth rates of woody species in cm/a of individuals that grew in full light compared with individuals that grew in the shade of older trees or shrubs.

	Prunus spinosa	*Fraxinus excelsior*	*Juniperus communis*	*Picea abies*	*Pinus sylvestris*
growth rate in the shadow	0,08	0,08	0,06	0,10	0,16
growth rate in full light	0,08	0,43	0,17	0,42	0,40

a) b)

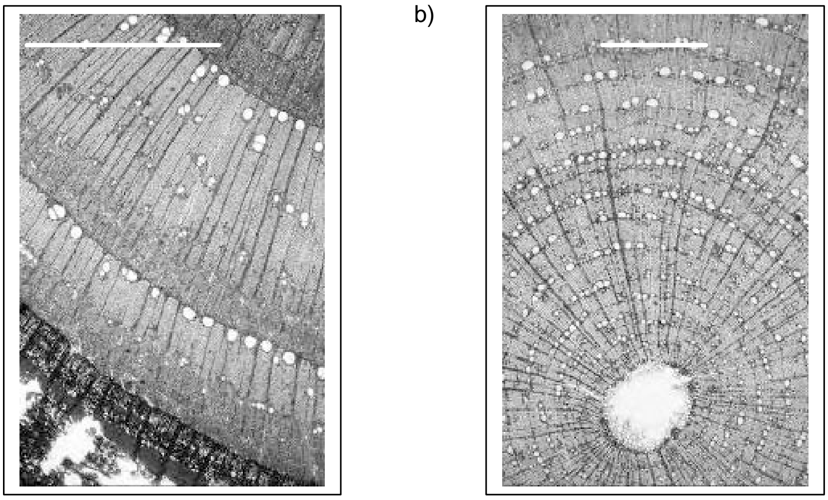

Fig. 2: Microscopic images of ash saplings that were exposed to the full sunlight (a) and that were suppressed by the shade of older trees (b). Individual a) had only 3 rings, whereas individual b) contained 23 rings from the pith to the bark. The length of the white bar in the upper left corner of the photograph represents 5 mm.

Age distribution

The process of dissemination of juniper is illustrated in figures 3 and 5, respectively. During the early stages of the succession, few individuals of juniper are scattered over the plot surface. The dispersion of junipers accelerates after 1972, when the pioneer individuals reach the age of fertility and start to form seeds. The spatial pattern of newly established seedlings is disperse, new individuals mainly establishing in gaps between older individuals, where the light conditions are most favourable. After a period of about 15 years of extensive dispersion, around 1985 the establishment of new individuals drastically decreases. Obviously, the density of shrubs was already too high to allow the germination of additional seedlings of this light-demanding species.

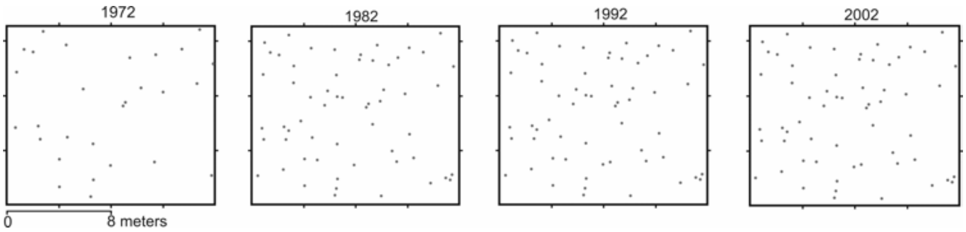

Figure 3: Multitemporal maps of establishment patterns of juniper on study plot A

On the other hand, the establishment of blackthorn starts from a small group of pioneer individuals that obviously has been disseminated by bird dispersal (Figs. 4 and 5). However, the temporal and spatial patterns of dissemination differs from those of juniper. After the young blackthorns reach an age over ca. 15 years, the number of newly established saplings between the pioneer individuals drastically increases. Obviously, these individuals require some years to develop to a stage in which they start to form vegetative runners.

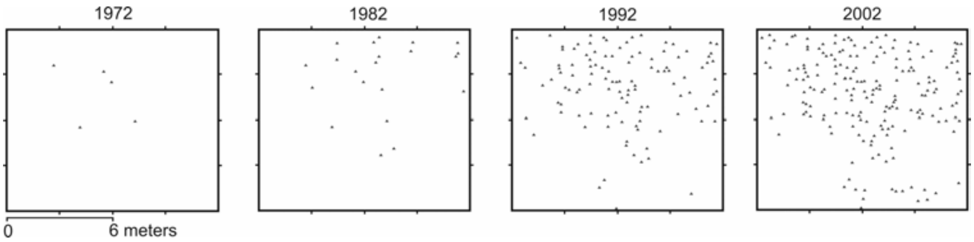

Figure 4: Multitemporal maps of establishment patterns of blackthorn on study plot B

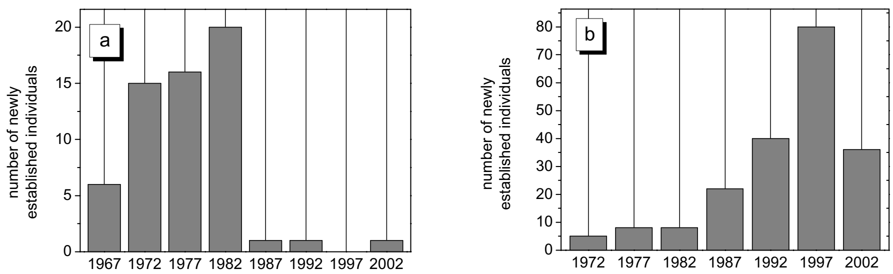

Figure 5: 5- year sums of newly established individuals of juniper (a) and blackthorn (b) on the two investigation plots

Conclusions

The dynamics of secondary succession processes can be studied by dendroecological methods. Different strategies of species propagation (Zoochorie versus Autochorie) can be analysed using the age structure and the spatial distribution patterns of different woody species. In this manner, the spatiotemporal progression of forest succession can be reconstructed.

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SECTION 2

GEOMORPHOLOGY

Past debris-flow activity from tree-ring analysis at the Bruchji torrent, Valais, Switzerland

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Introduction

The aim of the presented work is to reconstruct the frequency of debris-flow events at the cone of the debris-flow torrent Bruchji, Valais, Switzerland. A detailed geomorphic map (1:1'000) of the whole cone was realized in 2001 to get an idea of former flow paths and debris-flow deposits present on the cone. Based on this map all trees which have obviously been influenced by debris-flow activity on the cone were cored. The samples were analysed to determine disturbances in growth that could be related to debris flow activity. To represent common growth variations of each tree species in the area, a reference chronology for each species (*Picea abies* (L.) Karst. and *Larix decidua* Mill.) was established. The samples allowed determination of 39 event years in the past 140 years. By combining the results of tree-ring analyses and geomorphic mapping, the distribution of simultaneously disturbed trees in the same year allowed reconstruction of twelve formerly active flow paths. The results show that the combination of tree-ring analyses and geomorphic mapping is a valuable tool for reconstructing the activity of a debris-flow torrent.

Research area

The village of Blatten/Naters (Valais, Switzerland; Fig. 1) is close to the torrent Bruchji and is threatened by debris flows (e.g., Johnson 1970; Costa 1984; Johnson & Rodine 1984; Pierson & Costa 1987). In the past few years, different debris-flow events led to damage to elements of the infrastructure, such as roads or bridges.

To protect the village, between 1976 and 2002 different counter measures (debris-retention basin, deflection dam and enforcements of the channel) were taken (Municipality of Naters, 2001) without knowledge of the process characteristics at the location.

The chronological data regarding past events at the Bruchji torrent are absolutely insufficient. Debris-flow events are only known to have occurred between 1905 and 1907 and after 1987 (Jossen 2000).

The aim of this study is to reconstruct the activity of the Bruchji torrent as far back in time as possible. A further goal consisted of closing the data gap between 1907 and 1987.

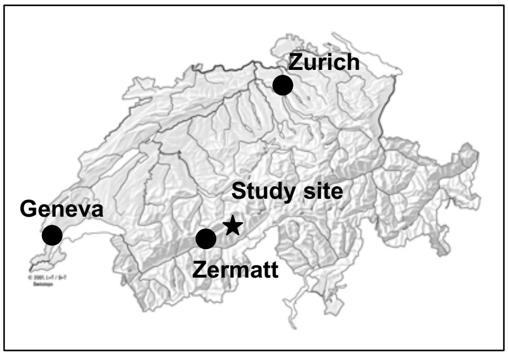

Figure 1: The study site Bruchji (Blatten/Naters) in the Valais, Switzerland.

Material and methods

The first step for this study was the realisation of a detailed geomorphic map of the whole debris-flow cone at a scale of 1:1'000 (Leser & Stäblein 1975). All forms related to debris flows were mapped. This map was used as the basis of the sampling strategy and the analysis of the samples, since the position of a tree within the debris-flow forms shows what kind of reaction can be expected in the wood.

To represent the debris-flow independent growth variations of each species at the location, a reference curve was established (methodology: see Cook & Kairiukstis 1990).

All trees on the cone, which were obviously disturbed by debris flows, were cored. Normally two samples per tree were taken with an increment borer. In total about 800 cores from 398 trees were sampled, of which the majority was *Picea abies* (L.) Karst. and the smaller part *Larix decidua* Mill.. The average age of the trees was about 102 years.

The comparison of the growth curve of the disturbed trees with the reference curve showed growth anomalies that could be related to the influence of a debris flow (e.g., Alestalo 1971; Shroder 1980; Braam *et. al.* 1987).

Results

We established a geomorphic map with all forms related to debris flows. Figure 2 shows a small part of the map with a channel and the lateral levees and some lobes. Most of the forms can be determined on the orographically right side of the cone.

The analysis of the cores allowed us to determine 39 event years in the past 140 years. Figure 3 gives an example for the determination of event years.

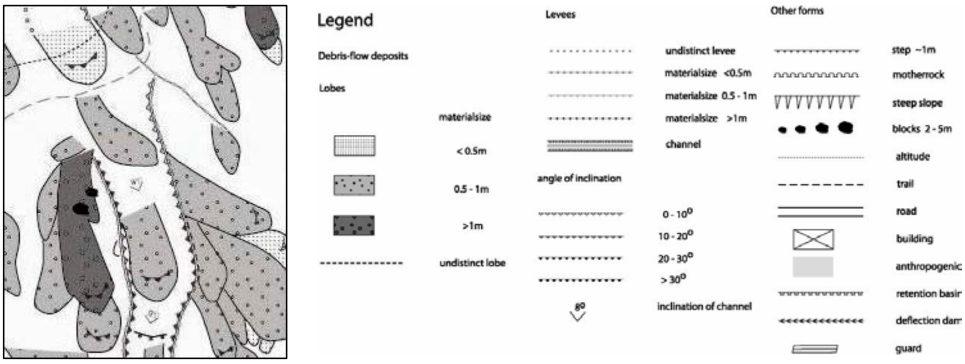

Figure 2: This is a part of the geomorphic map of the debris-flow cone. The symbols for the legend are based on the "Symbolbaukasten zur Kartierung der Phänomene" (Kienholz & Krummenacher 1995) and have been modified by Gärtner (1996, compare also Dikau et al. 1996).

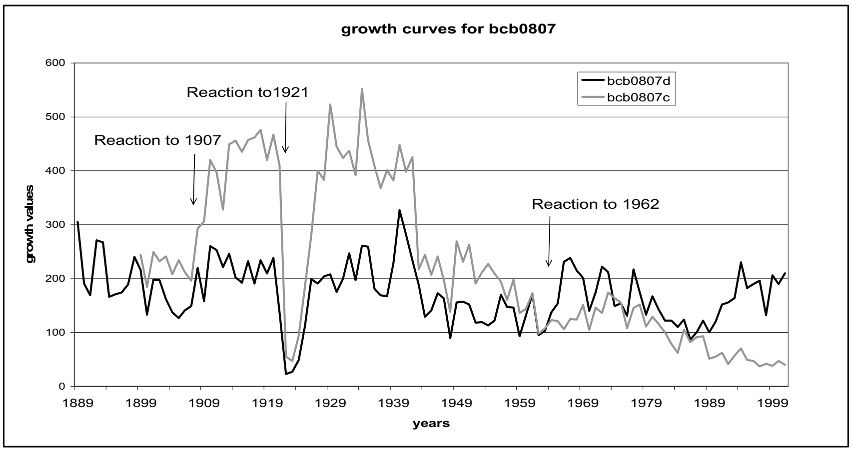

Figure 3: These are the two growth curves for tree No. 0807, where three event years could be identified (1907, 1921 and 1962). The tree shows eccentricity after 1907, a severe growth depression starting in 1921 and eccentricity on the other side after 1962.

Three event years could be identified in this tree. The first one must have taken place in 1907 because the tree starts to show eccentricity and compression wood in 1908. In 1921, rows of traumatic resin ducts are present and the growth curves show a severe growth depression. The eccentricity after 1927 is still caused by the event of 1907. Then suddenly, in 1962, the other side of the tree formed wider year rings. Again, traumatic resin ducts are visible in 1962, so the event must have taken place in this year.

Most of the defined event years have taken place in the twentieth century. This is due to the fact that the majority of the trees is not much older than 100 years. An intensive period with a

lot of debris-flow events can be seen between 1940 and ca. 1960. After 1976, only small-scale events involving a small number of trees could be determined, which can be explained by the protective constructions that have been built between 1976 and 1978.
The combination of dendrogeomorphological analysis and the geomorphic map allowed the elaboration of 12 formerly active flow tracks.

Discussion

The study closed the data gap between 1907 and 1987 by 28 event years. Our data proof that the Bruchji torrent has been active all the time but the debris-flow events have not been recorded.
Furthermore, the study shows that the combination of tree-ring analysis and geomorphic mapping is a valuable tool for reconstructing the activity of a debris-flow torrent. The mapping helped to identify formerly active flow tracks.
It must be taken into account that this study shows only a minimum-frequency for debris-flow events in the Bruchji torrent. Events not leaving the channel or not influencing trees strongly enough, cannot be identified and therefore do not appear in the frequency.
Nevertheless, 39 event years could be established, which makes the combination of dendrogeomorphology and geomorphic mapping a valuable tool for the reconstruction of past debris-flow activity.

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Changes in growth rates and wood anatomy of broad-leaved and coniferous tree species after a landslide event in the Remstal Valley (southern Germany)

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Introduction

On April 7th 2001, a landslide with a volume of 70.000m^3 occurred in the Rems valley nearby Stuttgart (southern Germany), resulting in a vertical sandstone cliff with a width of 240m and a height of 17m. The geological underground consists of marls and sandstones of the middle Keuper formation (upper Trias). The rapid mass movement started in the marls at the slope foot and caused a trench collapse at the middle slope, which points to a high content of pore water. Since the area had been used as garden land, many fruit trees and other planted trees were affected and tilted or even killed. For this study, the area was divided into the landslide area including the affected trees, and a neighbouring reference area carrying undisturbed trees.

The aim of this study was the documentation and examination of typical tree-ring structures like growth changes and wood-anatomical features triggered by the landslide event. Furthermore, the trees were examined for traces of former geomorphic activities, to test whether trees can be used as monitoring organisms for hazard assessment in a potentially endangered area.

The dendrogeomorphological investigation focused on *Picea abies* and *Betula pendula*, since these species are widely available in all parts of the study area. In total, 24 spruces and 18 birches were examined. From each tree, 4 cores were taken in the directions parallel with and perpendicular to the inclination of the slope. In order to be able to distinguish between changes in growth rates that were triggered by either climatic or geomorphological events, climate-growth analyses were carried out on the trees from the reference site to determine the general growth-controlling factors. Reference chronologies from unaffected trees from nearby sites included 9 spruces and 10 birches.

Methods

The surface of the increment cores was smoothed with razor blades, the visual contrast was enhanced by white chalk and ring width was measured to a precision of 0.01mm with a LINTAB II measuring system.

Climate-growth relationships between ring width and climate data were calculated for the trees in the unaffected reference site as Pearson correlation coefficients between ring width chronologies and climate data from the nearest meteorological station of Stuttgart-Echterdingen, which is located about 30km south-west. Abrupt growth changes and pointer

years were determined according to Schweingruber et al. 1990. The decreasing sample size in the older parts of the developed tree-ring chronologies was accounted for by weighting the number of observed abrupt growth changes with the logarithm of the sample size.
The degree of eccentricity of the trunks caused by reaction wood formation was quantified by calculating the ratio of ring width along two different radii which were cored parallel with and perpendicular to the slope (Alestalo 1971). An index of eccentricity was calculated according to the formula given by Braam, Weiss & Burrough (1987):

$$E_i = (RA_i – RC_i) / (RA_i + RC_i) * 100 \qquad (1)$$

where E_i is the eccentricity in year *i*, RA_i is the ring width in year *i* of radius A and RC_i is the ring width in year *i* of radius C, respectively.

In addition, cores of *Picea abies* were investigated for the occurrence of qualitative wood anatomical features like intra-annual density fluctuations, tangential rows of resin ducts and compression wood. Their annual frequency was documented by skeleton plots.

Results

Climate-growth relationships

As shown in Fig. 1, the correlation functions for birch and spruce are similar. Precipitation during the summer season (May to August) has a positive influence on ring width, whereas temperature during this period and during late summer of the year prior to growth is negatively correlated with tree growth. The influence of moisture availability on growth is most noticeable in negative pointer years. The most prominent growth reduction occurred in the well known regional drought year 1976, when the amount of rainfall in June was 82 mm below the mean of 1970-2002. Further growth reductions occurred in 1989, 1991/92, 1998 and 2001. Characteristic release reactions after growth suppressions occurred in 1977, 1993 and 2002.

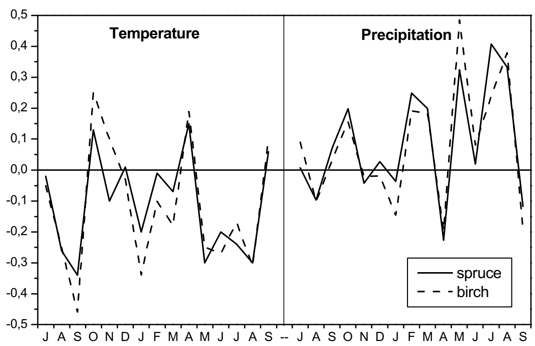

Figure 1: Correlation functions of spruce (Picea abies L. and birch (Betula pendula) ring width index chronologies with monthly means of temperature and precipitation from July of the year prior to growth until September of the year of growth for the 50-year period 1953-2002

Growth reductions and eccentricity of ring width

10 trees (2 birches and 8 spruces) which were affected by the landslide could be examined. In 2001, the year of the landslide, significant reductions in ring-width occurred on the landslide area as well as on the reference plot (Fig. 2). However, whereas more pronounced growth reductions like in 2001 occurred on the reference plots several times before, the landslide caused unprecedented growth suppression in the immediate affected trees. The growth reductions in 1976 and 1989 can be assigned to climatic events (see above). In 2002, the trees on the reference plots and the spruce trees within the landslide area exhibited growth releases, whereas growth suppression still continued in the birch trees of the landslide plot. Thus, growth reductions alone can not be used as an unequivocal indicator of landslide activity.

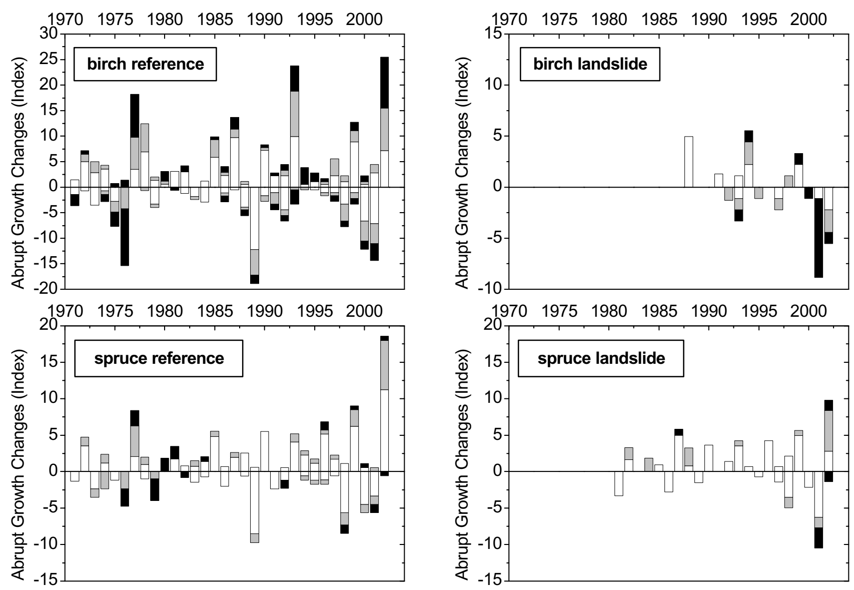

Figure 2: Abrupt growth changes of spruce and birch trees within the reference area and within the landslide area. White, grey and black parts of the columns refer to light, medium and severe growth changes which mean growth suppressions of 40%-55%, 56%-70% and >70% and growth releases of 50%-100%, 101%-200% and >200% in relation to the mean of the previous 5 years (after Schweingruber et al. 1990), respectively.

Unexpectedly, the eccentricity method did not deliver definite results. Only some of the disturbed trees show a change of the eccentricity level in 2001. Before 2001, no high eccentricity indices occur, which points to the absence of comparable landslide events before 2001. One reason for the even distribution of the eccentricity level may be the continuous process of hill creeping that occurs in the clayey soils of the study area, which causes a high "background noise" from which overlain signals caused by landslides cannot be clearly distinguished (Schmid & Schweingruber, 1995).

Wood anatomical features

Compression wood was formed in 25% of all affected spruce trees in 2001 and in more than 50% of all spruce trees in 2002 as an unequivocal reaction to the impact of the landslide (Fig. 3). However, an increase of compression wood in 2002 is also found in the reference area. This means that the site was not stable and was also affected by geomorphic activity, even though to a smaller degree than the landslide area proper. This could be caused by the high amount of precipitation in the years 2001 and 2002, when annual rainfall was 180 mm and 390 mm above the long term mean, respectively. The abundant moisture could have caused an intensification of soil creeping activity which may have led to an increased formation of compression wood. Although a significant statistical correlation between higher precipitation rates and the occurrence of compression wood can not be observed, an influence of the higher rainfall amounts in the preceding years on the increase of the pore water content in the affected slopes must be assumed. No significant periods of reaction-wood formation can be found in the tilted trees before 2001.

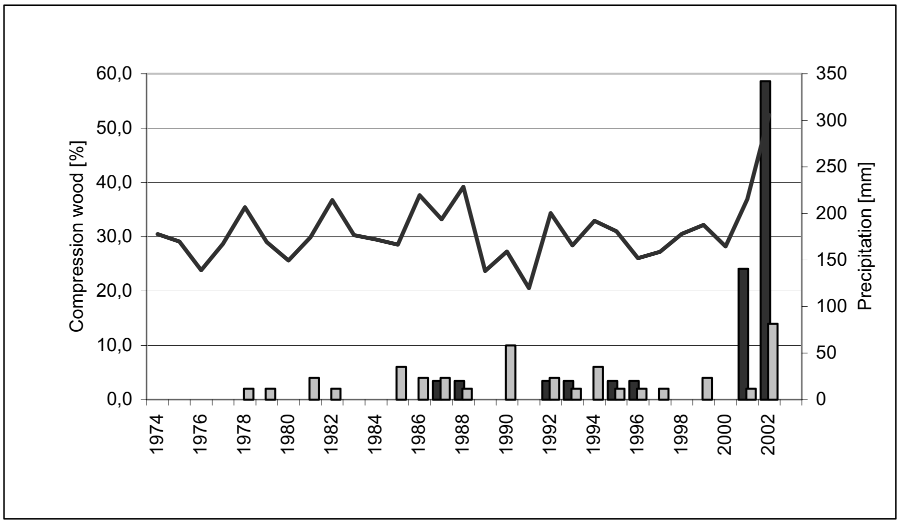

Figure 3: Annual frequency of compression wood formation in spruce trees of the sites that were affected (black bars) and unaffected (grey bars) by the landslide of 2001. The black line shows means of summer rainfall (May-August).

The annual portion of trees that show the formation of tangential resin ducts usually amounts to 10% to 15% in the landslide area as well as in the reference area (without graph). This shows that both areas are affected by continuous geomorphic activity. In 2001, however, 40% of all trees in the landslide area and 25% of all trees in the reference area exhibit this feature. In the years 1990 and 1993, 30% of the trees in the landslide area produced tangential resin ducts, compared to about 10% of the trees in the control plot. However, this finding could not be clearly assigned to a certain triggering event, since annual rainfall was not enhanced in one of these years (Fig. 3).

Conclusions

It was not possible to detect former landslide activities in the study area. Since landslides of the amplitude like the one that occurred in April 2001 are rare events in the study region, it is very likely that prior to 2001 no such event had ever taken place during the lifetime of the investigated trees, which only covered the past 30 years.

The landslide event of 2001 is clearly documented in qualitative and quantitative features of the disturbed trees. Thus, the possibility to use trees as monitoring organisms for geomorphological processes (Schweingruber 1996) can be confirmed. However, due to the continuous slope activity on the clayey soils in the study area which forms a continuous background signal influencing the formation of reaction wood, a combination of wood anatomical features and abrupt growth changes is needed to verify unambiguously the nature of the triggering factors. Since the reference plot is situated on the same geological situation in the vicinity of the landslide, the trees on the reference plot are also affected by geomorphic activity which reduces the suitability of the plot to act as a true reference in the proper sense. To distinguish between growth reductions caused by geomorphologic activity and climatic singularities, a thorough study of climate-growth relationships with trees from a neighbouring, unaffected control site is necessary. The reconstruction of the frequency of landslides in a certain area could allow an improved estimation of hazard risks.

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Tree rings and Geomorphological Processes in a Mountainous Region (French Alps)

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Introduction

Mass movements on slopes are regularly observed in mountainous regions. Assessment of mass movement hazard risks requires, besides the spatial mapping of endangered zones, insight in the temporal character of related processes. In many regions information about these temporal aspects is not available. However, information about frequency, magnitude and duration of mass movement processes is needed to reliably forecast possible future changes.

Our research concentrated on tree ring- and tree stem characteristics in relation to the periodicity of recent and formerly active landforms: landslides, hill slope debris flows and a sub-recent active rockglacier.

Survey Area

The survey area lies in the Southern French Alps, about 100 km northwest of Nice (Fig.1.). Fieldwork was done by students of the Department of Physical Geography in the central and eastern parts of the Ubaye valley and surroundings. Altitudes vary from 1100 m to peaks exceeding 3000 m. The tree line is found between 2000 m to 2400 m and is strongly affected by man in many locations. In many cases the tree line is situated about 200 m below the natural tree line. Lithology varies from very unstable thick series of black marls to hard sandstones, limestones, dolomites and quartzite's. Climate has a mountainous character with Mediterranean influence. Precipitation peaks are found in spring and autumn, but also heavy rainy summer storms can occur. The trees are relative young, mostly 100-150 years old. On isolated places trees of more than 700 yrs can be found. At the highest elevation of the tree line, Swiss stone pine and European Larch grow. Towards lower levels Mountain pine and Scotch pine are found. Most study areas are positioned near the tree line at about 2000 m.

In the Rioux de Bourdoux drainage basin, northwest of Barcelonnette (Fig. 1), a complex of active landslides in highly erodable marls overlain by moraine deposits was investigated on periodic movement patterns. The drainage basin was strongly deforested by man at the end of the 19th century, but reforested up to 2200 m in the 20th century. Common species are Scotch pine in the lower parts and European Larch and Mountain pine on the higher parts. At three landslide locations (A, B and C, Fig 3), between 1200 and 2000 m, tree ring eccentricity was measured. For comparison location D was chosen on a relative stable slope without moving parts (Braam et al. 1987a; Weiss, 1988).

Figure 1: Location of study areas

Hill slope debris flows coming from above the tree line were studied on their frequency patterns in the drainage basin of the river Bachelard (Fig. 1). Larch trees growing in the deposition zone are in many cases affected by strong mechanical forces. The result can be tilting, bark damage, burial and nudation. Undisturbed trees can give a minimum date for the age of flow deposits.

Detailed investigations on the dynamics of debris flows took place south of the small village Bayasse (Blijenberg 1996; Overbeek & Wiersma 1996). Five deposition zones with 117 debris flows were selected for geomorphological investigations and dating.

In the Tronchet valley of the Parc Naturel Regional du Queyras (Fig. 1) a nowadays-inactive rockglacier was studied (Meijer & Wils 2001). Recent living trees were used to date the moment the rockglacier became inactive.

The rockglacier is situated at about 2450 m with its lowest point at 2400 m. Active parts of rockglaciers in the vicinity are reported at 2600 m (Assier 1996). Glacier relics in the direct environment are found at 2500 m (Pics de la Font Sancte).

Dendrogeomorphological Concepts

Dendrogeomorphology studies the relation between active or inactive landforms, tree form and tree ring patterns, generally on a local scale.

Besides the general concepts of dendrochronology (Fritts 1976), the concept of process-event-response systems in relation to tree growth and geomorphological environment was formulated (Alestalo 1971; Shroder 1986).

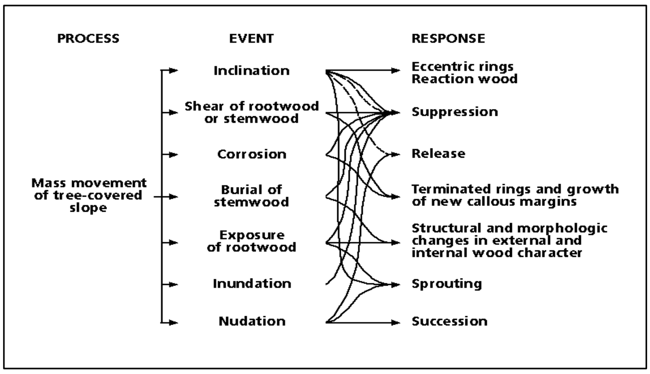

Figure 2: Process-event-response model between geomorphic processes and tree growth (after Shroder 1986)

Geomorphological processes can produce several basic events and processes on trees as shown in Figure 2.

On dynamic hill slopes, inclination, corrasion and nudation were factors that mostly act on trees. Tilting is a most frequent and obvious phenomenon in mass movement areas. Stem form and ring eccentricity combined with compression wood can help to decipher the temporal pattern of mass movements.

Methods

This study concentrates mainly on trees with stem deformation and eccentricity ring patterns to detect periodic characteristics of gravitational surface processes. Braam et al. 1987a,b describes several tree stem forms in relation to mass movements. These forms are a first indication of movement and movement history.

A more precise dating of tilting can be inferred from the patterns of eccentricity pattern and reaction wood. In conifers reaction wood is formed as compression wood on the lower side of the tilted tree. A relation between tree characteristics and landform must be clear when used as an indication for mass movements. Many other factors such as wind stress and avalanches can also result in eccentricity.

Eccentricity is best described and calculated by comparing several radii in cross sections. In most cases this is not possible or desirable. Eccentricity is then calculated from several increment cores: one in the tilting direction (*rA*) and one perpendicular to it (*rB*). More extreme degrees of eccentricity occur in opposing radii but then the problem of many missing rings can arise.

Eccentricity for year *i* is computed according to: $E_i = \frac{rA_i - rB_i}{rA_i + rB_i} * 100\%$

The beginning of a mass movement is indicated by a jump in the eccentricity level and is calculated by a simple filter technique of the running means in a split-moving window. Significant jumps are determined with a t-test at a 0.01 confidence level.

After synchronizing the trees-ring series, significant responses are expressed by an index. A high index means that many investigated trees have a response in the same year. Finally a response curve can be constructed. Periods with index peaks point to possible active mass movements. Periodicity of movement was estimated by constructing power spectra of the index series (Braam et al. 1987a).

In case of debris flow studies, eccentricity of tree rings can be used as indicator for dynamic flows after 5-10 years. Colonization time of minimum age trees appears to be only a few years. Not all debris flows have trees with movement indication or probably, some trees are not affected. In those cases, if possible, lichens are used to date the flows. Where lichens and trees exist together on debris flows, the age of the lichens can be related to characteristics of trees concerning age, ring eccentricity, growth suppression and date of bark damage. Lichens also date flows without trees, especially the higher positioned parts of debris flows above the tree line.

Results

Frequency of Landslides in the Rioux Bourdoux Drainage basin

A period of about 100 years, given by the age of the trees, could be studied. The index time series of eccentricity for two larger slides (A and B) is based on about 20 synchronized trees, that for a smaller one (C) is based on 6 trees (Fig. 3).

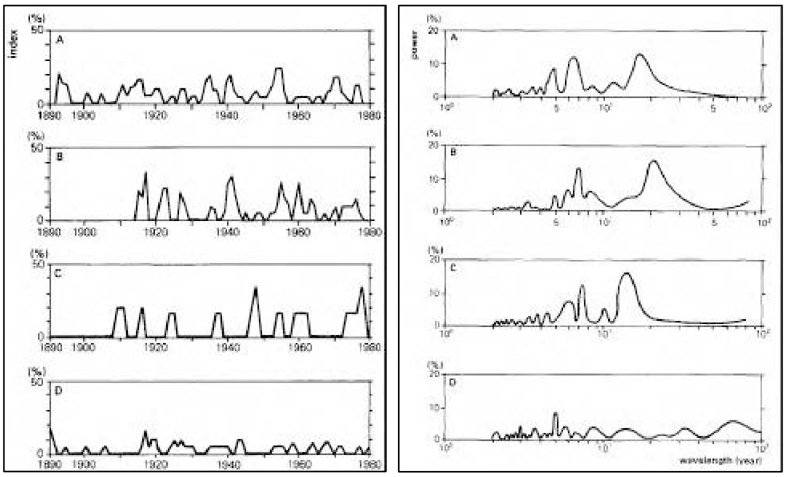

Figure 3: Index time series and power spectra at 4 locations in the Rioux Bourdoux Basin

The eccentricity series on the active landslides A, B and C show clear response peaks with rather regular periods. In contrast, trees on the stable slope show no relevant index peaks.
Typical wavelengths in the power spectra are different for each landslide. It seems that periodic components are related to specific internal variables such as type of bedrock, slope, hydrology and erosion at the foot of the slope. Direct relationship between landslide activity and precipitation could not be proven, however rainfall can be a trigger factor. From the analyses, no relation was found between the maturing forest and an in- or decrease in intensity or frequency of mass movement.

Frequency of hill slope debris flows in the Bachelard drainage basin

Of 117 mapped flow deposits, south of Bayasse, 21 could be dated by tree age, suppression of ring width, ring eccentricity, or date of stem damage (Blijenberg 1998).
The maximum age of the larch trees on the investigated flows is 50 to 70 years. Individual trees on flows show mostly 1 to 2 significant responses.
As trees growing on debris flows above the tree line are sparse and absent, lichens were also used for dating. From observations it seemed that the colonization time (ecesis) of trees and lichens on debris flows is different. For (larch) trees a period of 5-10 years and for lichens 15-20 years was found (fig.4).
The temporal pattern of debris flows from the five trigger zones is demonstrated in Figure 4. In the graphs some degree of relationship in activity periods can be seen. The number of useable trees for dating is relatively low. Many debris flows are treeless or are not colonized by lichens. This means that the number of debris flows in an active period can be larger. Nevertheless clear periods of strong debris flow activity can be distinguished in the late forties to early fifties and in the late sixties to mid seventies (Fig. 4). Deposits before 1940 are most likely to be buried by more recent ones. More recent debris flows after the mid seventies could only be dated if they had influenced tree growth. Lichens could not be used as they are yet in their colonization period.

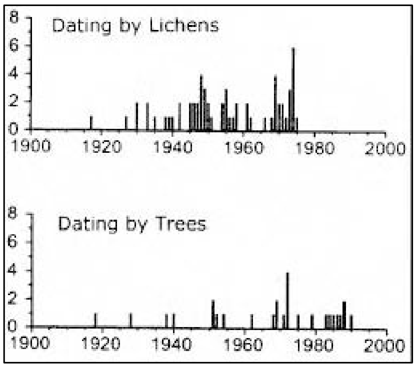

Figure 4: Temporal distribution of debris flows at 5 locations south-east of Bayasse in the Bachelard Valley (after Blijenberg 1998)

The event frequency per year for the five trigger zones indicates a relation between frequency and size of trigger area. However, no clear and significant relation was found with monthly precipitation data. Field observations showed the beginning of debris flows in this area within 5-10 minutes after the start of very high intensive rainfall of 50-100 mm/hr. Flow velocities of 3 – 10 m/s were measured.

Periodicity analysis of response curves of the above mentioned area and other areas in the Bachelard valley indicate several peaks in wavelength of years (Fig.5). Three areas showed a remarkable peak around 11 years (De Redelijkheid 1988).

However the data is too scarce to be of statistical significance for a climatological interpretation. No relation with data of the nearest climate station was found.

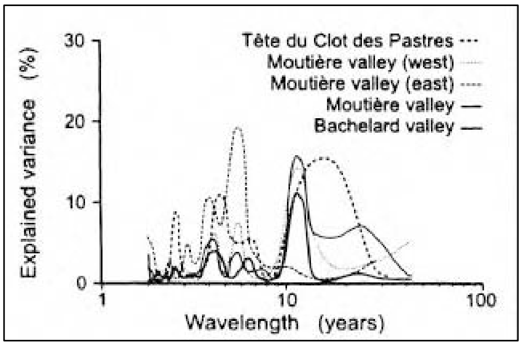

Figure 5: Periodicity of debris-flows in the Bachelard valley (after De Redelijkheid 1988)

Stabilizing phase of a rockglacier

Surface forms of the studied rockglacier show fresh sharp ridges and clear boundaries, sparsely vegetated by grasses, shrubs and a few larches. These observations of fresh forms seem to indicate that the rockglacier became inactive recently. This interpretation implies that the moment of inactivation can be dated using the oldest tree on it, corrected for missing rings, colonization delay and response time of the rockglacier.

The oldest tree counted 81 rings. Nine missing rings were identified by crossdating and by extrapolation of the ring width series to the tree's pith at ground level. Colonization delay was estimated 20-30 years (based on McCarthy & Luckman, 1993; Winchester & Harrison, 2000). Response time was also estimated 20-30 years (Barsch, 1996). Hence, inactivation of the rockglacier was dated between 1850/1870.

Inactivation of rockglaciers occurs when the mean annual air temperature (MAAT) exceeds -2° C (Barsch 1996). The MAAT is known from the neighbouring village Ceillac at 1665 m. The MAAT for the rockglacier can be calculated with the specific temperature gradient for the Alps. The difference between the inactivation temperature of -2° C and the recent MAAT yields a temperature change of +3° C since about 1850, the end of the Little Ice Age.

This reconstructed temperature increase of 3° C seems extremely high in comparison with the same kind of data (Grove, 1988). Possibly the rockglacier was only cleared of vegetation in the Little Ice Age and afterwards it was revegetated.
However, compared with the MAAT change in Ceillac over the last 40 years (1.5 to 2° C) the calculated value could be realistic over the time span in question (125 years).

Conclusions

Analysis of tree rings of trees on active landforms may enhance the understanding the dynamics of mass movement. Understanding development of landforms using tree ring eccentricity can only be successful with a good analysis of the terrain characteristics and verification with data not based on tree rings.
Weather condition is one of many trigger factors in mass movement development. However, monthly and yearly data from local climate stations are not sufficient to explain the short-term dynamics of landforms in the studied area.
Long-term climatic developments can be sustained by tree-ring dating of rockglaciers.

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SECTION 3

CLIMATOLOGY

Temporal and spatial variability of tree growth in mountain-forest steppe in Central Asia

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Introduction

A network of 140 tree-ring sites in the mountain regions of Central Asia and the low-land regions of Flat Altai and Khakasia (Fig. 1) was established between 1994 and 2002. It is suggested that southern Siberia and Mongolia form an important region in Central Asia. Due to the extreme continental climate conditions, forest is restricted to small areas and climate changes may have a high influence on the distribution of the forest. Also several big Siberian rivers (e.g., Ob, Yenisey, and Selenge) have their headwaters in these mountain ranges.

These regions are covered by different types of forest. The low-land areas of Flat Altai and Khakasia are covered by forest steppe, the intramountainous basins of Mountain Altai, the southern part of Tannu-Ola mountains and the mountain areas of Mongolia by mountain forest steppe and the upper tree line ecotones of Mountain Altay and Sayan mountains and the northern part of Tannu-Ola mountains by light taiga (Fig. 2a-c).

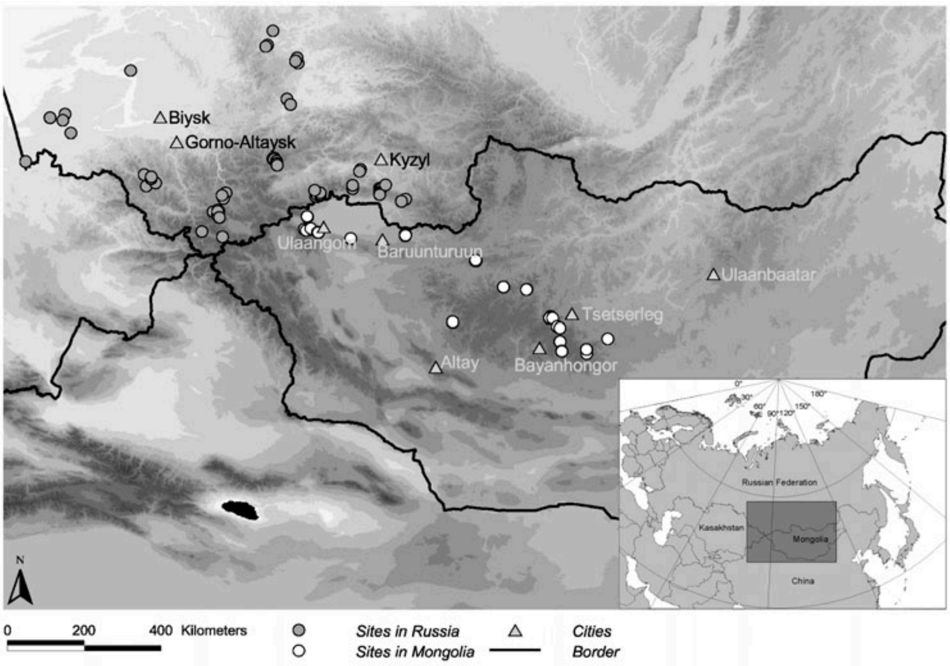

Figure 1: Overview map of sampled sites in Central Asia

The upper tree line is situated at 2200 m a.s.l. in Tannu-Ola and Sayan, at 2400 m a.s.l. in the Altai Mountains and Western Mongolia and up to 2700 m a.s.l. in Central Mongolia. In regions with mountain forest steppe in Mongolia, Tannu-Ola, Sayan and in the intramountainous basins in Mountain Altai a lower tree line is formed at an elevation of 1400 to 2100 m a.s.l. Fire is an important ecosystem factor in the whole region, with higher fire frequency in the locally more dry areas.

Figure 2: a) Landscape in central part of Mountain Altai. b) Typical landscape in Central Tannu-Ola mountains in Tuva. c) Mountain forest steppe landscape in Northwest Mongolia.

Material and Methods

Primarily typical and homogenous upper and lower timberline sites and sites in forest-steppe ecotones were selected. Cores and disks were taken from Siberian Larch (*Larix sibirica* Ledeb.), Siberian Pine (*Pinus sibirica* Du Tour) and Scots Pine (*Pinus sylvestris* L.) in Mountain Altai, Flat Altai, Khakasia, Western Sayan, Tannu-Ola (Russia), Turgen-Kharkhiraa, Khan-Khokhiyn and Khangai mountains (Mongolia).

Samples were prepared (cores and disks), tree-ring width was measured, and site and regional chronologies were built in accordance to dendrochronological methods as described by Fritts (1976), Cook and Kairiukstis (1990), Schweingruber (1996) and others, by using TSAP, COFECHA and ARSTAN.

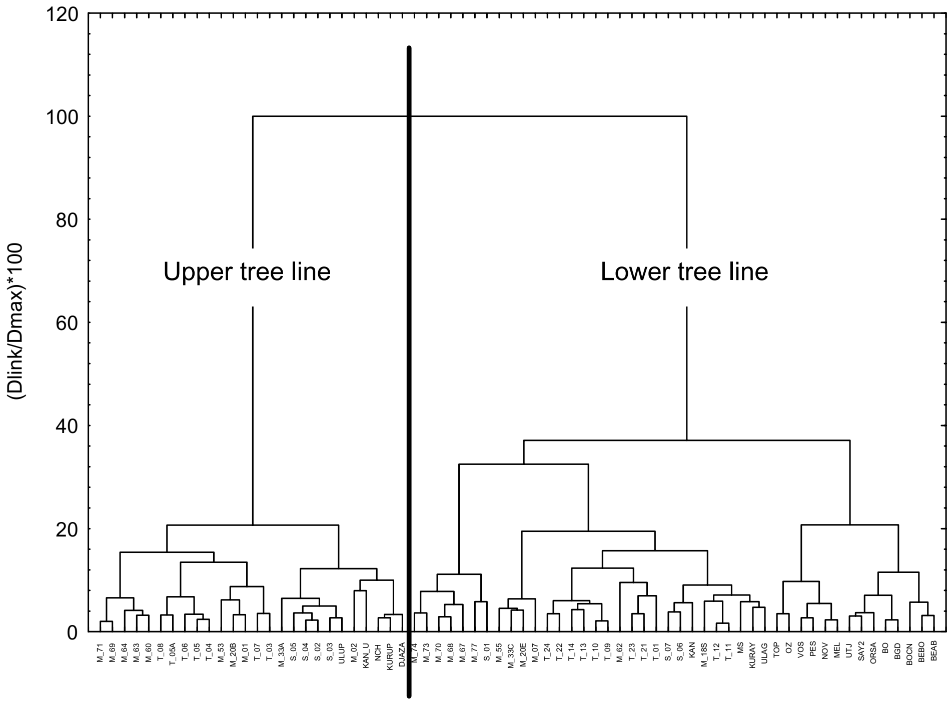

Figure 3: Tree Diagram (Ward's method, 1-Pearson r) for the last 100 years for selected sites, shown in the map in Fig 1. Upper timberline sites (left) and lower timberline sites (right) fall to two different groups.

Cluster analysis was used for the analyses of spatial patterns (Fig. 3), stepwise cluster analysis (Fig. 6) and moving correlations (Fig. 4) were used to define temporal patterns, and response functions, factor analysis (Fig. 7) and other statistical methods were used to understand the reactions of the trees to the environmental factors.

Results

The results of cluster analysis for the last 100 years show two well defined groups for the upper and lower tree-line sites (Fig. 3), but clear groups become weaker if the whole chronologies are used for clustering. In many periods pointer years of upper and lower tree line sites are inverse, so a negative pointer year at upper sites coincides with a positive pointer year at lower tree line sites, and vice-versa. But in some cases during some periods, pointer years at upper and lower tree line sites coincide.

Figure 4: Moving correlations between upper and lower tree-line sites in the Mountain Altai region.

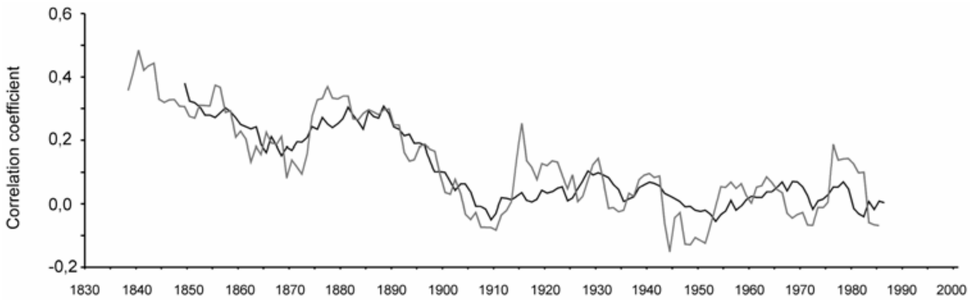

Figure 5: Moving correlations between upper and lower tree-line sites from Fig. 4 (grey) and reconstructed moving correlations, calculated by the summer temperature of the Barnaul meteo station (black line).

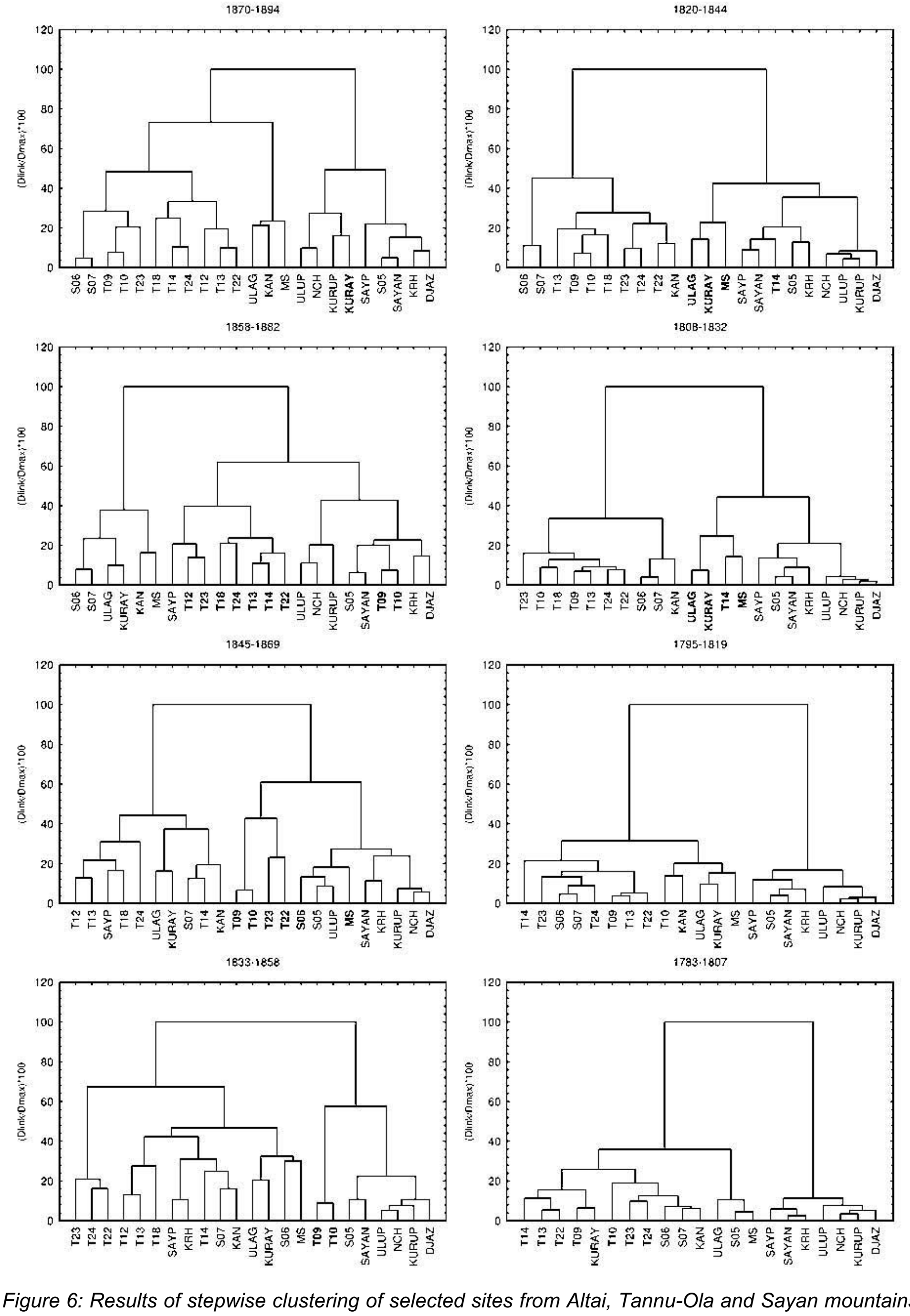

Figure 6: Results of stepwise clustering of selected sites from Altai, Tannu-Ola and Sayan mountains for 25-year periods with an overlap of 12 years. "Jumping" sites are marked.

Moving correlations in a 25-year window were calculated to study temporal variability. These moving correlations show different periods with positive, negative and approximately zero correlations (Fig. 4).
In addition to cluster analyses based on the entire chronologies, stepwise cluster analysis with a 25-year window and 12-year overlap were calculated for the last 300 years. Stepwise clustering shows periods when some sites from the group of lower tree line switch to the group of upper tree line ("jumping" sites in Fig. 6).

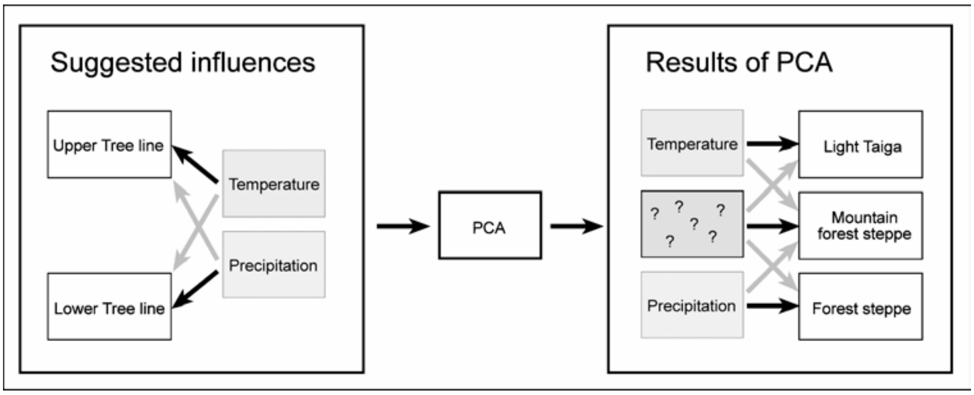

Figure 7: Suggested influences of environmental factors to tree growth and results of factor analysis (black arrows = primary factors, grey arrows = secondary factors).

Conclusion

We considered results from moving correlations as well as from stepwise cluster analysis and examination of extreme values as evidence of changing climatic conditions. We hypothesize that at the lower tree line during cooler periods the influence of temperature on tree growth increases. This means that upper and lower tree line-sites are reacting synchronously during such time periods, which leads to higher correlations. Distributions of extreme values and moving correlations support this hypothesis. The variance of moving correlations explained by summer temperature is quite high. As proof for dependence of moving correlations from temperature, we reconstructed moving correlations with the summer temperatures of Barnaul meteo station, using regression models. The good agreement is evident in Figure 5. Moving correlations as well as extreme values clearly show the known cool period in the middle of 19th century.

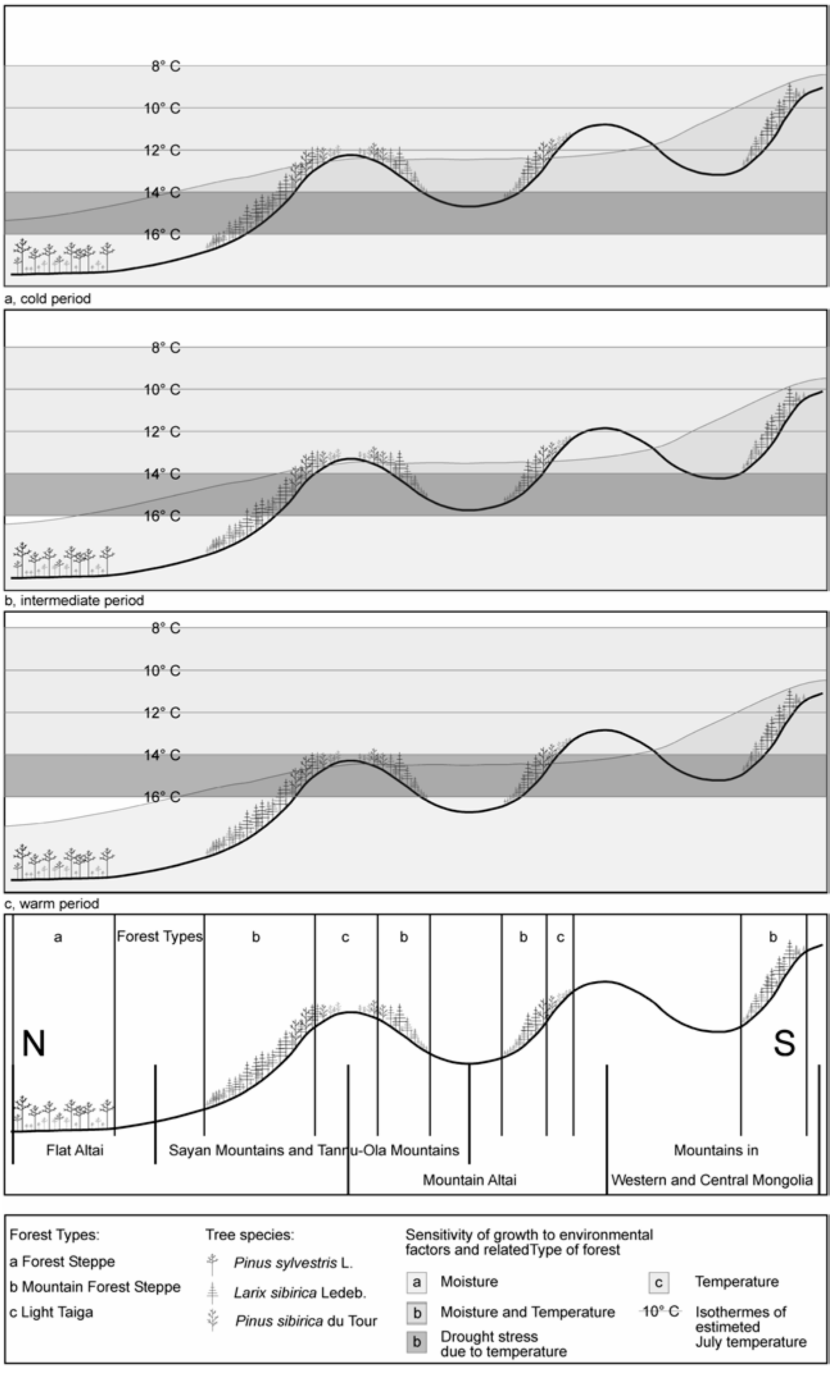

Figure 8: Forest types and forest distribution in the northern part of Central Asia and the influence of temperature and precipitation on tree growth in (a) cold, (b) intermediate and (c) warm periods.

Trees of the mountain forest steppe always have a mixed signal of temperature and precipitation; even trees of the upper tree line sites react to precipitation. Using factor analysis, we found another - still unknown – factor that explains a very high percentage of the chronologies variance (Fig. 7). These results explain why response function analyses using climate data do not always give satisfactory results.

On the basis of this study we were able to develop a classification for the forests in Central Asia using dendrochronological methods, yielding the same results as geobotanical studies. The light taiga shows a temperature signal, the forest steppe a precipitation signal and the mountain forest steppe a mixed signal. The schematic profile across the mountains in Fig. 8 shows these results. The model can also explain the temporal variability of temperature influence.

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The first principal component of a high-elevation ring-width network from the western and central Alps

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Introduction

Tree-ring data play a vital role in assessing climate variability prior to the instrumental time period. Relying upon the expected temperature sensitivity of high-elevation tree sites, we have compiled a multi-species network of 53 ring-width sites from the central and western-European Alps with the objective of reconstructing regional temperature variations.

Material

Data contributions from P. Bebi, W. Elling, H. Fritts, W. Huesken, B. Neuwirth, R. Niederer, C. Rolland, F. Schweingruber, F. Serre, and L. Tessier were incorporated into the network and are gratefully acknowledged. All sites are from elevations at or above 1500 m a.s.l. The network is composed of four species: *Picea abies*, *Abies alba*, *Larix decidua* and *Pinus cembra* (herein abbreviated as PCAB, ABAL, LADE & PICE, respectively), with PCAB being highly dominant and ABAL being well represented although concentrated in the southern and western parts of the network.

Methods

Site chronologies were made by using an adaptive power-transform to stabilize the variance of the raw ring-width data (Cook and Peters 1997). Age trends were then removed by taking residuals from 300-year splines (Fritts 1976; Cook 1985). The detrended series were averaged on a site-by-site basis and the site chronologies truncated at a minimum of 5 series. Principal components (PC's) of the 45 of 53 chronologies sharing the 1850-1973 common period were computed. In Principal Components Analysis (e.g., Peters et al. 1981), as done here, the variance of the correlated variables (chronologies) is expressed in terms of new uncorrelated variables (PC's), where the first PC is defined to explain the maximum amount of variance possible, and each successive PC explaining less and less variance. At a minimum, the 1st PC explains more variance than any of the initial variables (chronologies). Factor loadings of the initial variables (chronologies) onto a PC represent their correlation or common variance with this PC.

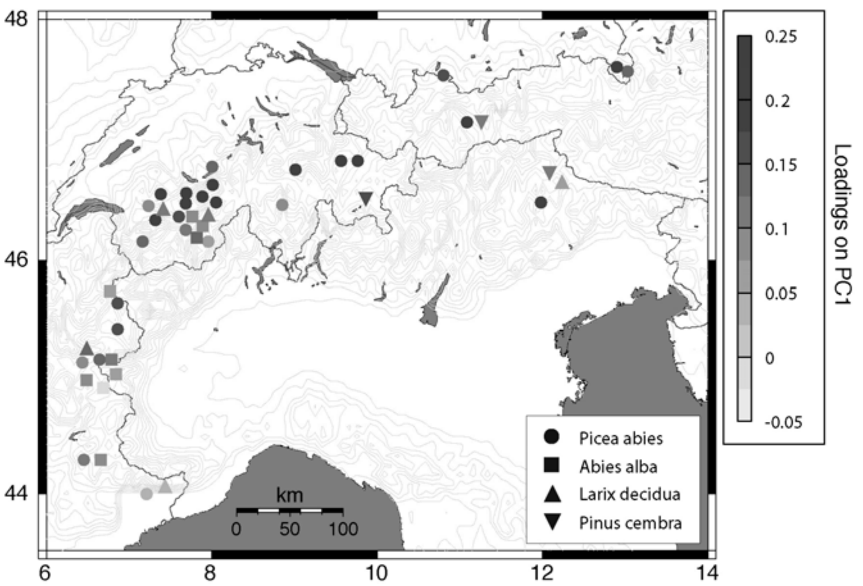

Figure 1: Factor loadings of chronologies on the 1st PC.

Results and interpretation

The 1st principal component explains 20% of the network's variance. All chronologies (except for a single ABAL site) have positive loadings on this PC (Fig. 1), indicating that this component represents a common dominant signal across the network. Chronology loadings on this PC seem to be related to the species (and perhaps their prevalence within the network) and their geographical location. Highest loadings tend to occur in southwestern Switzerland where the most dense concentration of chronologies exists. These high correlations extend to fairly great distances eastward along the alpine arc, but diminish more rapidly southward towards the more Mediterranean influenced portion of the network. The PCAB, LADE and PICE chronologies tend to have higher loadings, whereas the ABAL chronologies, in general, have lower loadings. Part of the tendency for the lower ABAL loadings can be explained by their concentration towards the southwestern portion of the network, where generally lower loadings from PCAB and LADE occur as well. However, the low loadings of ABAL, that even occur within the dense concentration of chronologies in southwestern Switzerland, suggests that this species displays a more unique signal than PCAB, LADE and PICE.

To assess the common climatic forcing captured by this principal component, comparisons with temperature data were expected to be (and were) relevant. Correlations over the 1850-1973 period were computed between this first PC and monthly temperature data from a single high-elevation grid point (47°N, 9°E) from the Böhm et al. (2001) dataset (Fig. 2).

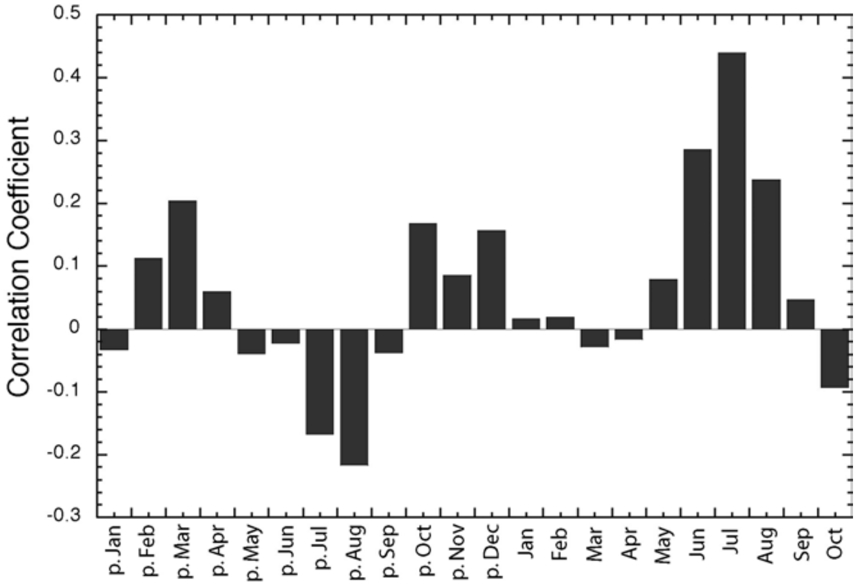

Figure 2: Correlations of the 1st PC with monthly temperature. (p.= previous year)

Highest correlations with July temperature of the current growing season are obtained, with significant ($p < 0.05$) correlations during the surrounding June and August, indicating a positive response to current growing season temperatures. Correlations with temperature in the months prior to the current growing season are not significant at $p < 0.05$, except for the previous August and March. From this correlation analysis (and comparisons with precipitation data – not shown) we conclude that summer (June-August) temperatures are the dominant common influence in PC1 and hence over the network.

Figure 3 shows a comparison of PC1 and average June-August temperatures from the single gridpoint (Böhm et al. 2001) for the 1850-1973 common period. The relationship between PC1 and average June-August temperatures is evident visually, and statistically is characterized by a correlation coefficient of 0.54.

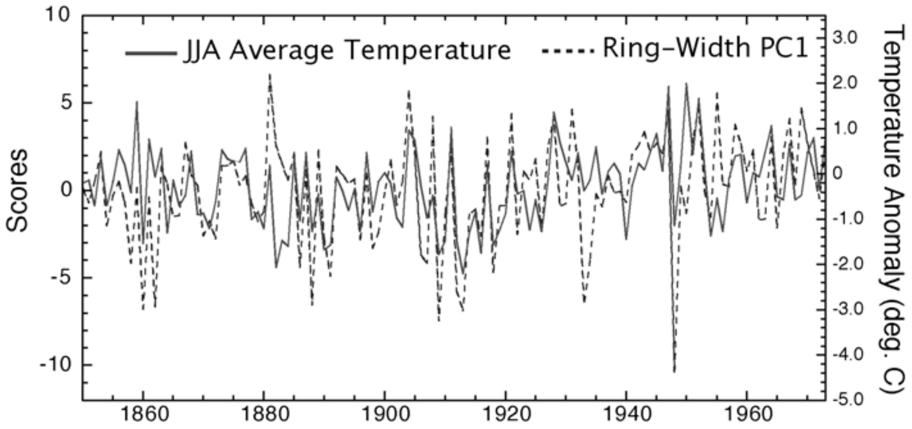

Figure 3: Comparison of the 1st PC with average June-August temperatures

Conclusions

These results indicate the common temperature signal across this high elevation central-western Alp tree-ring network. In addition, they demonstrate the potential of using Principal Components Analysis to extract the dominant common signals within this network for the purpose of climatic reconstruction.

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NAO and Tree Rings - A dendroclimatological network analyses of Central European chronologies

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Introduction

Tree ring width chronologies are appropriate and often used proxies for reconstructing past climate conditions, especially in areas with extreme climate. In general such areas have only one dominant climatic forcing factor influencing tree ring growth (FRITTS 1976). In boreal (BRIFFA et al. 1998) or high mountain areas (ESPER 2000, BRÄUNING 1999) temperature is the limiting factor, in arid to semiarid regions (TREYDTE 2003) precipitation is decisive.
Recently, the North Atlantic Oscillation (NAO) has been reconstructed width (COOK et al. 1998, GLUECK & STOCKTON 2001, COOK et al. 2002) with some of the predictors being tree ring chronologies from West and Central Europe. Recognizing that tree ring growth in Central Europe is forced by changing influences of climatic factors, namely temperature and precipitation (SCHMIDT 2003), a greater knowledge of the NAO as forcing factor for tree-ring growth is necessary.
This study analyzes the NAO fingerprints in tree-ring width chronologies in the Central European region by investigating following questions:

- Is there a significant correlation between NAO and tree rings in Central Europe?
- Are there species specific differences in these correlations?
- Where are highest correlations located?
- Are there spatial pattern in the distribution of site related correlations?

The NAO can be regarded as a dominant pattern of atmospheric circulation variability and refers to a meridional oscillation in atmospheric mass with centers of action near Iceland and over the subtropical Atlantic. It is considered to be the dominant mode of atmospheric variability in the Northern Hemisphere, especially in the North Atlantic region. The NAO affects the spatial pattern of air pressure areas and is responsible for the variability of precipitation and temperature over Europe.
An index can be constructed that representing the phases of the NAO. The corresponding index (the NAOI) is commonly based on the normalized surface pressure (SLP) difference between meteorological stations representing the Azores high and the Iceland low. HURREL et al. (1995) calculated a NAOI from the stations Ponta Delgada (Azores) and Reykjavik (Iceland) from AD1865 to 1995. The Climate Research Unit (CRU) used the data from Gibraltar (Spain) and Reykjavik (Iceland) for calculating an index over the longer time window from AD1825 to 2000. We abbreviate these two indices as PON and GIB, respectively. Based on these data many NAO reconstructions have been calculated. In detail

they show different results depending on the chosen index and especially the chosen tree-ring data.

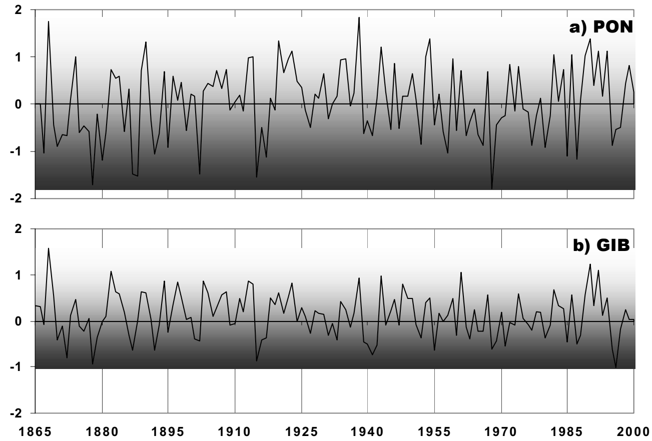

Figure 1: In this study used NAO indices as normalized sea pressure differences between a) Ponta Delgada and Reykjavik and b) Gibraltar and Reykjavik for the common time window AD1865 to 2000.

A positive NAO phase in the winter months results from a relatively high subtropical pressure centre and a deep Icelandic low, and yields warm and wet winters in Northern Europe and dry winters in Southern Europe. A negative winter NAOI results from weak a subtropical high and a weak Icelandic low. This causes fewer and weaker winter storms on a west-easterly track and brings moist air into the Mediterranean. For Northern Europe the consequences are cold and dry winter conditions.

Database and methods

In addition to the NAO data the network analyses is based on a dendrochronological database containing more than 300 tree ring width chronologies that all span the AD1875 to 1974 time window. This dataset includes the major forest tree species in Central Europe (*Abies alba, Fagus sylvatica, Larix decidua, Pinus cembra, Pinus uncinata, Picea abies, Quercus petrea, Quercus robur*) with a heterogeneous distribution. More than 38% of all chronologies are spruce, while all deciduous chronologies together amount to only 24%. The spatial distribution of the sites is shown in Figure 2. The dendroclimatological network is connected with a Geographical Information System (GIS) that includes all site related metadata such as altitude, elevation, exposition, inclination, soil conditions.

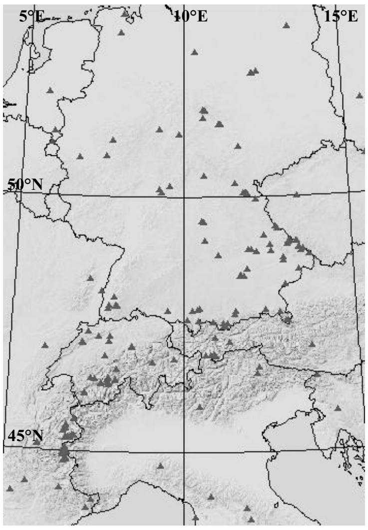

Figure 2: Sites of the tree-ring width chronologies spanning ad1875 to 1974 in Central Europe.

All tree ring width (TRW) series were detrended using a) residuals from a 5-year moving average (here abbreviated as 5gs) and b) residuals from a 25-year moving (25gs). Using simple correlation analysis, the index TRW series were compared to i) monthly NAOI data for PON and GIB using a 19-month period from April of the previous year to October of the growth year and ii) the winter (DJFM), the summer (AMJJ), and the annual (J to D) NAO. These NAOI windows allow the assessment of the influence of previous and present year's climate on the current year's growth. According to this the dendroclimatological network for the study consists of three tree ring datasets (TRW-raw, TRW-5gs, TRW-25gs) for 300 sites and 22 NAOI windows for each GIB and PON. The whole dataset is composed of 944 time series all spanning the AD1875 to 1974 common period.

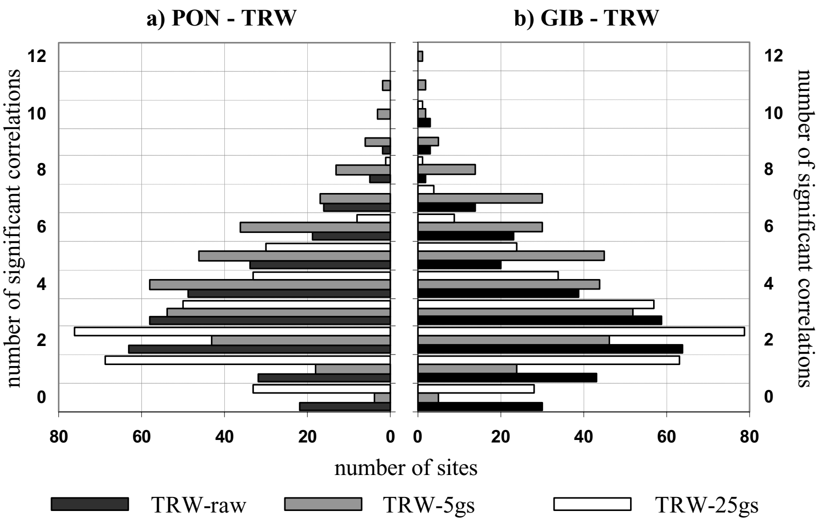

Figure 3: Significant correlations between NAOI based on the data from a) Ponta Delgada (PON) and b) Gibraltar (GIB) and TRW chronologies; black - raw tree-ring width data, grey - index data after 5gs detrending, white - index data after 25gs detrending.

Results and discussions

A total of 39,600 correlation pairs between the NAO and TRW data were computed. Figure 3 shows the number (from a maximum of 22) of correlations significant at the $p < 0.05$ level for each tree-ring site with the PON-data (Fig. 3a) and the GIB-data (Fig. 3b).

The 5gs filter yields the strongest link between NAO and the chronologies, evidenced by the 5gs filter having many more chronologies that have around 5 or more significant correlations in comparison to the raw or 25gs filtered chronologies. Surprisingly, the 25gs indexation results in a low number of significant correlations (white beams). Approximately 10% of all 25gs indexed sites (33 for PON and 28 sites for GIB) have no significant correlation, and only 39 sites have 5 or more significant correlations with the 22 NAO windows. In contrast, the 5gs indexation has 123 and 129 sites that correlate significantly with the PON and GIB data, respectively. We interpret this fact to suggest that there are differences in the longer term NAOI and TRW data. Therefore the following discussion focuses on the 5gs filtered TRW data.

In comparing results from PON with GIB in figure 3, only negligible differences are found. The greatest differences are found in the group with 7 significant correlations, where 30 and 17 sites fall into this group for the GIB and PON indexes, respectively. Regarding the lowest row of figure 3 (number of significant correlations is equal to zero) for the TRW-5gs-data there are only 4 and 5 sites with no significant correlations to the PON and GIB NAOI, respectively. Consequently, at least 295 from a total of 300 sites, representing over 98% of the chronologies, have at least one or more significant correlations with monthly and seasonal NAOI.

Figure 4 shows these correlations at monthly resolution. The grey bars in the background illustrate the range of the correlation coefficients. For every NAOI-window there are sites with positive and negative correlations. The mean of all sites for each NAO-window generally results in values that fluctuate around zero. Therefore the correlations must be investigated in a more detailed manner.

The smaller bars show the number of sites with significant correlations to the various NAOI windows differentiated into three levels of significance. For the PON-data the greatest peak is found in summer. Nearly 100 sites react significantly to the summer NAOI with maximum correlation of 0.4457 for a high-elevation, northerly exposed spruce site in the Tarantaise valley (French Alps). For the winter NAOI there are only a few sites with significant correlations, 25 with positive and 20 sites with negative correlations. The GIB-data have nearly the same pattern: 30 sites with positive and 34 sites with negative correlations to the winter NAOI, and 119 sites with positive correlations and only 5 sites with negative correlations to the summer NAOI.

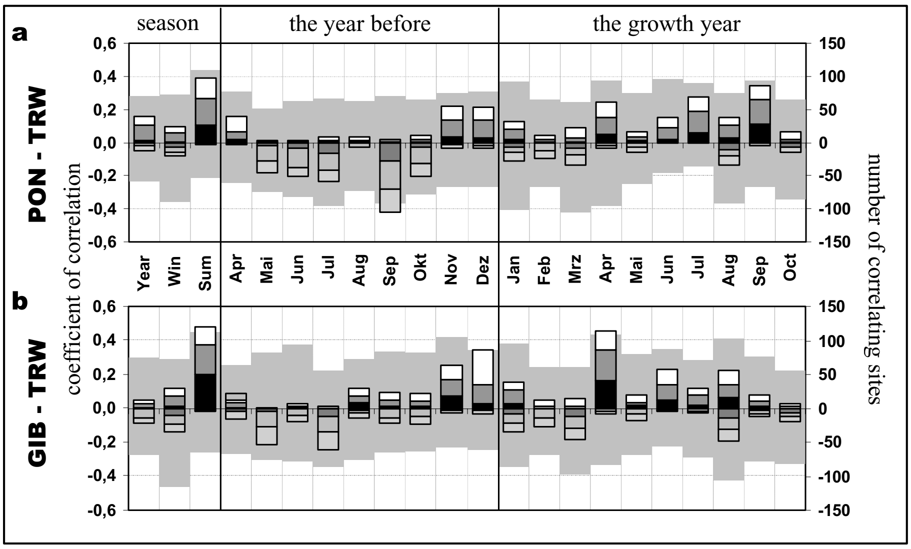

Figure 4: Correlations between a) PON – NAOI and b) GIB – NAOI and tree ring width chronologies detrended by residuals from a 5 year moving average. The grey background areas show the range of correlationt coefficients, the bars show the number of sites with significant correlations, differentiated in following levels:

positive correlations:	*99 %*	*95 %*	*90 %*
negative correlations:	*99 %*	*95 %*	*90 %*
levels of significance:	*0.2593*	*0.1998*	*0.1673*

For these calculations at monthly resolution, the greatest number of sites correlate significantly with the September PON. 86 sites have positive correlations to the September NAO of the growth year and 104 sites show negative correlations to the September of the prior year. For the GIB data, April of the growth year is the dominant month with 115 sites having significant positive correlations. In sharp contrast to the PON index, the September GIB index has nearly no correlations with radial growth. However, in August 94 sites with significant correlations are found, divided into 56 positive and 48 negative reactions. This split reaction appears contradictory initially.

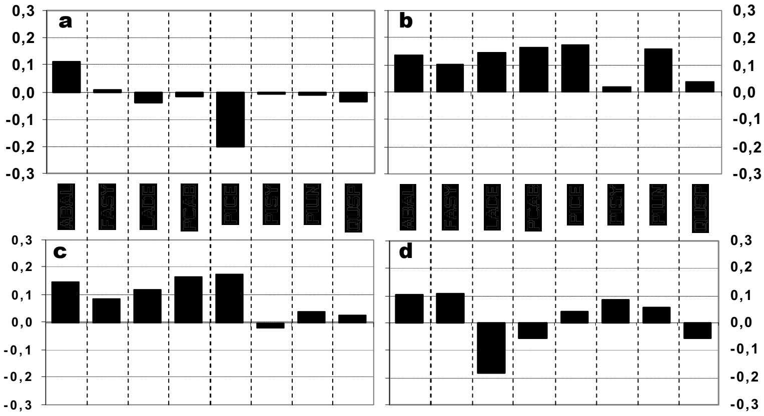

Figure 5: Species specific average correlations between the NAOI derived from Gibraltar and Reykjavik and the TRW chronologies detrended by residuals from 5 year moving average for specifically chosen NAOI windows: a) winter (December to March), b) summer (April to July), c) April, and d) August.

To help address this apparent contradiction species specific correlations are shown in Figure 5. Particularly in August (Fig. 5d), the various species show unequal correlations to the GIB NAOI. While fir, beech, and pine are positively correlated with the NAOI, spruce, oak, and especially larch show negative correlations to the August NAOI. April (Fig. 5c) and the summer NAOI (Fig 5b) show more homogeneous distributions, with nearly all species having positive correlations to these NAO data. For the winter NAOI (Fig. 5a), only positive correlations are found with the fir and negative correlations with the stone pine.

To explain the negative correlations of stone pine the spatial distribution of this species must be taken into account. The present network only includes stone pine sites from near the upper tree line, constrained to a small area in the Western Austrian and the Northeastern Italian Alps. In figure 6d, which shows the spatial distribution of correlations between winter NAOI and TRW, only negative correlations to the NAOI are displayed in this area. Therefore the species specific information of stone pine (see Fig. 5a) can only be explained by the specific site ecological conditions. Furthermore all sites with negative correlations (see small bars in Fig 4) are stone pine sites. This leads to the conclusion that the wintertime negative correlations in Central Europe are mainly a reflection of the special ecological behavior of stone pine.
Regarding the spatial distributions of the correlations for summer, April, and August (Fig. 6a-c) different reasons are expected, and so far, a universally valid explanation for the various spatial patterns cannot be given.

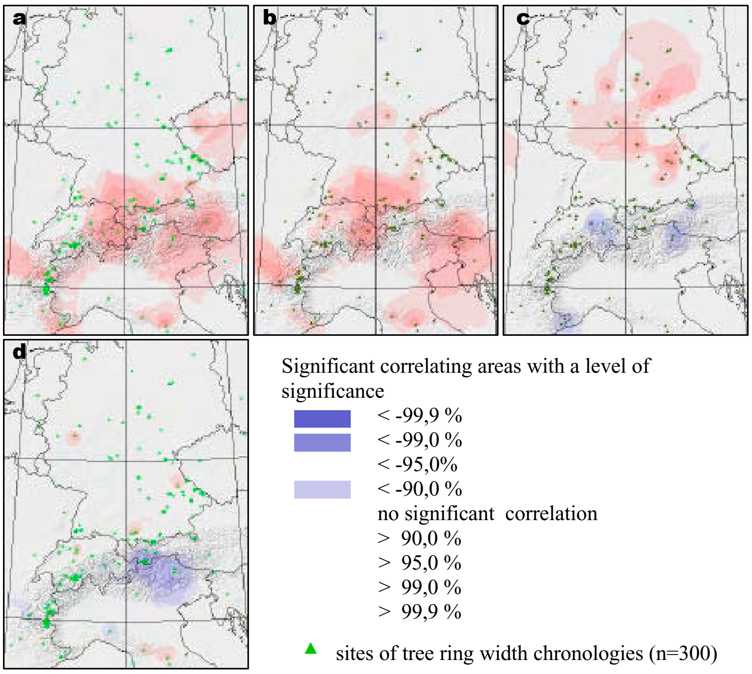

Figure 6: Spatial correlation pattern between GIB-NAOI and TRW-index-data for a) summer (April to July), b) April, c) August, and d) winter- (December to March) NAOI. Red colours represent positive and blue negative significant correlations.

Conclusion and outlook

The entire connection between NAO and TRW is not yet predictable as a general rule, due to the complexity of this system and network. But the first results of this study permit us to give some general remarks.

Most of the tree ring width chronologies include a significant NAO-signal. But this signal may differ depending on the specific NAO index. More sites show significant correlations to the NAOI derived from the meteorological station of Gibraltar in comparison to that of Ponta Delgada.

The correlations to the summer NAOI are substantially higher than those of the winter NAOI. Additionally they are more uniform, with mostly significant positive correlations to the summer NAOI. For the months April to July all species show positive correlations to the NAO, for the months of the late growing season and the winter period differing correlations are found.

The spatial correlation patterns show no clear relationship between NAO and TRW. So far we have only been able to explain some spatial patterns.

Further investigations are necessary, with the following steps deemed useful:

- to increase the number of sites in sparsely covered regions of the dendrochronological network (western and northern Germany, south eastern Alps),
- to use a NAO index that considers the spatial dynamics of the air pressure fields over the North Atlantic (PAETH 2000),
- to compare the NAO fingerprints with tree ring pointer years (NEUWIRTH & WINIGER 2003, NEUWIRTH et al. 2003)

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Exploring oaks in modern wetland woods in Europe to trace the climate signal in tree-ring series of sub-fossil bog oaks

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Introduction

Long tree-ring chronologies have been derived from sub-fossil bog oaks, i.e. oaks preserved in peat, from various sites in NW Europe. They cover the period from about 6000 BC to AD 1000 (Jansma 1995; Pilcher *et al*. 1996; Spurk *et al*. 1998; Leuschner *et al*. 2002). There are three main reasons why these bog-oak chronologies have great potential as proxy data for studying natural changes in past climate. First, bog-oak chronologies cover a long period and therefore enable the reconstruction of natural variation of certain climate aspects. Second, bog oaks are considered to contain a strong environmental most likely climate-related 'signal' because they grew close to their ecological limit in wetland woods that were characterised by high ground-water level and/or frequent inundation. The specific growth pattern of sub-fossil bog oaks with alternating phases of normal and depressed growth confirms this last assumption (Sass-Klaassen *et al.* 2003*,* this issue). Third, bog-oak chronologies from different locations in NW Europe contain common variation, i.e. a common 'signal', indicating that large-scale climatic factors influenced the growth of these oaks (Leuschner *et al.* 2002).
To assess the relationship between climate and growth in the tree-ring patterns of sub-fossil bog oaks, a straight-forward approach was used: living oaks that grow in modern wetland woods under comparable site conditions as sub-fossil bog oaks were sampled and analysed. The idea was to study the relationship between climate and growth and to calculate a model that can subsequently be projected to the long bog-oak chronologies.

Material and Methods

Sampling took place at 14 wetland woods, located in the Netherlands (8), Germany (2), Estonia (1) and Poland (Biebrza National park; 3). At these sites, oaks are growing in different types of wetland woods, which match the description of wetland woods where bog oaks grew together with other wetland species (Leuschner et al. 1987; Kooistra et al. 2003). Alder (*Alnus glutinosa*) is the dominant species at all sites. Other common species are birch (*Betula spp.*), ash (*Fraxinus excelsior*) and, on somewhat dryer sites, beech (*Fagus sylvatica)* and hazelnut (Corylus spp.). The trees all grow on (mineralised) peat.
On each site, 10 to 20 dominant oaks were sampled by taking one core per tree. Measurement and data processing was done using standard dendrochronological equipment and software (TSAP, Rinn 1996; COFECHA, Holmes 1983). Site chronologies were calculated using program ARSTAN (Cook 1985). Climate data were taken from the nearest

climate station with long data records (sources: www.knmi.nl (The Netherlands), www.dwd.de, (Germany), University of Torun (Polen), Tartu University (Estonia). Response-functions were calculated using program PRECON (Fritts, unpubl.)

Results and discussion

Growth pattern of oaks from modern wetland woods

Most of the sampled oaks at the investigated sites are between 30 and 70 years old, with some trees reaching an age of 100 years. The mean annual growth rate of the oaks varies between 3 and 5 mm, meaning that the oaks were good growing. Prolonged periods of depressed growth are absent in all tree-ring series. Figure 1 shows an example of the growth pattern of oaks from the *Unterspreewald*, a wetland wood in Eastern Germany. The growth pattern of these oaks does not resemble the growth pattern of the sub-fossil bog oaks (see Sass-Klaassen *et al.*, this issue; Fig 2).

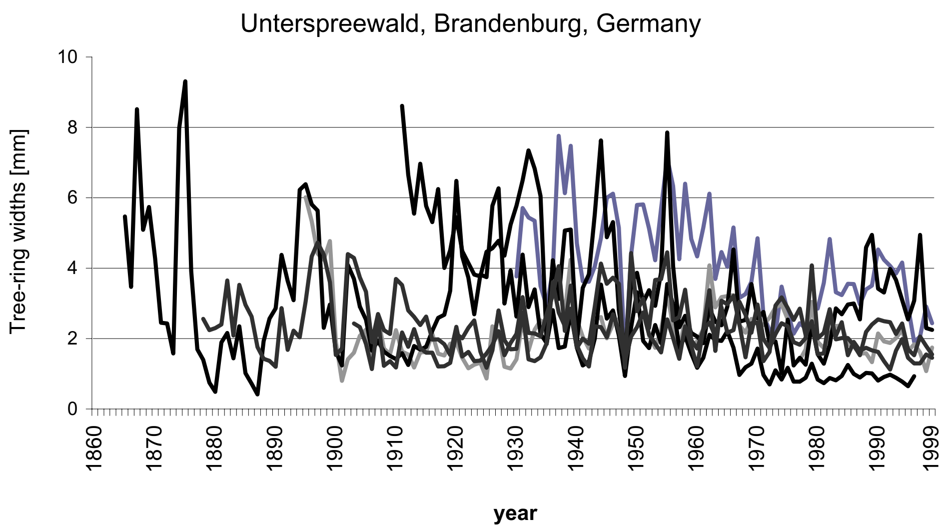

Figure 1: Tree-ring series of six oaks from the Unterspreewald, Germany

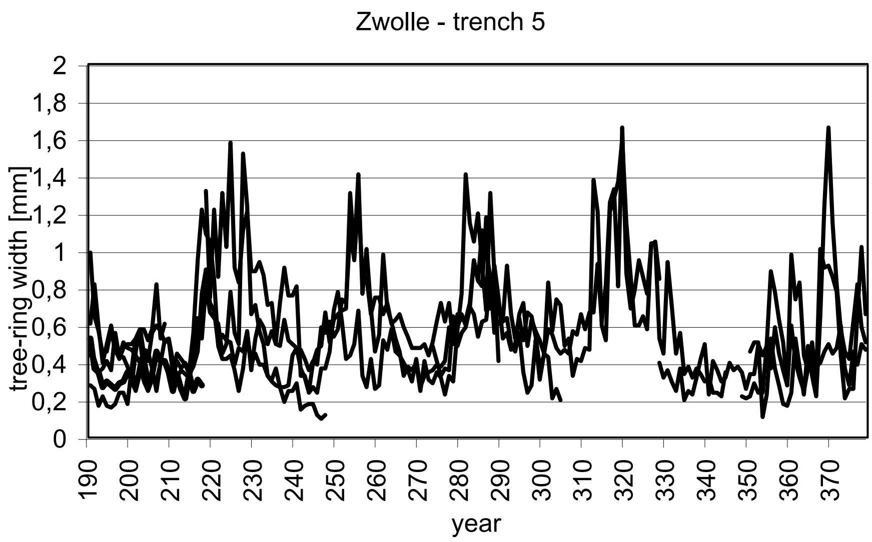

Figure 2: Tree-ring series of sub-fossil bog oaks from Zwolle Stadshagen, The Netherlands with alternating phases of normal and depressed growth

Climate-growth relationship

The response functions for the oaks from the different wetland sites show no strong influence of either temperature or precipitation. However, there exists a general tendency towards a positive influence of winter and/or spring precipitation, whereas above-average precipitation during the vegetation period had a negative influence on the growth of the oaks. Figure 3 documents the positive relationship with winter- and spring precipitation for the oaks from the *Unterspreewald,* Germany.

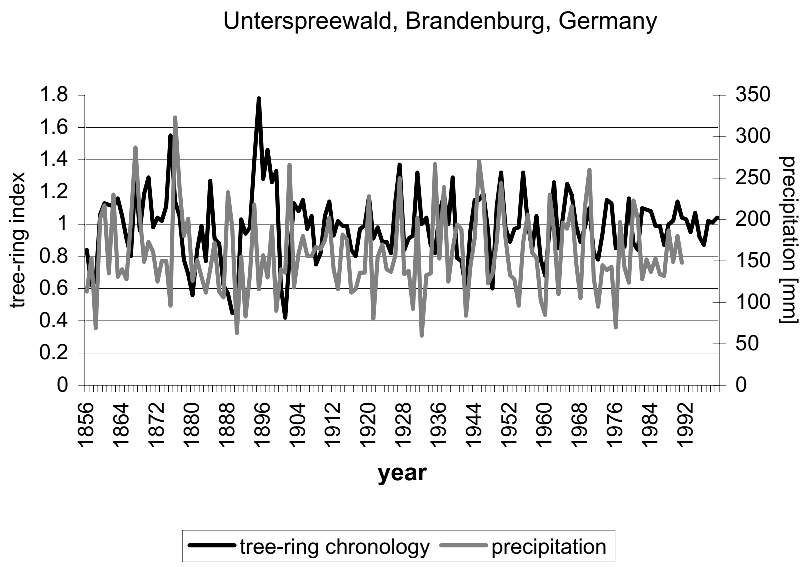

Figure 3: Comparison between the tree-ring chronology of oaks from the Unterspreewald, Germany, and the winter and spring precipitation from climate station Berlin

Ecological growth conditions of oak in modern wetland woods

Average ring width shows that the oaks in the wetland woods are growing under generally favourable site conditions. There is no indication that the relatively high ground-water level limits the growth of the oaks. The positive relationship with high precipitation in winter and spring most likely points to the refilling of the soil-water reservoirs before the start of the vegetation period (Fritts 1976). The hydrology at almost all investigated sites is directly (flooding) or indirectly (via ground water) linked to river systems. This ensures that the trees are provided with nutrient-rich (soil)water mainly during winter and spring. A negative response with above-average rainfall during the vegetation period indicates the susceptibility of the oaks to anoxic conditions in the shallow topsoil layer. A lack of oxygen in water-saturated organic soil may inhibit physiological activity of the roots and even damage them, which subsequently causes a reduction in growth activity (Kozlowski 1984; Armstrong *et al.* 1994).

Why can't we find "living bog oaks"?

After sampling and dendrochronologically investigating oaks from various wetland woods in different geographical regions, it has to be concluded that it is impossible to find oaks that show the characteristic growth pattern of the sub-fossil bog oaks (see Fig 2). The assumption is that the growth depressions in sub-fossil bog oaks are the result of (temporary) high ground-water level (groundwater level above the soil surface) and/or inundations (Pilcher *et al*. 1996; Leuschner *et al.* 2002; Sass-Klaassen *et al.* 2003*,* this issue) most likely in the beginning of the growing period (Poole et al. 2003, this issue). A surplus of water during the growing season may moreover have resulted in an early growth stop, which also resulted in narrow tree rings. Following this assumption the only conclusion can be that the hydrology at the investigated modern wetland woods differs from that at the ancient wetland woods. With large-scale exploitation of the peat-land areas beginning in the 10th century AD in the Netherlands (Vervloet, pers. comm.) a lot of wetland woods were destroyed. The hydrology of wetlands has been irreversibly changed by the drainage of vast areas for peat exploitation and subsequently agricultural use. This process took place even in more remote areas like North-eastern Poland. The consequences are that only few natural wetlands (still) exist in NW Europe (Succow & Joosten 2001) and that none of them has reached the phase of a wetlands wood with oak.

Alternative research approaches

Based on the above, other approaches have to be used to assess the climate signal in the long bog-oak chronologies, if they are to be used as proxy data for past climate. Two of these approaches are described elsewhere in this issue (Sass-Klaassen *et al*. 2003, this issue; Poole *et al*. 2003, this issue).

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Frost ring distribution at the upper tree line in Mongolia

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Introduction

The only thing common to all definitions of frost rings is the more or less anomalous tissue that appears intra-annually and parallel to tree rings (Schweingruber 2001). Frost rings can be identified on well prepared surfaces of increment cores, cross sections and on micro-sections. The position of the frost damaged tissue in relationship to the tree-ring boundary is determined by the season in which the frost event occurred. It is therefore possible to distinguish between damaged rings caused by late and/or early frosts.

The prime aim of this study is to conduct research about the frequency and distribution of frost-ring formation across the mountain areas of Mongolia. By means of a regional and inter-regional comparison, it will be determined whether characteristic regional distribution patterns of frost-ring frequency exist and whether these can be used to identify the temporal and spatial variability as well as changes of climate in Mongolia.

According to the present state of knowledge, Mongolia is situated at the fringe or the intersection of different atmospheric circulation systems, the influence and extent of which can vary from year to year (Zhang & Lin 1992, Yatagai & Yasunari 1994, 1995). However, the spatial and temporal variability of climate in Mongolia is not sufficiently represented by the relatively sparse network of meteorological stations. At altitudes at which the forests of the Taiga and mountain woodland steppe predominate, no meteorological stations are present. This lack of climatic data hinders the verification of the climatic causes of frost ring formation. Due to the unequivocal anatomical appearance, however, it is likely that the occurrence of such anomalies in *Larix sibirica* Ledeb. at the upper tree line of the Mongolian mountains is exclusively the result of frost events.

A regionalisation of frost ring chronologies will be used to draw conclusions about the occurrence and spatial extent of extreme climatic events such as late and early frosts, thus contributing to the establishment of a differentiated climatic regionalisation.

Materials and methods

At the upper tree line of the Turgen-Kharkhiraa- and Khangai Mountains in Mongolia, frost rings were studied at 13 sites (Fig. 1). The forests consist exclusively of Siberian larch (*Larix sibirica*) and are restricted to slopes exposed to the North (Treter 1996, 1999, 2000a, 2000b).

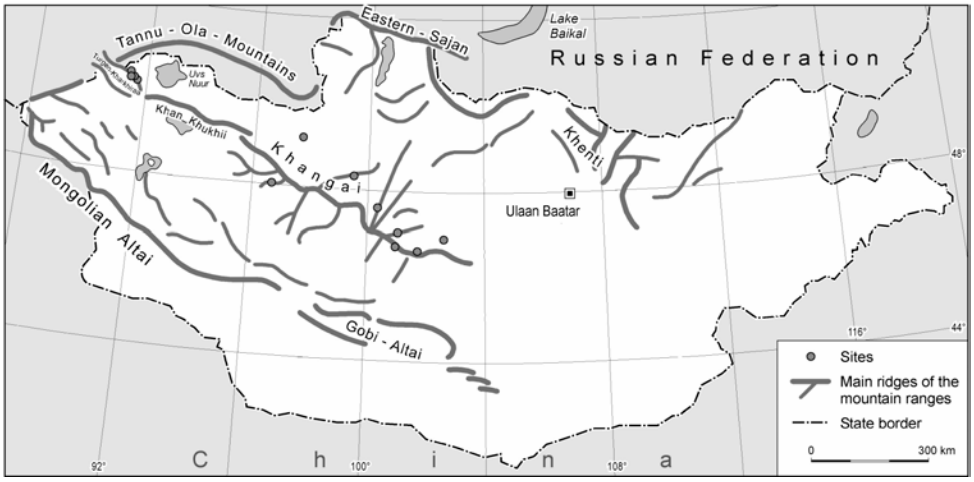

Figure 1: Location of the monitoring sites in the mountain areas in Mongolia

All sites are characterised by nearly the same age class (30-70 years) and a similar open stand structure. Two sampling methods were applied. Sampling of cores and cross sections of all trees within a study plot of 200-400 m² was carried out to get insight into the frequency, varying intensity and spatial distribution of frost damage occurrence. Alternatively, sampling of randomly selected trees (minimum of 10 trees per site) was done at most of the sites to decipher regional disparities in the occurrence and intensity of frost events.
The dendrochronological analysis and interpretation of cores and cross-sections followed commonly used procedures: (a) measurement of tree-ring width using a LINTAB measuring table, (b) determining the age of the cambium taking into account the sampling height, (c) synchronisation and cross-dating of the tree-ring curves using TSAP and COFECHA software and (d) the compilation of site chronologies by using ARSTAN. Frost rings were identified under the binocular and accurately dated on the basis of the synchronised tree-ring curves. In addition, micro-sections were prepared from some cross-sections (see also Fig. 2). Finally, the relative frequency of frost ring occurrence was determined.

Results and interpretation

In the study area, frost rings are found predominantly in earlywood. Only incidentally, e.g. in the years 1940, 1957, 1971 and 1972, do frost rings occur in latewood. An exact determination of the year of formation is difficult if the frost damaged tissue occurs in the late latewood or early earlywood. Two frost rings occurring in the same year were only found at some sites in the area of the Turgen-Kharkhiraa Mountains. They correspond to the year 1968. One frost ring is located within the earlywood, the other at the transition zone from earlywood to latewood. The location of the frost rings within the annual ring of a certain year can vary within one site as well as between sites of different regions and can be traced back to individual phenological developmental stages (Fig. 2).

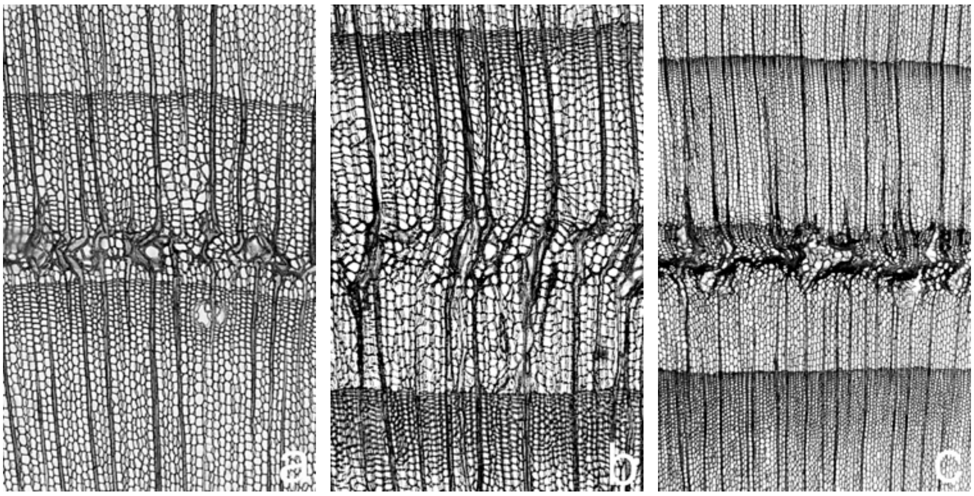

Figure 2: Examples of formation of frost rings (a) in early wood, (b) in the transition zone from earlywood to latewood, (c) in latewood

In this study, the distribution and relative frequency of frost rings in Mongolia is restricted to the stands of trees of the 30-70 years age class. This ensures the comparability of the analysed samples. Frost-ring frequency varies significantly between different areas that were grouped as distinct mountain regions. While frost rings occur only relatively rarely in the Turgen-Kharkhiraa Mountains in Western Mongolia, they are more abundant in the Khangai Mountains in Central Mongolia.

Only a few years show frost rings in both mountain regions, such as 1971 and 1972 when frost rings are present in the latewood, and 1951 and 1966-1968 with frost rings present in the earlywood (Fig. 3a). These years are associated with high relative frequencies of frost rings at the individual sites in several regions. This means that these years were obviously characterised by large-scale frost events.

The contrast between the two mountain regions with respect to frost-ring frequency is pronounced. Exclusively in the Khangai-Mountain area, in all or most stands frost-ring formation occurs in 1940, 1951, 1957, 1966, 1967, 1971, 1972, 1974, 1975, 1982, 1987 and 1991 (Fig. 3b). In addition, the exclusively local occurence of frost rings is restricted to individual sites or few sites within a limited area. With respect to different years one can therefore distinguish between supra-regional, regional, and local formation and distribution of frost rings.

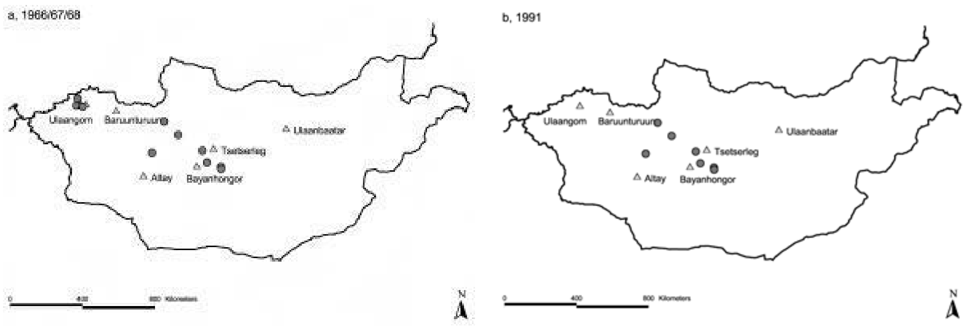

Figure 3: Examples of the distribution of frost rings for different years (a) 1966, 1967, 1968, (b) 1991

Discussion and conclusion

A spatially comprehensive regionalisation of frost-ring years at the upper tree line of the Mongolian mountain areas relies on several preconditions:

1. The network of sample sites should, ideally, include all mountain regions with a climatically determined upper tree line. This condition has not yet been fulfilled in Mongolia. Although the results of this study are well founded, they remain preliminary as far as a complete regionalisation is concerned.

2. A complete record of the presence or absence of frost ring years at particular sites and in particular regions is only possible if all sites exhibit the same or a very similar age structure. The comprehensive study of specific sites has shown that frost rings are either very rare or completely absent when the cambium age averages 30-35 years or exceeds 40-45 years.

3. This observation indicates that damage to the cambium is the key cause for frost ring formation. In trees that exceed an age of approximately 50 years, the protective bark is so well developed that damage to the cambium does not occur and thus frost rings are also absent. This leads to a gap in the regional distribution patterns of frost rings. This gap is exclusively age dependent and not caused by regional climatic effects. For the compilation of a complete and historically accurate frost-ring chronology, it is thus imperative that trees of all age classes are considered.

4. It is at present not possible to explain why the two mountain regions differ with respect to frost ring frequency. Data from all relevant climatic stations that would be necessary to find possible explanations are currently only partly available. Future investigations, however, will take into account data on the seasonal air-mass distribution and the spatial extent of atmospheric circulation systems. On the basis of these data, it will then be possible to find climatological explanations of frost ring distribution in Mongolian mountain areas.

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On the potential of cedar forests in the Middle Atlas (Morocco) for climate reconstructions

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Introduction

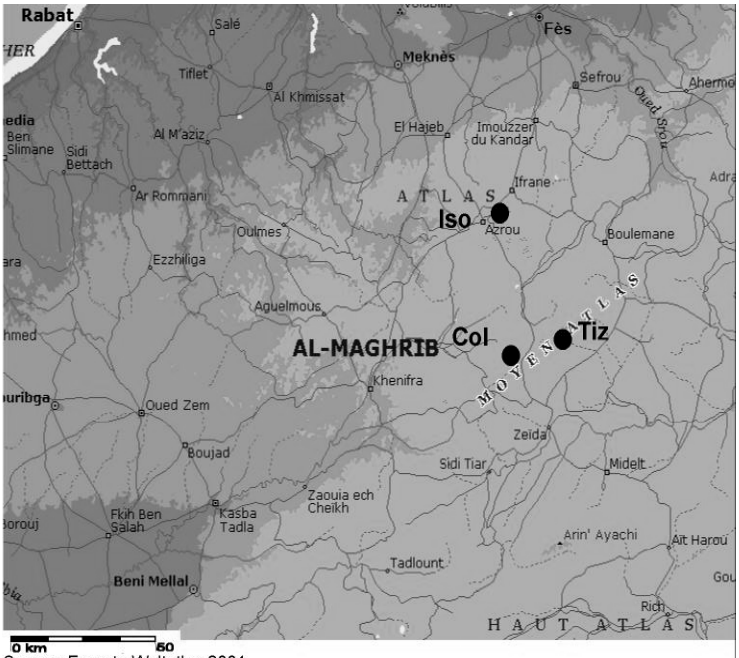
Cedrus atlantica from Morocco has been used to reconstruct regional precipitation patterns (Stockton 1988), the North Atlantic Oscillation (Glueck and Stockton 2001), and even in Northern Hemisphere temperature variations over the last millennium (Mann et al. 1999). The species is described to be highly suitable for such analysis because of its precipitation sensitivity and long lifespan.

In order to update some of the existing records, and to further increase the sample replication particularly of younger trees, new samplings and re-samplings of cedar sites in the Middle and High Atlas were performed in 2002. Here we present preliminary results on three of these sites that represent quite different ecological habitats in the Middle Atlas of Morocco. We then present the setup for a climatic analysis of cedar ring width variations, and demonstrate the high common variance between detrended site chronologies. This result is astonishing, since the chronologies represent data from three sites that differ in aspect, elevation, total rainfall, soil layer and moisture availability. The maximum ages recorded at the sites range from AD 1784 to AD 982, and mean ring widths from 0.71 to 3.05 mm/yr. These differences in growth, however, are largely related to the amount of rainfall and local soil of either basaltic or limestone origins.

Tree-ring data

In the Middle Atlas in Morocco, about 50 and 100 km South of the city Fes, the sites Issou Harroug (Iso) situated in the Azrou forest, and Col du Zad (Col) and Tizi n' Tarhzeft (Tiz) situated in the main range of the Middle Atlas were sampled (Fig. 1).

In all sites, *Cedrus atlantica* is the dominant tree species. The ecological conditions, however, differ considerably. The sites were selected to maximize the hydrological gradient that is found in the Middle Atlas. Iso is by far the most moist site, followed by Col in the rain shadow of the first mountain ranges, and Tiz receiving the lowest amounts of precipitation.



Source: Encarta Weltatlas 2001

Figure 1: Location of the sampling sites Iso, Col and Tiz in the Middle Atlas of Morocco

Further ecological settings are listed in Table 1. They indicate a correlation between increasing elevation and decreasing tree cover from the North to the South. The tree cover decreases from 90% at Iso on basalt, to 35% at Col and less than 10% at Tiz, both on limestone. The sampling strategy also considers a slight vertical gradient from 1,830 m to 2,180 m a.s.l. We found the trees at Iso to be largely undisturbed, and at Col and Tiz to be disturbed and heavily disturbed, respectively. Human impact primarily occurs when tree branches are cut off as a food source for grazing animals. The intensity of this activity is again related to moisture supply, and as a consequence to the density of the grass, herb and shrub cover. In Tiz, where these plants are scarce, the intensity of human impact is greatest, and such cutting has killed many of the cedar trees.

Table 1: Settings of investigated sites

Name	**Iso**	**Col**	**Tiz**
Latitude **Longitude**	33°24'' N 5°10'' W	32°58'' N 5°04'' W	33°06'' N 4°54'' W
Elevation [m]	1,830	2,120	2,183
Geology	Basalt	Limestone	Limestone
Humidity	Moist	Dry	Very dry
Tree cover [%]	90	35	< 10
Human impact	Low	High	Very high

At every site, two cores per tree were sampled with a 5 mm increment corer (Suunto). In total, 102 trees were sampled: 38 at Iso, 25 at Col, and 39 at Tiz. At Tiz 21 living and 18 dead trees were sampled.

Meteorological data

To analyze the climate forcing on radial growth of *Cedrus atlantica*, temperature and precipitation data from Casablanca, Fes, Kasba-Tadla, Marrakech, Meknes, and Midelt will be used (Table 2).

Table 2: Meteorological station records. Values in parentheses are for precipitation, if different from temperature data. T and P are temperature and precipitation, respectively.

Name	Meknes	Fes	Midelt	Marrakech	Kasba-Tadla	Casablanca
Latitude Longitude	33°54'' N 5°30'' W	33°54'' N 4°59'' W	33°42'' N 4°42'' W	31°42'' N 8°00'' W	32°36'' N 6°18'' W	33°36'' N 7°42'' W
Elevation [m]	549	579 (414)	1515	466	518 (507)	62 (58)
Parameter	T, P	T, P	P	T, P	T, P	T, P
Start date	1961 (1931)	1951 (1914)	1931	1924 (1900)	1962 (1915)	1924 (1902)
End date	2000	1960 (1984)	1996	2000	1971	2000
# Missing Months	32/41	0/10	80	75/95	0/124	67/69

We intend to use monthly means of temperature and precipitation for the analysis. However, many of the station records are too short to allow robust calibration and verification statistics. Further, the distances between the stations and tree sites are quite significant, and many of the records miss a considerable number of monthly values. Alternatively, gridded temperature and precipitation data provided by the Climatic Research Unit (UK) will be considered (Jones *et al.* 1999).

Methods

After counting the tree rings on each core, skeleton plots for each site were made following the procedure outlined by Schweingruber et al. (1990). For ring width measurement a LinTab device including TSAP (Rinn 1996) was used. Crossdating was verified using COFECHA (Holmes 1999). Mean site chronologies were computed and the growth patterns seen at the ecologically differing sites compared. Standard deviation (sd), Gleichläufigkeit (Glk), and Pearson correlation coefficients (r) are used for comparison analyses.

In addition to the raw chronologies (in mm), standardized chronologies were calculated to search for the common signal between the three sites. In so doing, we fit 300-year fixed splines (Cook and Peters 1981) to the individual measurements and detrended the original series by calculating ratios. As a consequence, low frequency, centennial variations (including the age-trend) are removed from the data, and higher frequency, inter-annual to inter-decal scale variations are emphasized.

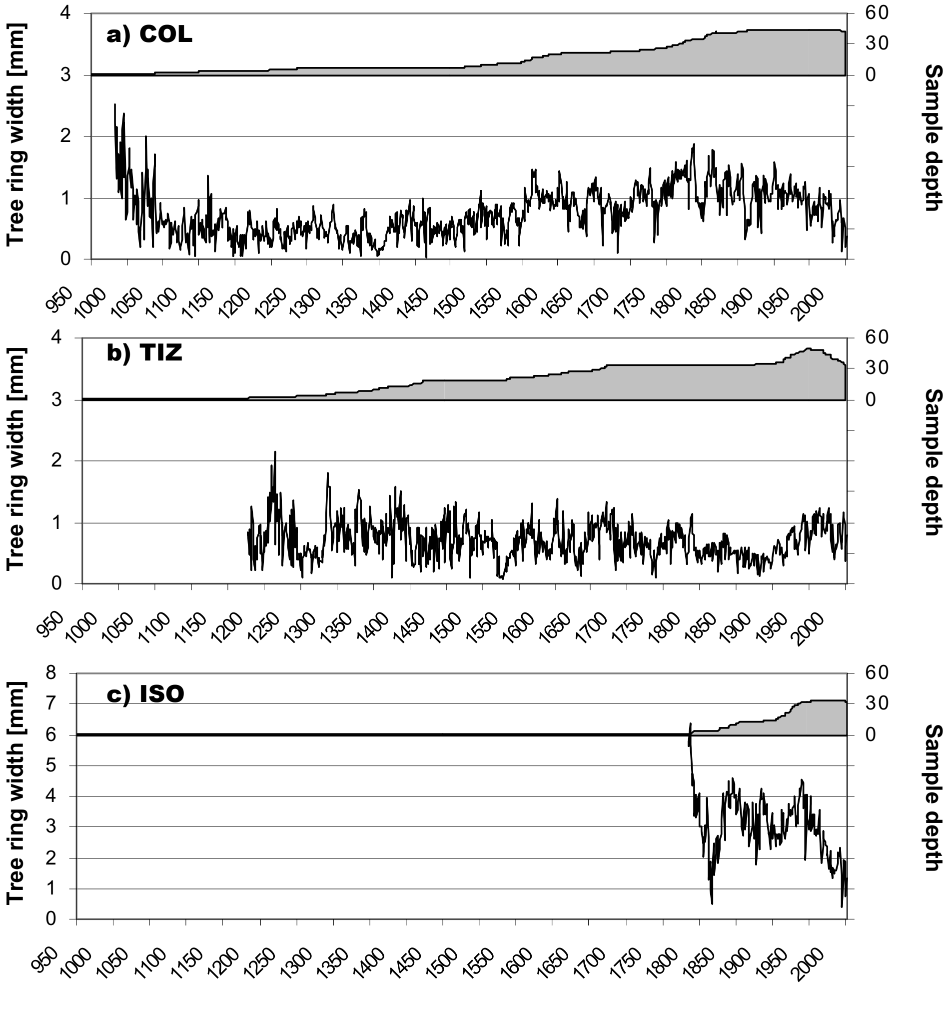


Figure 2: Raw chronologies and sample replications of Col, Tiz and Iso

Results

Col represents the longest chronology covering 1020 years back to AD 982, followed by Tiz extending back to AD 1177 (825 years) and Iso extending back to only AD 1784 (218 years). The lower ages obtained at Iso are related to significantly higher growth rates recorded in more moist conditions on basalt. The difference between Col and Tiz, however, seems to be related to some sampling bias, and might not be significant enough to stress the differing site ecological settings.

Maximum replications are reached in the 20th century (Col = 44, Tiz = 49, Iso = 33 samples). In Tiz this number decreases again towards the present, when the dead trees drop out of the chronology.

Table 3: Mean, maximum and minimum ring width values for the complete chronologies, for the last 50 years, and for the age-classes 101-200 after aligning the individual measurements by cambial age.

		COL	TIZ	ISO
Chronology	**Mean**	0,76	0,71	3,05
	Max	2,53	2,15	6,35
	Min	0,04	0,09	0,41
1951-2000	**Mean**	0,73	0,88	2,21
	Max	1,17	1,24	4,00
	Min	0,13	0,36	0,41
Cambial age 101-200	**Mean**	0,49	0,87	3,05
	Max	1,36	1,79	4,53
	Min	0,04	0,10	1,33

When focusing on the raw chronologies, the mean ring width at Iso is about four times larger than in Col and Tiz (Table 3). Similar conclusions can be derived for the minimum and maximum values. This difference is reduced, particularly for the mean values, when a common time window in the 20th century (AD 1951-2000) is compared. The reduction seems to be related to the significant age trend that still affects the Iso trees in the 20th century.

Since the different age classes that compose a chronology (older rings in Col and Tiz, and younger rings in Iso) generally bias such comparisons, all individual measurements were aligned by cambial age and a mean curve calculated from these data. The resulting age-aligned data are directly comparable and still demonstrate the high growth rates recorded in Iso. For the 101-200 year age class however, a significant difference between the Col and Tiz sites is apparent, as well. Mean and maximum values from Tiz (0.87 and 1.79) clearly exceed the numbers from Col (0.49 and 1.36).

Despite the significant differences in the ecological settings and the mean growth rates between the three *Cedrus* sites from the Middle Atlas, the detrended chronologies display highly similar growth patterns over the past centuries (Fig. 3). After eliminating the age-related noise from the raw measurements, the spline-standardized chronologies retain common inter-annual to multi-decadal scale variations. The similarity is higher between the two high elevation sites, Col and Tiz, but remains quite robust even if the lower elevation site Iso is considered. The correlation coefficients between the detrended chronologies are 0.57 between Col and Tiz, 0.30 between Col and Iso, and 0.40 between Tiz and Iso, all calculated over the period 1784-2001 (218 years). These results are significant at the $p < 0.001$ level for Col/Tiz and Tiz/Iso, and at the $p < 0.01$ level for Col/Iso, considering the reduction of degrees of freedom for autocorrelation at lag 1.

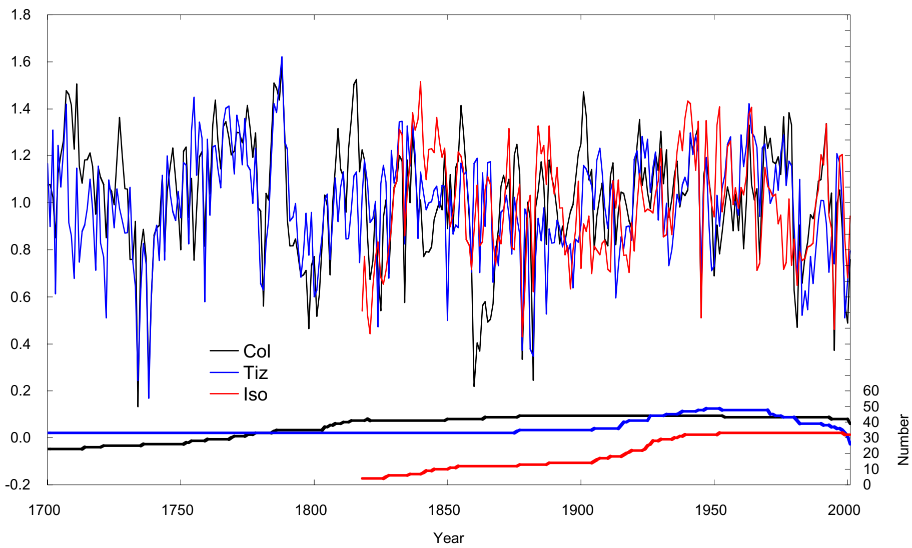


Figure 3: Comparison of the standardized chronologies from Col, Tiz and Iso since AD 1700. All series were detrended by fitting 300-year splines to the raw measurements and calculating ratios from these fittings.

We intend to relate these chronologies to the instrumental data outlined in the methods section. The working hypothesis is that most of this common variance is related to precipitation variation, and via this signal, also a fingerprint of the North Atlantic Oscillation may be found.

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Using recent and historical larch wood to build a 1300-year Valais-chronology

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Introduction

To add understanding to the current 'Global-Change-debate', it is relevant to study the variability of Holocene climate (IPCC 2001). By placing the 20th-century warming in the context of long-term temperature variations, dendroclimatic reconstructions spanning the past millennium enable further analyses of the role of greenhouse gases on recent climate change.

Tree-ring chronologies are frequently used as a proxy for climate variations, because width, density, and stable-isotope measurements obtained from trees correlate with temperatures over the growing season (e.g., Fritts 1976, Schweingruber 1996, Treydte 2003). These proxy time-series provide a detailed history of changing temperatures throughout the last millennium on local, regional and even hemispheric scales (Briffa et al. 2001, Esper et al. 2002, Jones et al. 1998, Mann et al. 1999). The reconstruction of climate variations using proxy data is closely tied to the calibration of tree-ring records against observational temperature (and precipitation) data to provide estimates of the magnitude of past changes.

To extend the about two centuries long observational records from the Alps (e.g., Böhm et al. 2001) back in time, local tree-ring (or other proxy) data are needed. The development of millennia-long reconstructions is possible by combining wood from living trees with, for example relict timber from historic buildings. If such historical wood is used to develop a long chronology, information can be derived on both, historical dating and multi-centennial environmental variations. Here we show first results of building a millennial-long larch (*Larix decidua* Mill.) ring-width chronology from recent and historical wood from sites in the subalpine Lötschental and surrounding areas in the Valais (Swiss Alps). The sampled larch trees and the wood from historical buildings originate from high-elevation forests near the upper timberline, which improves the chance of finding high correlations between ring-width and growing season temperature variation - primarily June, July and August (Frank and Esper 2004). The climatic sensitivity of larch and its recurring defoliations caused by larch budmoth (*Zeiraphera diniana*) attacks (Björnstad et al. 2002, Rolland et al. 2001) support successful crossdating (Douglass 1941) and allow the absolute dating of historical timber. The recent and historical larch data were merged and standardized to preserve mid-frequency, inter-decadal variations. As a result, a new 1300-year Valais chronology was developed that can be used to study mid-frequency temperature variations in the Central Alps. Furthermore, the study might contribute to the understanding of spatio-temporal patterns of the larch budmoth outbreaks, and enable addressing the history of local settlement.

Tree-ring data

Recent and historical sampling sites were selected in the Lötschental and surrounding areas in the Valais from 7-9°E and 46-47°N. The collected larch wood originates from forest sites > 1,500 m a.s.l. The high-elevation setting of all larch wood hopefully leads to a homogenous response to temperature variations as the dominant growth-limiting factor. To extend the about 300-year long chronologies from living trees in the Lötschental, several datasets composed of historical construction wood are analyzed (table 1). The data from Simplon-Dorf developed by M. Schmidthalter lengthens the composite record back to AD 685.

Table 1: Dendrochronological data

Site location	Number of samples	Period	Mean segment length	Average series intercorrelation
Lötschental recent	90	1682-2001	223.2	r = 0.667
Lötschental relict	147	1168-1940	213.3	r = 0.608
Goms/VS relict	143	1082-1995	117.8	r = 0.478
Simplon-Dorf relict	26	685-1200	352.0	r = 0.638
Valais recent + relict	30	1200-1995	159.9	r = 0.510

The composite dataset is characterized by specific advantages and disadvantages. Advantages include *(i)* the well-documented metadata information, particularly for the Lötschental samples, *(ii)* the spatial homogeneity of construction wood, *(iii)* the significant segment lengths, *(iv)* the expected temperature sensitivity resulting from high-elevation origins, and *(v)* excellent crossdating characteristics. Disadvantages include *(i)* the reduced site-ecological information of construction wood, *(ii)* the frequently missing outermost rings (waney edge resp. Waldkante) on samples from construction wood, *(iii)* the frequently missing pith-offset information, and *(iv)* the defoliation caused by budmoth outbreaks affecting the high-frequency climatic signal.

Methods

Of a total of 471 samples from 60 buildings and 95 samples from living trees in the Lötschental, and of 320 series from several locations in the Valais, we use only 436 series for the development of the new chronology (figure 1). All samples were first checked for sufficient segment length and the quality of the core. Only cores with more than 60 rings and less than 5 breaks were measured. Such breaks occur frequently when collecting dry wood from historic buildings.
The measured series were then crossdated using the program COFECHA (Holmes 1999). For crossdating we standardized the ring-width series by calculating ratios from a 32-year

cubic spline. This procedure reduces the amplitude of 32-year wavelength variations by 50%. COFECHA was then used as a tool to help identify missing rings and incorrect matching. Finally, a total of 237 samples from the Lötschental, and 199 series from surrounding sites were retained to build the 1300-year larch chronology.

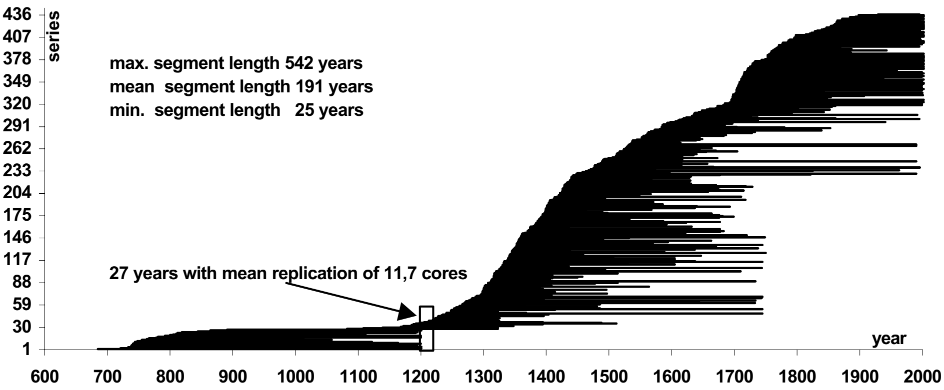

Figure 1: Segment length and dating of 436 individual larch series from the Valais.

To remove age-related noise from the data, first an adaptive power transformation was applied to the measurements to stabilize the variance (Cook and Peters 1997). The resulting homoscedastic time series were then detrended by calculating residuals from individually fitted 300-year spline functions (Cook and Peters 1981). This method eliminates any long-term growth trend and retains annual to multi-decadal variations. In total, chronologies from five independent sub-datasets were developed, using the program ARSTAN (Cook 1985). The composite of these records spans the AD 685-2000 period.

Results and Discussion

According to the outlined detrending methods, several regional chronologies emphasizing annual to inter-decadal variations were constructed (figure 2). The Schmidhalter chronology covers the longest period back to AD 685, followed by the historical chronology from the Lötschental, which runs back to AD 1168, and the three Lötschental chronologies from living trees, which run back to ca. 1700. A 31-year moving average emphasizes the decadal to multi-decadal variations.

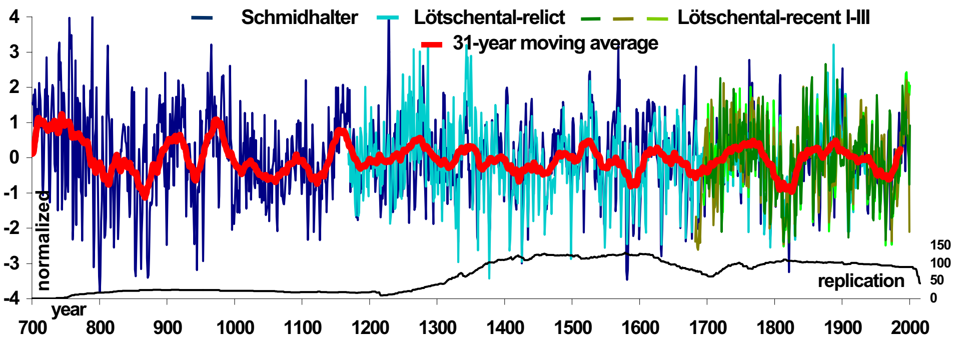

Figure 2: Five larch chronologies standardized using 300-year splines.

The individual detrending of recent and archaeological larch wood enabled the construction of well-replicated mean curves using only those ring-width series that showed a significant statistical agreement. The great mid-to-high frequency similarity of the different data sets demonstrates the potential to use the collection of relict wood from the Lötschental and surrounding sites to usefully extend the Lötschental living chronologies back in time.

To provide an overview of the historical construction wood from the Lötschental, a compilation of the numbers of collected and dated samples from each building is given in figure 3. From a total of 152 dated archaeological samples, only 91 contain sapwood. This group has an average of 26.7 sapwood rings with a minimum of 6 and a maximum of 58 sapwood rings. The mean segment length is 230 years, with a minimum of 80 and a maximum of 504. 55 samples have the waney edge, and this latter group had an average of 33.8 sapwood rings.

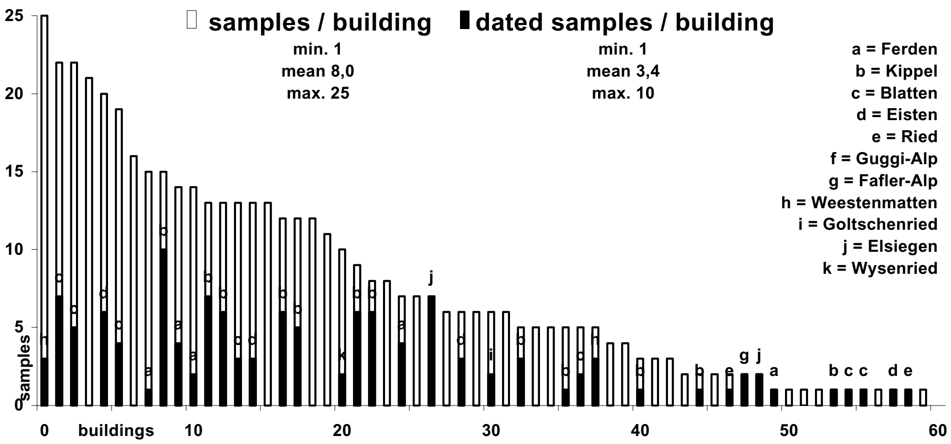

Figure 3: Numbers samples per house in the Lötschental, collected and dated within this study.

From the 152 dated historical samples, 21 contain the pith. Robust pith-offset estimates could be made on another 110 cores. From these, 80 cores miss the pith by 10 years or less. 30 samples have pith-offset estimates greater than 10 years. For the remaining 21 cores pith-offset estimates were not possible, because of incomplete cores. Historical construction wood from the Lötschental, classified into 7 groups by the date of the outermost dated ring is summarized in figure 4. Each circle represents an individual sample. The observed pattern partly results from patchy sampling throughout the Valley and does not consider the presence of the waney edge. Therefore these patterns should not been over interpreted. In an attempt to date buildings properly the existence of the waney edge is necessary to date the felling. Similarly, the number of samples per building should in general range between 5 and 8 well chosen samples. The actual number of cores per building needed to ensure correct dating of buildings is individually related to the building size, the architecture, the historical metadata background and the identification as well as the number of different building phases. After precise dating, verification of the existence of the waney edge and consideration of building phases, houses can be dated by adding one year to the felling date.

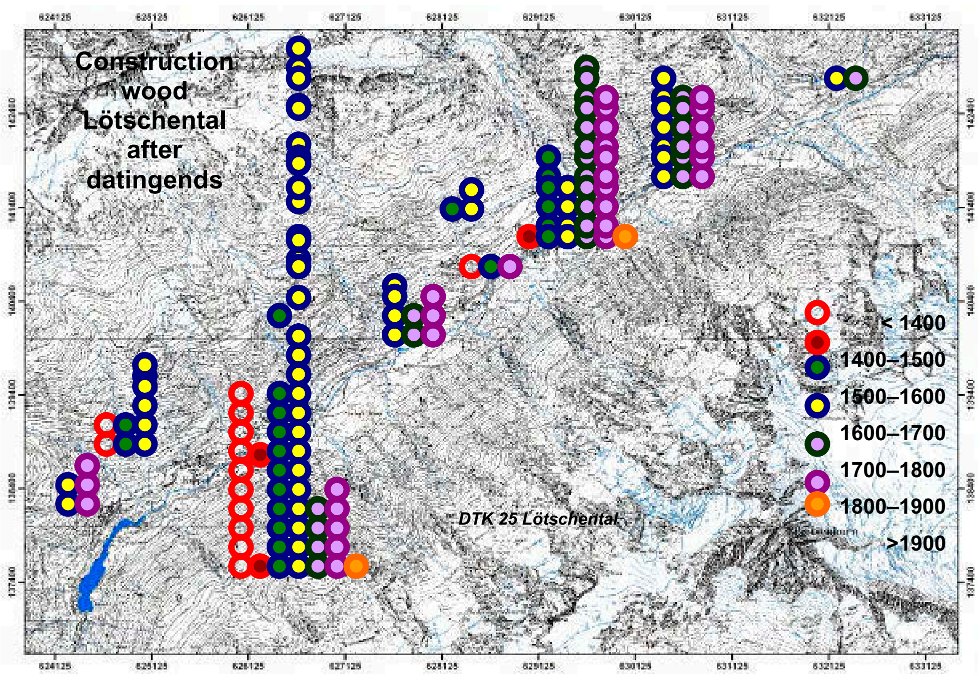

Figure 4: Spatial distribution of the Lötschental series computed after end-dates

This value is based on the fact that construction wood was processed shortly after felling (Hollstein 1980). The so-called “green-wood” allows for easier handling of the beams (Schmidt et al. 2001). The successful dating of samples that do not include the waney edge, is a function of the number of cores within the same building including the waney edge, as well as the existence of sapwood, which allows an estimation of the felling date by 20 ±5 years. Furthermore, historical details, such as inscriptions and ornaments, provide useful dating information.

Conclusions

In order to develop a 1300-year long chronology for the Lötschental area, samples from living trees and historic buildings were combined. Here, we demonstrated the possibility of crossdating such samples from larch trees and pointed to the potential of using this 1300-year record for climate analyses. This conclusion is confirmed by the substantial common variance that occurs in the period of overlap between samples from living and relict material. Similarities are seen in the inter-annual to multi-decadal frequency domains. To reach this feature, the data were detrended by fitting 300-year fixed splines. The common variance on the inter-decadal time scales in both the living and relict samples are likely related to summer temperature variations.

As another outcome of these efforts, a significant number of old buildings were dated in the Lötschental. These data are useful to further complete the understanding of settlement history in this Central Alpine valley. We intend to provide a more detailed description of this history together with historians from the Valais. An interdisciplinary approach is necessary to reach this goal.

The current study also demonstrates that individual detrending methods utilizing 300-year splines would not be useful to address longer-term changes of temperature variation. To study the potential of analyzing centennial climatic trends, we intend to apply age-related standardization methods, such as the Regional Curve Standardization (RCS) (Esper et al. 2002) or the Age – Banding technique (Briffa et al. 2001), to these data. On theoretical grounds, the size of the dataset now compiled is large enough to use such standardization techniques.

Acknowledgements

We thank Werner Bellwald, Ignaz Bellwald and Hans Kalbermatten for their great help during the fieldtrips in the Lötschental, and Daniel Nievergelt, Falco Anders and Tanja Wohlleber for field and lab support. Supported by the Swiss National Science Foundation, NCCR Climate (VITA project).

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SECTION 4

ISOTOPES AND CLIMATE

The use of stable isotope dendrochronology for environmental interpretations from tree-ring patterns in sub-fossil bog oaks

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Introduction

Across Northwest Europe over 200 sites have yielded sub-fossil bog oak material. Together, these trees have catalogued changes in their sub-optimal site conditions for thousands of years. High ground water levels characterised these conditions and the changing status of the environment, through for example inundation, impacted tree growth and population dynamics (Leuschner *et al.* 2002; Sass-Klaassen and Hanraets 2003). Environmental shifts, such as changes of hydrological status and climate, have been recorded in the tree-ring chronologies of material excavated from these sites. Thus these chronologies provide a valuable basis for climate reconstruction during the Holocene (e.g. Mayr *et al*. 2003).

Material and Methods

Characteristics of bog oaks

Dendrochronologically dated bog oaks excavated from Zwolle-Stadshagen (The Netherlands) were used to try to determine more fully those changes in the environment that resulted in the characteristic growth depressions seen in the ring patterns of bog oaks across Northwest Europe (Fig 1). The underlying hypothesis centres on the fact that the bog oaks originally grew and subsequently became preserved in wet environments. This implies that variations in tree growth were determined predominantly by changes of the environment to relatively wetter conditions (as evidenced by anoxic soil conditions), which would have limited annual growth rate of the trees and provided the trigger for these growth depressions (Kooistra 2003; Sass-Klaassen and Hanraets 2003; Kozlowski 1984; Crawford and Braendle 1996). Since no analogous sites with living oaks exist in Europe today (see Sass-Klaassen this issue) from which environmental comparisons could be drawn, stable isotope dendroclimatology was applied to this sub-fossil bog-oak material.

The stable isotope approach

Relative changes in environmental conditions underpin the use of stable carbon and oxygen isotope dendrochronology. Carbon and oxygen originate from different sources (i.e. carbon dioxide and water respectively) thus the combination of these isotopes may provide a clearer understanding of the physiological factors affecting tree growth (e.g. Edwards *et al.* 2000). Water is often a growth-limiting factor and therefore water loss must be kept to a minimum. Water enters the plant through the roots, ascends to the leaves via the xylem and is expelled by the stomata on the leaves. Stomata help to minimize water loss through evapotranspiration where $H_2{}^{16}O$ is preferentially lost from the plant. Too much water and permanently saturated soil result in oxygen deficiency lowering root-osmotic potential and hindering hydraulic conductivity, which affects the $\delta^{18}O$ signature (Everard and Drew 1987). Stomatal behaviour is also involved in carbon dioxide uptake from the atmosphere. Plants discriminate against the isotopically heavier ^{13}C which determines the stable carbon isotope value of the plant. Upon stomatal closure an increase in ^{13}C is used in photosynthesis and this in turn alters the $^{13}C/^{12}C$ ratio locked up within the organic entities (Farquhar *et al.* 1989). Relative shifts in stable isotope signatures and their relation to environmental change and manifesting in the normal *versus* depression growth are the focus of this study. It was hoped that this will form a sensitive additional technique for dendrochronological interpretations of bog-oaks.

Results and Discussion

Molecular composition

The wood of the individual oaks from Zwolle was analysed (c.f. van Bergen and Poole 2002, Poole and van Bergen 2002) to determine the molecular composition (for further details, see Sass-Klaassen *et al.* submitted) since inherent differences in molecular preservation can affect the isotope signature and hence any ecological interpretation based on those signatures (van Bergen and Poole 2002). Cellulose was the dominant component with only relatively small amounts of lignin present (for further details, see Sass-Klaassen *et al.* submitted). Thus, the bulk wood isotope signal is biased in favour of cellulose in all samples, which eliminates the need for further correction prior to interpretation.

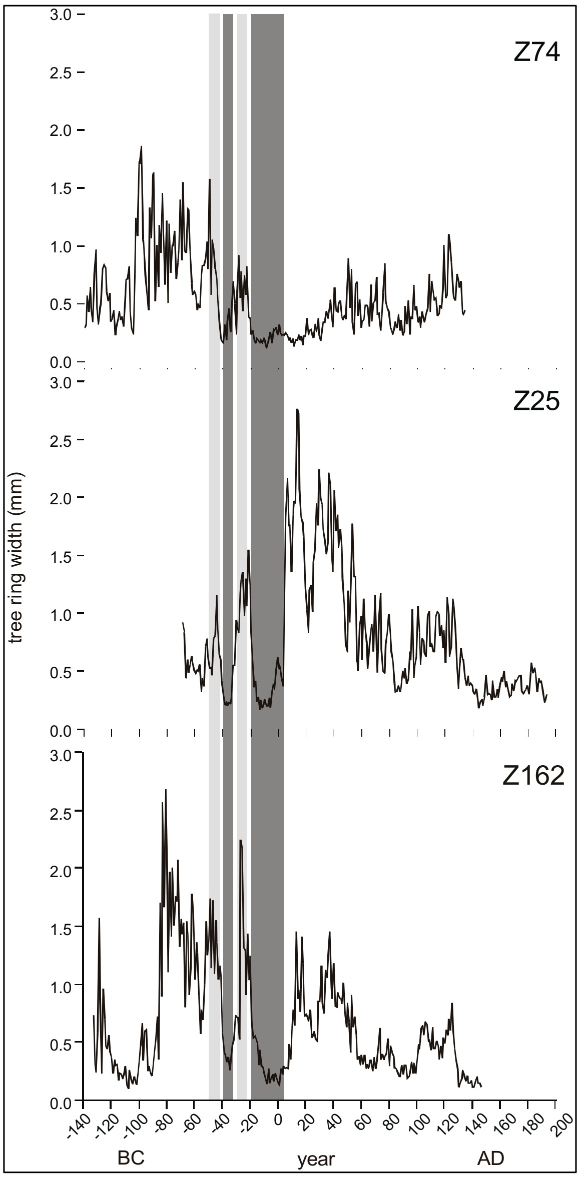

Figure 1: The relative positioning and duration of the depressed- (dark grey) and normal (light grey) growth years in the three trees (Z74, Z25, Z162) studied.

$\delta^{13}C$ and $\delta^{18}O$ Stable isotope composition

No apparent directional trend was evident for either $\delta^{13}C_{bulk}$ or $\delta^{13}C_{cellulose}$ (data not shown) with depressed or normal growth in any of the trees. The shift in the $\delta^{13}C$ isotopic signature (i.e. <2.4 ‰) in values between the depression and normal growth phases is similar to that (1-3 ‰) documented for intra tree-ring variation (Schleser 1999; Leavitt 2002).

A similar scenario was noted for the $\delta^{18}O$ values (Fig 2) between depression and normal growth years with no obvious overriding directionality. However, there is a slight tendency towards depleted $\delta^{18}O$ values in the growth-depression samples. The maximum shift (<2.5 ‰ for the bulk wood and c. 1‰ for cellulose) in $\delta^{18}O$ is smaller than the difference (4 - 5 ‰) documented for intra tree-ring variation (Helle and Schleser 2003). These trends could be explained by the difference in relative amounts of early wood *versus* late wood in the samples measured obscuring any ecophysiological signal. Therefore the observed changes in isotopic shifts between periods of normal and depressed growth have to be interpreted with caution.

Unfortunately the underlying mechanisms of isotopic fractionation in the whole tree as well as the processes that finally result in a specific (intra-annual) pattern of isotopic composition in the wood are not yet fully understood. Ongoing investigations into the intra-annual pattern of isotopic composition in sub-fossil oak focusing on consecutive periods of normal and depressed growth will provide greater insight into this latter aspect. However, it is evident that the hydrological status of the environment, previously thought to result in the characteristic tree-ring pattern, appears not to be recorded in the isotopic composition. This may imply that changes in hydrology have not been severe enough to induce physiological stress, although it cannot be ruled out that changes in the hydrological status may have affected the length of growing season.

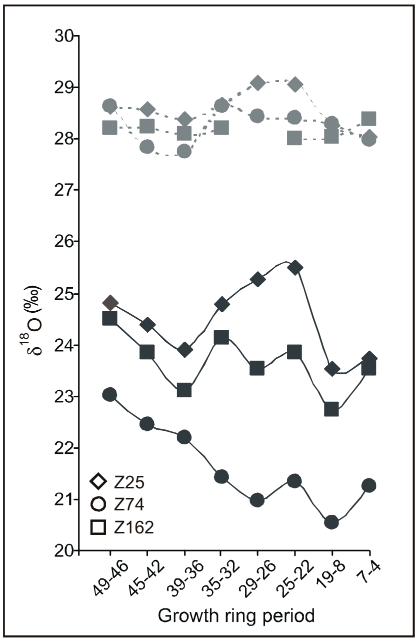

Figure 2: Shifts in the oxygen isotope signal with normal-growth (49 to 42 BC, 29 to 22 BC) versus depression-growth (39 –32 BC, 19 BC to AD 4) periods as determined from celluose (grey symbols and broken line) and bulk wood (black symbols and solid line) for the trees Z74, Z25 and Z162.

Conclusions

The combined stable carbon- and oxygen isotope approach has successfully eliminated direct physiological stress on the leaves or roots as the cause of the characteristic growth patterns seen in the tree-ring series of the Zwolle bog oaks. However, shortening of the growing season through hydrological changes may have indirectly given rise to the characteristic tree-ring patterns observed. This would imply that in this study tree-ring widths provide a more sensitive monitor of the changing status of the external environment than shifts in stable carbon- or oxygen isotopes

Acknowledgements

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The climatic signal in oxygen isotopes of junipers at the lower timberline in the Karakorum, Pakistan

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Introduction

Ice-core and sea-sediment studies have shown that oxygen isotopes are a suitable tool for temperature reconstruction (Johnsen *et al.* 2001, Jouzel *et al.* 1997). However, the question remains, whether this parameter measured in tree-rings can also be used as a "paleothermometer". The analysis of oxygen isotopes in wood cellulose requires great technical and time expenditures, and only since the late 1990's have modern on-line measurement systems enabled the processing of large numbers of samples. Consequently, only a few publications currently exist that show annually resolved oxygen measurements from multi-decadal tree-ring series (Lipp *et al.* 1996; Anderson *et al.* 1998; Saurer *et al.* 2000; Robertson *et al.* 2001). Most of these studies describe highest correlations between the isotope values of tree-rings and the water uptake that originates from precipitation and/or ground or soil water sources. The relationship between tree-ring oxygen isotopes and climate variations mostly results from the climatic dependence of the source-water isotope values (Craig 1961; Dansgaard 1964; Siegenthaler and Oeschger 1980; Gray 1981; Rozanski *et al.* 1992; Cole *et al.* 1999; Jouzel *et al.* 2000; Gonfiantini *et al.* 2001). Consequently, the atmospheric forcing of $\delta^{18}O$ in tree-rings is maximized by choosing dry and thus precipitation controlled sites.

Here we present five, 100-year oxygen records, from living juniper trees (*Juniperus excelsa*), growing at a warm and dry site (3000 m asl) near the lower timberline in the Bagrot Valley (Karakorum Mountains / Pakistan) (Fig. 1). The aim of the study was to investigate:

1. the suitability of this tree species for oxygen isotope analyses, and
2. the tree-ring / climate relationships and their potential for climate reconstruction

Methods

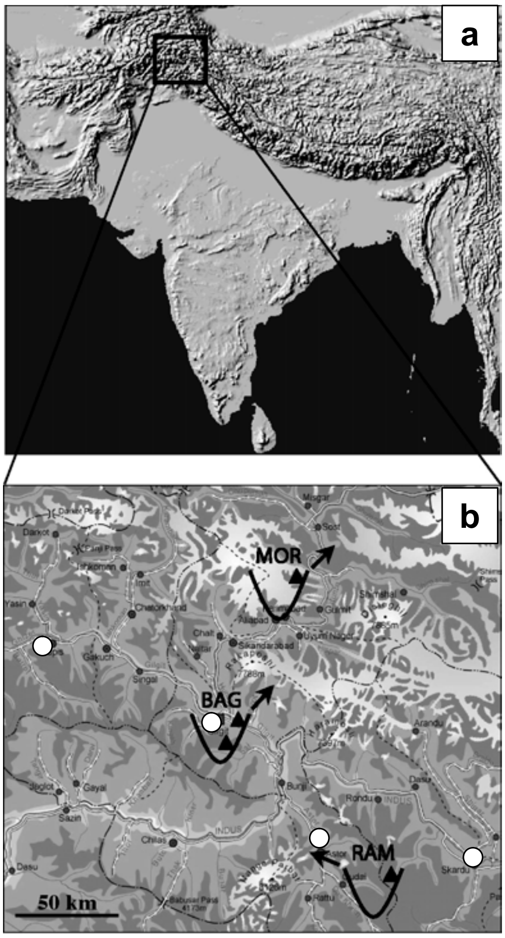

Figure 1: High Asia (a) and location of the sampling sites in northern Pakistan (b); the lower site in BAG is focused in this paper [*dots = climatic stations*]
Map sources:
(a): http://edcdaac.usgs.gov/gtopo30/e060n40.html
(b): Spohner & Winiger (2001), Institute of Geography, University of Bonn, Germany

We sampled juniper trees (*Juniperus turcestanica* and *J. excelsa*) at 4 sites in 3 valleys situated both south and north of the main Karakorum ranges in Northern Pakistan. Site selection strategy sought to cover the whole range of ecological conditions typical for this subtropical high mountain system. Figure 1b shows the locations of the sampling plots. They are situated along a S-N precipitation gradient, resulting from decreasing monsoonal influences from the SW. Three sites are situated near the upper timberline (3900 m asl) and one site near the lower timberline (3000 m asl, BAG low). The latter site is relevant for this study.

12 to 20 trees per site were sampled and 5 to 7 cores per tree were taken from opposing radial directions. After cross dating and measuring the ring widths, 5 to 7 trees per site and 2 cores per tree (similar radii for all individuals) were chosen for isotope analysis displaying few missing rings and straight ring boundaries. Individual tree-rings were separated with a scalpel, wood was milled with an ultra-centrifugal mill and then the cellulose was extracted (Treydte *et al.* 2001). This procedure was done for every single tree-ring. The cellulose samples were pyrolized to CO in an elemental analyzer (Carlo Erba) interfaced to an isotope-ratio mass spectrometer (Micromass-Optima), and the measured oxygen isotope values scaled to the Vienna standard of mean ocean water (VSMOW). Additionally, a record of annually pooled samples (using all five trees) was derived at BAG low, with the aim to test this method of combining samples for oxygen isotope measurements. The value of this approach is already established for carbon isotope investigations (Leavitt and Long 1984; Borella *et al.* 1998; Treydte *et al.* 2001).

Results

Figure 2 shows the raw ring width (TRW) and $\delta^{18}O$ series of the five isotope trees at BAG low. The mean inter-series correlation (MISC) between the TRW records is 0.74 for the period of maximum overlap (1866-1998 AD) and 0.77 for the 20th century. The common percentage of year-to-year intervals with similar trends (termed “Gleichlaeufigkeit” GLK or “coefficient of parallel variation”) for this 100-year period is 73%. In comparison, MISC of the $\delta^{18}O$ records (0.69) is lower while GLK has nearly the same value (75%). The higher correlation value of the TRW series results from a common decreasing long-term trend due to aging processes of these approximately 150 year old trees. At the other three sites with older trees such a trend in the 20th century is not seen in the TRWs (Treydte 2003). In contrast, the $\delta^{18}O$ series remain on a similar level over the whole investigation period. Consequently, the calculation of a mean site record from raw measurements seems to be appropriate for the isotope series. In contrast, the age trend from the TRW records need to be removed prior to climate analyses (Cook and Kairiukstis 1990; Briffa 1995; Briffa *et al.* 1996; Cook *et al.* 1997; Esper *et al.* 2002; Esper *et al.* 2003).

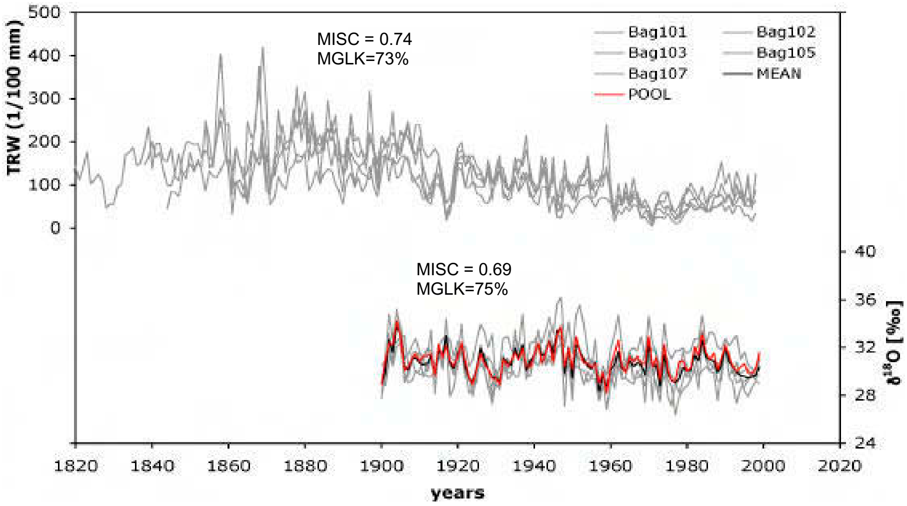

Figure 2: Raw ring widths (upper part) and $\delta^{18}O$ values (lower part) of the 5 isotope trees at BAG low (MISC = mean inter series correlation, MGLK = mean Gleichläufigkeit)

The pooled record of tree-rings mirrors the mean calculated from all separately measured samples, with a correlation of 0.9 (Fig. 2, lower part). This result proves the suitability of this time and cost saving method for oxygen investigations when addressing site comparisons.

The climate response of the tree-ring parameters was studied using monthly records of temperature and precipitation from 4 climatic stations within the high mountain area (Fig.1). It has to be taken into account that all stations are situated at valley bottoms, limiting their representativeness of conditions at the tree sites. Even the nearest station (Gilgit, 1460 m asl) has a difference in elevation of 1500 meters to BAG low. The approximately 50-year long records from the single stations were averaged to form a regional record. This leads to higher correlations with the tree-ring data. We calculated the correlation coefficients with standardized TRW series, using ratios of 51-year Kernel filters, and with the raw $\delta^{18}O$ data. Tests with standardized isotope records showed similar results (Treydte 2003).

The moisture dependency of this warm/dry lower timberline site is obvious in the formation of tree-ring widths. Warm and therefore dry conditions during the vegetation period result in narrow rings, whereas wet and cool conditions result in wide rings. The precipitation conditions of the whole year influence tree growth, in the sense that melt water from winter precipitation plays a role when growth starts in spring. Most clearly, the winter season is pronounced in the highly significant negative relationship between oxygen isotopes and November to February precipitation.

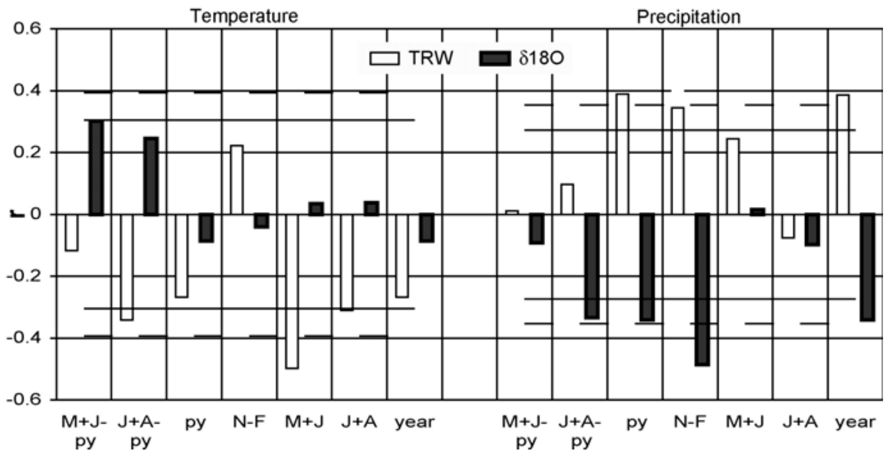

Figure 3: Correlation coefficients (Pearson) between the mean records of the two tree-ring parameters and the regional temperature and precipitation records; TRW were standardized using a 51-year Kernel filter; solid and dashed lines = 99% and 95% significance levels; M+J, J+A, N-F = mean temperatures and precipitation sums of May+June, July+August and November-February, py = previous year

In contrast, the relationship to temperature is less distinct. For $\delta^{18}O$, these correlations with temperature and precipitation are homogenous at all sites (Treydte 2003).

Discussion

But how does the amount of winter precipitation influence the oxygen isotopes of tree-rings and why is this relationship negative? As mentioned above, the $\delta^{18}O$ values in tree-rings to a certain extent reflect the isotope values of the water uptake. Comparisons with data from the Global Network of Isotopes in Precipitation (GNIP), established by the International Atomic Energy Agency (IAEA), are problematic as the GNIP network is patchy for Central Asia. Closest stations to the research region are Kabul, Tashkent, Karachi, Lhasa or New Delhi. However, synoptic weather conditions at these sites are not representative of those in Northern Pakistan, which is situated at the fringes of the westerlies and the SW monsoon.

Secondly, the records are short and/or incomplete with missing values in nearly every month. Therefore, it is not possible to calculate robust correlations with these data. However, from the GNIP-Network (Rozanski *et al.* 1992) and from our own measurements of precipitation samples in the Karakorum (Treydte 2003), we know that the isotope values of frozen precipitation are strongly depleted in comparison to those of rain (ca. 30‰ lower).

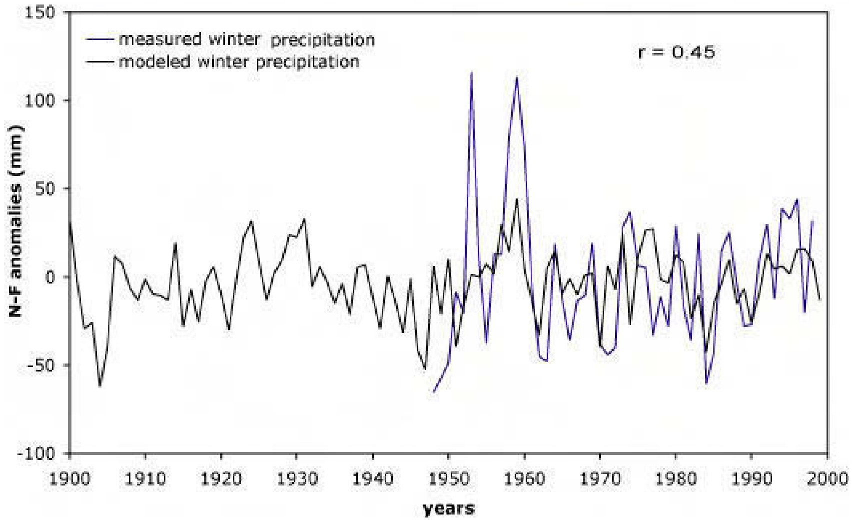

Figure 4: Winter (Nov.- Feb.) precipitation anomalies (residuals from the mean) - direct measurements versus modeled values from $\delta^{18}O$ at BAG low

Considering that the tree-rings of *Juniperus* species contain about 90% early wood vessels, built in spring and early summer, a large fraction of the incorporated water should originate from the snowmelt. Larger amounts of frozen winter precipitation will result in more depleted oxygen values in the tree-rings. On the other hand, a low or even absent melt water supply leads to higher tree-ring isotope values. This explains the negative relationship between precipitation sums and tree-ring isotopes. However, temperature and hence evaporation and transpiration effects at the beginning of the vegetation period modify the isotope values of both the melt water and the organic material.

Figure 4 shows a comparison between the regional winter precipitation record (November to February), calculated from single stations, and the modeled precipitation derived from the oxygen isotopes in the tree-rings at BAG low. Both records show strong similarities in the high and lower frequency variations. This is somewhat surprising considering the limited representativeness, particularly for precipitation, of the climate station data for the tree site. Moreover, statistical inhomogeneities of the precipitation measurements result in additional uncertainties. These facts probably are the reason for the differences between both records in several years, especially in the early 1950s. Despite these limitations, this example proves the suitability of oxygen isotopes in tree-rings for precipitation reconstruction in the Karakorum Mountains. Following publications will demonstrate, that this result is true for ecologically different sites, with a particular focus on one site, where millennia length tree-ring chronologies can be established.

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Tropical *Swietenia macrophylla* wood reveals a systematic recurring carbon isotope pattern

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The highly resolved radial distribution of $\delta^{13}C$ values in wood from an evergreen broad-leaf Mahagony tree (*Swietenia macrophylla* King) of a subtropical site near Caparo, Venezuela, South America is presented. The wood structure of the tree investigated is more or less uniform and growth zones are separated only by narrow parenchyma bands (Fig. 1).
This short study was aimed at testing whether or not a systematic carbon isotope pattern can be detected and if so, to what extent this pattern compares with the universal intra-annual $\delta^{13}C$ pattern that was found in broadleaf deciduous trees from temperate zones (Helle 1997, Schleser et al. 1999, Helle & Schleser 2004a, b).
High resolution measurements of the radial distribution of $\delta^{13}C$ were performed on a wood segment of c. 10×5mm size taken from a stem disk. Because of the varying curvature of growth zones a segment with parenchyma bands, as straight as possible, was identified and selected with the aid of the gridlock of a binocular. The chosen wood segment was trimmed to fit into a specially designed sample mount attached to a fixed-blade sledge microtome (Polycut E, LEICA Microsystems, Bensheim, Germany). The sample mount allows appropriate sample adjustment without loosening the sample during the cutting process. Contiguous tangential slices of 25µm thickness were cut. Accurate sample adjustment, as well as meticulous identification of conspicuous wood anatomical features like terminal parenchyma bands was provided by visual inspection using a binocular. The assignment of each micro-slither position to wood anatomical features was documented with a digital camera (DC100, LEICA Microsystems, Bensheim, Germany). Details of this procedure are given by Helle 1997.
As documented in Fig. 1 the results reveal a systematic and recurring $\delta^{13}C$ pattern in wood of *Swientenia macrophylla*. In this case three cycles can be observed. Each cycle begins with a marked increase of $\delta^{13}C$ values of up to 1.5‰. After reaching a maximum a more or less gradual decline towards a minimum $\delta^{13}C$ value follows. It is interesting to note that the minimum is always located in the terminal parenchyma bands of each growth zone. Contiguous $\delta^{13}C$ values rarely differ from each other by more than 0.2‰, i.e. the data point to data point variability along each isotope profile is generally low. Minimum and maximum $\delta^{13}C$ -values show slightly different levels. The isotope minima and maxima of each cycle differ by no more than 0.3‰.

Although the difference between minima and maxima of the $\delta^{13}C$ pattern in Mahagony wood is lower compared with broadleaf deciduous trees a remarkable similarity to the fundamental and seasonally recurring $\delta^{13}C$ pattern of broadleaf deciduous trees from temperate zones is evident (see Helle & Schleser 2004b for comparison). At the very beginning of tree-ring development of these trees, i.e. during the early vegetation period, the $\delta^{13}C$ trend shows an increase of up to 5‰. There the maximum $\delta^{13}C$-value of each vegetation period always occurs during earlywood development, i.e. in the first third of a tree-ring, when growth mostly depends on carbon reserves. Each maximum is followed by a subsequent decline by up to 3.5‰. The minimum $\delta^{13}C$-value is normally located in the late wood, i.e. the last third of each tree-ring. The only difference between the $\delta^{13}C$ pattern of Mahagony and that of deciduous broadleaf trees can be recognized at the end of each cycle. $\delta^{13}C$-values in tree-rings from temperate zones start rising again before crossing the tree-ring border from one tree-ring to another. An increase at the end of a growth zone in *S. macrophylla* can not be observed in Fig. 1.

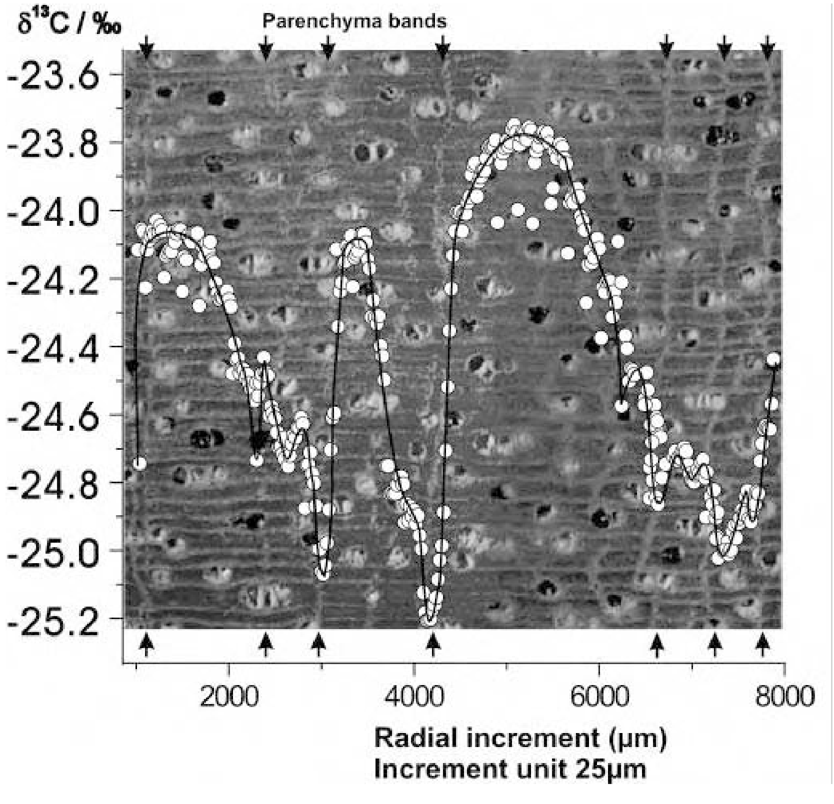

Figure 1: Radial distribution of $\delta^{13}C$values in tropical Swietena macrophylla showing three cycles of an unambiguous recurring pattern.

Due to the narrowness of the terminal parenchyma bands of Mahagony wood it can not be decided whether an increase in $\delta^{13}C$ at the end of each cycle does not occur or can just not be seen at the present data resolution.
Unfortunately, this study did not allow any comparison with climate or other environmental data since the radial growth zones could not be dated. The reason being that suitable ring width sequences normally can not be established due to indistinct tree ring boundaries and master chronologies are not available. However, the remarkable cyclicity in the high-resolution profiles of stable carbon isotopes has also been found in tropical *Rhizophora mucronata*, a mangrove species from Kenya, lacking any distinct growth rings (Verheyden et al. in review). Verheyden et al. have proven that the observed cyclicity in *R. mucronata* is annual and that high resolution $\delta^{13}C$ sequences of wood from tropical trees promise a high potential for tropical dendrochronology. For example pointer years could be identified in three different trees of a site indicating that crossdating can be successfully applied to high-resolution isotope sequences of tropical timbers.
Nonetheless, more tropical tree species and longer high resolution $\delta^{13}C$ sequences have to be studied in order to prove whether or not the method of crossdating is generally applicable to stable isotope variations in tropical timbers allowing the identification of the exact year in which each ring or growth zone was formed. An important question remains to be answered: what are the ecophysiological causes for the seasonal $\delta^{13}C$ pattern in wood of tropical trees?

Acknowledgement

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SECTION 5

PALAEO-ENVIRONMENTS

How did bog oaks grow?
Excavation of a past woodland at Zwolle-Stadshagen, The Netherlands

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Introduction

The NW-European dendrochronological data set consists of tree-ring series of about 2600 sub-fossil 'bog' oaks from approximately 200 sites. Ultra-long bog oak chronologies were derived extending from 6069 BC to the tenth century AD (Jansma 1995; Pilcher *et al*. 1996; Spurk *et al*. 1998; Leuschner *et al*. 2002). These chronologies can be used as proxy data for climate. However, for this purpose it is necessary to assess the relationship between the growth of bog oaks and (changing) ecological site conditions, e.g. hydrology. By excavating an ancient woodland at Zwolle Stadshagen it was possible to investigate sub-fossil bog oaks and ash *in situ* and to collect additional information on vegetation and soil(hydrology) to explain the growth patterns of the oaks and ashes. Moreover it was evaluated whether local factors that influenced the growth of the bog oaks and ashes were triggered by large-scale regional factors, such as weather and climate.

Material and Methods

At Zwolle-Stadshagen, an area of about 1270 m^2 was excavated. All wood remains were numbered, their morphology (i.e., stem, root, branch) was described and their position was recorded in three dimensions. Wood samples were taken for species determination in order to reconstruct the local tree vegetation and pollen profiles were analysed to provide additional information on the structure and development of the (surrounding) vegetation. Soil samples were studied by micromorphology to assess (changes in) site hydrology.

Out of 521 wood samples (215 ash, 103 oak) 60 % of the oaks and 15 % of the ashes were dendrochonologically dated and studied with respect to annual growth- and population dynamics. Tree-ring width was measured and tree-ring series were dated and analysed using standard dendrochronological methods (TSAP, Rinn 1996; COFECHA, Holmes 1983; Mean-age method (Leuschner *et al.* 2002).

Results and discussion

Of 59 oaks and 36 ashes, the year of germination and dying-off as well as the growth pattern was established. The results show that the woodland at Zwolle Stadshagen existed at least for a period of 700 years, from ca. 150 BC to AD 586.

All dated oaks and ashes showed a characteristic growth pattern with alternating phases of normal and depressed growth (Fig. 1). Growth depressions occur with a frequency of between 20 and 40 years throughout the studied period of 700 years. The comparison between the oak and ash chronologies from Zwolle with an aggregated (NW German and Dutch) continental chronology (University of Goettingen, Ring Foundation, unpublished data) showed that almost all phases of normal and depressed growth in the Zwolle trees are synchronous with those in oaks from other wetland sites in the Netherlands and NW Germany (Fig. 1). This means that the striking changes in growth of oak and ash from Zwolle were not merely the result of *local* impacts but instead were triggered by *regional* factor(s), which are most likely related to climate (Sass-Klaassen & Hanraets 2003).

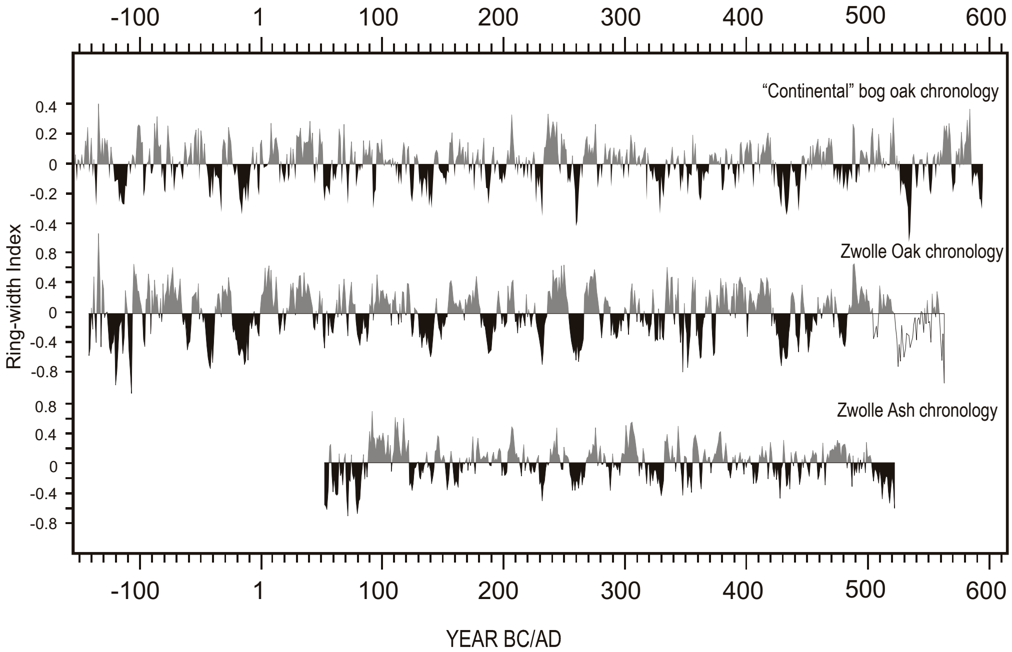

Figure 1: Comparison between the Zwolle oak and ash chronologies and the continental (aggregated Dutch and German) bog-oak chronology

The results of the micromorphological analysis indicate frequent changes in site hydrology that are most likely the dominant factor influencing the growth of oak and ash in Zwolle Stadshagen (Kooistra 2003). Peat formation started according to the general rise in sea level (=transgression) around AD 25. However, the soil archive documents that peat growth was not continuous but periodically interrupted by dryer periods with a lower ground-water level (Kooistra 2003). From AD 300 onwards, site hydrology changed and frequent flooding with shallow water became an additional (growth-limiting) factor. The flooding frequency steadily increased, until after ca. AD 540 the woodland became completely inundated and changed into a huge freshwater lake (Kooistra *et al*. 2003). The site hydrology in Zwolle Stadshagen was complex. Two big river systems, the IJssel and the Vecht, had a major influence on the drainage and inundation of the woodland in the area (Kooistra 2003). Prolonged high ground-water levels during the first phase of the woodland (150 BC to 300 AD) and from AD 300 onwards in combination with frequent flooding caused anoxic soil conditions. Prolonged anoxic soil conditions may drastically reduce the radial growth activity of the trees due to a combination of root- and/or mycorrhiza damage as well as depletion of carbonhydrate reserves (Crawford *et al.* 2003). Isotopic studies on the Zwolle oaks suggest that periods of depressed growth can also be the result of a shorter growing season due to high ground-water level and/or flooding in winter and spring during relatively wetter periods (Poole *et al.,* this issue).

River run-off, ground-water level and precipitation were mutually connected at Zwolle Stadshagen. It is however remarkable that despite temporal and spatial (new river course from AD 300 onwards) changes in these three factors neither the general growth pattern nor the frequency of growth depressions in the oaks and ashes changed during the investigated period. This information together with the fact that growth depressions occur synchronous on different wetland sites in NW Europe supports the assumption that a large-scale climate-related factor triggered the (complex) hydrology at wetland sites in NW Europe. Current research including frequency analysis of the bog-oak time series and the comparison with tree-ring series of land-grown oak will provide more knowledge on the characteristics of the triggering factor.

Conclusions

Changes in the growth patterns of the oaks and ashes from Zwolle Stadshagen are related to changes in site hydrology. Prolonged high ground-water levels during the first phase of the woodland and from AD 300 onwards in combination with frequent flooding caused anoxic soil conditions, which caused abrupt, long-term growth depressions in oaks and ashes. The fact that these growth depressions in the Zwolle trees are synchronous to the NW European records points to a large-scale climate-related factor as a trigger of site hydrology at wetland woods in NW Europe.

Acknowledgements

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SECTION 6

CULTURAL HERITAGE

Great efforts on small woods
Analysis of short ring-series from the Neolithic lake-shore settlement of Hornstaad-Hörnle I A

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Introduction

On the shore of Lake Constance in southern Germany a Neolithic lake-shore-settlement has been investigated in length from 1973 to 1978 and again from 1983 to 1993 by the Archaeological Department for Monument-Preservation of Baden-Württemberg. The research has yielded a vast amount of information on both the ecology and economy of the Neolithic settlers and on the extremely complicated stratigraphy of the site. However, in spite of sedimentological and limnological analyses the genesis of the layers is still not well understood. Dendrochronlogical dating of the excellently preserved houseposts (carried out by A. Billamboz) did not improve our understanding, since the posts penetrated all layers of the stratigraphy. The aim of this study was to improve our understanding of the duration of the settlement and of the genesis of the stratigraphy. It was based on dendrochronological dating of the clearly stratified small pieces of wood and on analyses of as many other features as possible of these pieces.

Material and methods

The aim was to date all the single layers of the site. For this, we used the master-chronology of the house posts (several species) established by A. Billamboz (preliminary report in Billamboz 1990. A comprehensive publication is in progress.) Based on the calendre dates of the houseposts as well as on the stratigraphical data it was clear that the pieces of wood should date within about fifty years of each other, between 3930 and 3880 BC.

About 4000 small pieces of wood (Fig. 1) were analyzed in terms of their species and many other features such as grade of degradation, shape or presence of fungi. Some 250 of them – mainly beeches (Fagus sylv.) – were measured and synchronised optically making use of a thorough dendrotypological analysis (Fig. 2). This means that not only the ring-widths were taken into account but also the trend, species and features characterizing the sample as a whole as for example the shape (for a discussion of the term dendrotypology see Billamboz 2000). In a few instances it was possible to put pieces of wood back together just as an archaeologist does with potsherds. In order to integrate more and shorter series, I built many groups of similar curves with a high visual agreement thus creating longer mean curves for the comparison with the reference.

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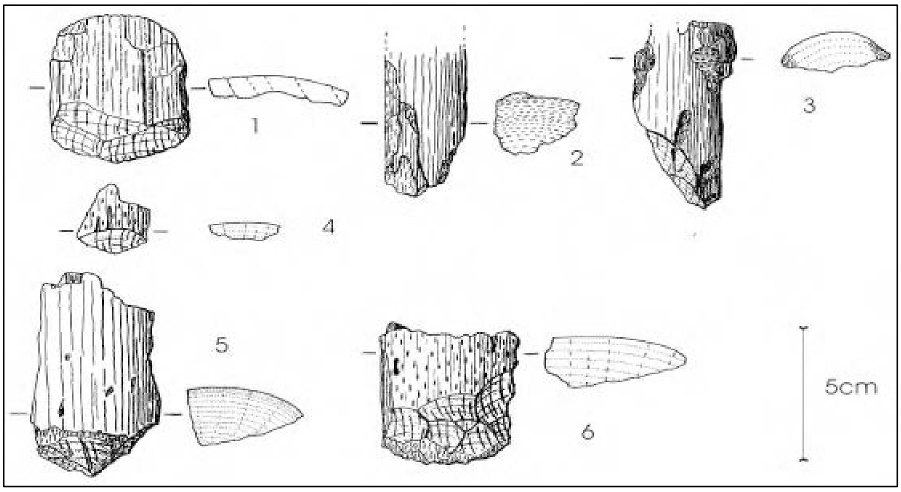

Figure 1 - Examples of small wood-samples sometimes capable of dendrochronological dating.

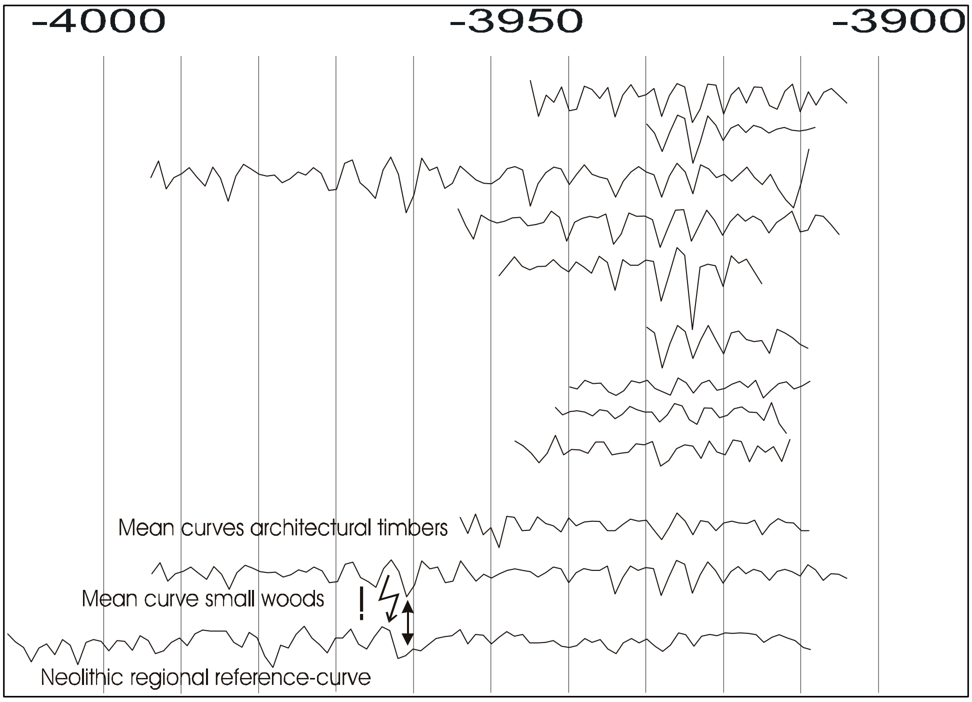

Figure 2 - Short ring-series of dendro-groups (above) and reference-curves (both detrended). The arrow marks a missing ring in the series of the small woods due to the small number of longer curves.

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This means that not only the ring-widths were taken into account but also the trend, species and features characterizing the sample as a whole as for example the shape (for a discussion of the term dendrotypology see Billamboz 2002). In a few instances it was possible to put pieces of wood back together just as an archaeologist does with potsherds. In order to integrate more and shorter series, I built many groups of similar curves with a high visual agreement thus creating longer mean curves for the comparison with the reference.

Results

45 series could be crossdated after sufficient tree curves had been included in these groups. Their mean chronologies had become long enough to allow for visual synchronization with the chronologies of the architectural wood. The presence of a characteristic sequence of ring-width variations in the master chronology (a ring-width 'signature') during the interval mentioned above improved the chance of successfully dating the short series. Experience has shown that among short series those of branches are the least reliable mainly due to pre-lethal phases (Schweingruber 2001) and mechanically induced flawed curves. On the other hand even tiny chips split from stem-wood can exhibit enough rings to yield a reliable synchronisation. Several pieces of just about an inch in radius showed about a hundred rings. One of the most important results was that two of the older layers very different in thickness represented equally long spans of time. These two layers were separated by the remains of a catastrophic fire that had burnt the village down. This fire was dated by A. Billamboz (A. Billamboz forthcoming).
Surprisingly the chips of the youngest two layers were often older than the fire and showed no duration exceeding the dates of their predecessors. The youngest dated wood was found in the thick layer after the blaze and thus in the middle of the stratigraphy.
The analysis of the distribution of wood-chips within the single layers showed that there was a time of concentration after the blaze while the time before this incident was rather characterized by diffusion. In the younger layers the concentrations fade again and the distribution becomes more diffuse.
Another interesting aspect was the anatomy: No preserved wood was cut in summer and there were hardly any fungi in the wood – save some in the outmost rings.

Discussion

The results were surprising at first since they obviously did not fit in with the stratigraphy. Of course we had expected the youngest dates to be in the youngest layers – but it did not turn out that way. Thus the dating of the single elements in the stratigraphy succeeded only partially.
The equally long duration of two layers very different in thickness point to ephemerally changed sedimentation processes after the fire. These are also reflected by the changing distribution of the woods in the layers. This is a step to understanding the distribution of archaeological finds and shows clearly that the lake constantly influenced the sedimentation.

It furthermore enables us to estimate the duration of the following layers. Since their structure is very similar to those that could be dated it appears reasonable to reckon with a similar span of time each. Thus the current estimation of the village´s duration is considerably longer than it has been up to now.
The interpretation of the fungi in the outmost rings is not easy. Fungi grow very quickly and their position in the wood means that the fungal growth was stopped very soon after the insedimentation. A possible explanation may be that the fungal growth was suppressed by low temperatures during winter and by the high seasonal water level of the lake during the warmer seasons. In the summer the winter-cut small woods were probably already so wet that they were not swept away with the rising tide as was all wood cut in summer.
If this hypothesis is true this means of course that we can hardly interpret the spectra of the species ecologically since we lack of all summer-cut wood (which is why these spectra will not be discussed in further detail here). Since the lake´s water level is about two meters higher in summer than in winter this implies also that the shore was flooded every summer. This fits perfectly in with the archaeo-ethnobotanical results and would mean that the houses were built on stilts. It also explains why all preserved wood was cut in winter for the summer-cut wood had no time to soak and was washed away. It does not appear likely to assume that the settlement was only seasonally inhabited just because we haven´t found wood cut in summer. This also fits the archaeobotanical results.

Conclusion

Small woods are a useful source of information and should be more frequently analysed. In this study it was possible to add some information on the beginning and duration of the settlement which probably began a bit earlier and lasted considerably longer than expected. Concerning the stratigraphy we showed that the lake played a major role in the genesis of the layers and we can estimate the effects of this quite exactly. It flooded the settlement every summer and thus washed some components of the cultural layers such as freshly cut wood away while others as for example soaked wood of the last autumn remained. This is particularly important when trying to interpret the remains and the spectra of many thousands of analysed small pieces of wood, twigs and all the architectural timbers from an ecological point of view. In this case it showed us the severe problems connected with this task . The dates also showed that the processes of sedimentation can change ephemerally and lead to false interpretations if not corrected by Dendrochronology. In this case layers of different thickness do not necessarily mean a different intensity of occupation.
Furthermore it was possible to demonstrate that – given a reliable masterchronology and a brief period for the possible results – short series of as few as twenty rings can be dated with a reasonable margin of certainty
Since the wood-anatomy and the fungi were the basis for the current interpretations this is therefore a reminder to pay attention to wood-anatomic features in order to use dendrochronology to its full extent.

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Dendroprovenancing ship's timbers. A pilot study on a Dutch 18th century 'ventjager'

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Introduction

The general consensus among archaeologists is that at from the year 1200 onwards, and possibly even earlier, Dutch indigenous oak forests were so severely depleted that wood had to be imported. A project involving both RING (the Dutch Centre for Dendrochronology) and the NISA (Netherlands Institute for Ship- and underwater Archaeology, Lelystad), which is part of the National Service for Archaeological Heritage Management (ROB, Amersfoort), has been initiated to find some first answers to the question of the origin of wood used in Dutch ships.

Our study is based on the fact that differences in climate, soil conditions and other environmental circumstances cause trees to grow at different rates. These differences are recorded in tree-ring sequences, and can be used to establish the exact provenance of timber. Our subject was an 18th-century shipwreck of a 'ventjager', which was found and excavated in 1971 near Swifterband (NL) and is now on permanent display at the NISA building in Lelystad. The aim of our study was to to establish the construction date of the ship and to determine the origin of the ship's timbers.

Material and methods

A 'ventjager' is type of a ship with a bun (i.e., a cargo hold with holes for water circulation, that is sealed from the rest of the ship), which allowed live fish to be brought from fishing boats to the market on shore (Beylen, 1970); selling provisions to the fishermen was done as a side business. The living room under the deck suggests that the crew of two men at the *ventjager* also lived on the ship.

The studied ship is 15 meters tall and largely intact, except for the mast and a large part of the board side of the hull (Vlierman, 1987). Except for four spruce (*Picea abies,* L. Karst.) timbers, the complete ship was made of oak (*Quercus spec.*), allowing for dendrochronological research as well as dendroprovenancing.

All timbers of the *ventjager* were sampled and the tree-ring pattern of each timber was measured and dated using standard dendrochronological methods. After dating, the measurements were clustered in order to obtain groups of similar measurements. The degree of similarity in a group of measurements can be estimated by calculating the (average) correlation coefficient. We have assumed that a group of measurements with an average correlation coefficient of 0,55 or higher originated from the same region. The value of 0,55 has been derived from research on bog oaks; since bog oaks are nearly always found on the exact place as where they grew, they indicate what average correlation coefficient can be expected from indigenous oaks that have grown on the same site. The growth patterns of bog oaks from the same site are characterized by average correlation coefficiens of > 5,2 (Jansma, 1995, chapter 5).

The mean curves of clusters of measurements were compared to all available chronologies from Europe, even though they were already dated. Of the matching chronologies, only the chronology representing the smallest known region of origin was refined by clustering the measurements that were used to make the chronology, so that the average correlation coefficient of the remaining cluster(s) was 0,55 or higher.

The final step was to add this refined group of measurements of the reference chronology to the cluster associated with the mean curve. The average correlation coefficient of the combined groups was computed to find out whether the tree-ring patterns were sufficiently similar. It was assumed that if the average correlation coefficient was 0,55 or higher, both groups originated from the same site; if the average correlation coefficient was lower than 0,55, we assumed a different origin. This procedure was repeated for all clusters.

To find out if certain regions within Europe provided more timbers of specific qualities or dimensions than others, each timber in the shipwreck was classified according to the shape of the timber. Four different classes of timbers were distinguished: (1) Beams; (2) Planks; (3) Curved timbers; (4) Repairs and small timbers (van Yk, 1697; Witsen, 1671). Next, the occurrence of classifications within the clusters was analysed.

We used standard dendrochronological measurement equipment including a microscope, measurement table and a PC, as well as a light table. Computer programs TSAP, CATRAS and COFECHA (Rinn, 1996; Aniol, 1987; Holmes, 1984) were used as analytical tools. Apart from the measurement series on the *ventjager*, our data consisted of all European chronologies available through the RING archive (Table 1).

Table 1: European master chronologies (after Jansma et al. 2002)

country	**region covered by the chronology**	CATRAS code used by RING	**author(s)**	**first year**	**last year**
Belgium	Meussevalley	MAAS672M	Hoffsummer 1989	672	1986
	paintings Flemish Masters	FRFLEMST	Lambert and Lavier, unpub.	1169	1518

country	region covered by the chronology	CATRAS code used by RING	author(s)	first year	last year
Germany	Ardennes-Eiffel area	AE1250MM	Hollstein 1980	94	1756
	Central Germany	WD400STD		400	1975
	central-southern Germany	EUBIG2ST	EU Contractnr. ENV4-CT95-0127	-681	1994
	Ems/Weserarea	EW1313MM	Hollstein 1980	1313	1617
	Hamburg	HAM1080M	Eckstein and Wrobel, unpub.	1080	1967
	Netherl. central-northern Germany.	EUBIG1ST	EU Contractnr. ENV4-CT95-0127	-971	1995
	lower Rhine	NR1326MM	Hollstein 1980	1326	1631
	Nedersaksen general	SAX959MM	Leuschner, unpub.	959	1873
	Nedersaksen heartland	NSSUB6HL		881	1992
	Nedersaksen coastal area	NSSUB7HL		865	1992
	Nedersaksen northwestern mountain area	NSSUB4HL		875	1992
	Nedersaksen eastern heartland	NSSUB5HL		880	1992
	Nedersaksen southern mountain area	NSSUB1HL		915	1873
	Nedersaksen Weserberg area 1	WBL1004M	Delorme 1972	1004	1970
	Nedersaksen Weserberg area 2	NSSUB3HL	Leuschner, unpub.	915	1991
	Nedersaksen western heartland	NSSUB9HL		876	1992
	lower coastal area	NKU1082M	Eckstein and Wrobel, unpub.	1082	1972
	eastern Frysia	OFR18MMM	Leuschner, unpub.	18	1992
	Rhine-Main area	RM1250MM	Hollstein 1980	440	1787
	Saar-Mosel area	SM1250MM		730	1975
	Sleeswijk Holstein	SH436MMM	Eckstein 1970	436	1968
	Westerwald Sauerland	WS1368MM	Hollstein 1980	1368	1773
	Westfalen	WF1260MM	Tisje, unpub.	1260	1972
	southern Germany	ZD631MMM	Hollstein 1965; Hollstein, unpub.	631	1950
	southern Germany (*laat)*	ZDLLAATT	Becker 1995	1300	1950
UK	General UK	ENG500MM	Baillie and Pilcher 1982	500	1981
	Baltic wood 1	GBBALTI1	Hillam and Tyers 1995	1156	1597
	Baltic wood 2	GBBALTI2	Hillam and Tyers 1995	1257	1615
	London	GBLONDON	Tyers, Hillam and Groves, unpub. (1994)	413	1728
	northern UK	GBNORTHC	Hillam and Groves, unpub. (1994)	1192	1663
	northern England-Wales	GBNORTHM	Hillam and Groves, unpub. (1994)	440	1742
	northern-central UK	EUBIG3ST	EU Contractnr. ENV4-CT95-0127	-991	1992
	southern UK	EUBIG4ST		-191	1990
	southern UK	GBSOUTHM	Hillam and Groves, unpub. (1994)	406	1594

country	region covered by the chronology	CATRAS code used by RING	author(s)	first year	last year
France	Bourgogne	FRBOURST	Lambert, Lavier and Bernard, unpub. (1994)	681	1991
	Fontainebleau	FRFB1531	Pilcher (gepubliceerd via de ITRDB)	1531	1979
	northern France	FRNO1274	Divers, unpub.	1274	1984
	Eastern France	FROO1360	Divers, unpub.	1360	1970
	Eastern France, Besancon	FREASTST	Lambert and Lavier, unpub. (1992)	582	1991
	Paris region	FRPARDST	Lambert, Lavier and Bernard, unpub. (1994)	848	1597
	Paris region	FRPAREST		1618	1984
	Western France	FRWESBST	Lambert, Lavier and Doucerain, unpub. (1994)	1093	1912
Netherlands	various construction wood	NBH1036M	Eckstein *et al.* 1975	1036	1972
	central Netherlands	NLCENTRAL	Jansma 1995	1023	1666
	northwestern Netherlands	NLNORTHERNM		1041	1346
	paintings Dutch Masters	SCH1115M	Bauch *et al.* 1972; Eckstein *et al.* 1975	1115	1643
	Twente 1	NTWE1357	Tisje, unpub.	1357	1724
	Twente 2	DV1272MM	De Vries, unpub.	1272	1578
	Twente-Westfalen	NLWF1040	Tisje, unpub.	1040	1972
	Zeeland/West-Vlaandere	NLZEELAN	Jansma, unpub.	824	1251
	southern Netherlands	NLSOUTHERNMM	Jansma 1995	427	1752
Baltic	central Poland	POLWSTDM	Krapiec, unpub. (1996)	449	1410
	north-western Poland	EUBIG7ST	EU Contractnr. ENV4-CT95-0127	813	1995
	eastern Poland	EUBIG8ST		770	1995
	eastern Pommeren	POL996MM	Wazny 1990	996	1985
	Poland	POLZWSTD	Krapiec, unpub. (1996)	1319	1994
	Wolin	POL1554M	Wazny 1990	1554	1986
Denmark and Sweden	Denmark and southern Sweden	EUBIG5ST	EU Contractnr. ENV4-CT95-0127	?	1974
	northern Sweden	EUBIG6ST		660	1991

Results and interpretation

A total of 127 samples were taken from the *ventjager*, of which 103 (excluding double measurements) could be dated. The samples date between 1174 and 1696 AD. If this latest date is corrected for missing sapwood, the earliest possible construction date of the *ventjager* is 1705.

Out of the 103 dated measurements, 3 clusters were formed (Table 2). Per cluster there is a different distribution of timber classes. The wood was not randomly applied: a closer look reveals that the wood from one batch has been processed in several different places, and not evenly throughout the ship (Fig. 1).

We were able to determine the provenance of two out of three clusters. The timbers in cluster1 originally grew in the area around Hannover (D); the timbers in cluster2 were derived from the area around Liege (B) (Fig. 2). The region of origin of the measurements in cluster 3 could not be determined, due to a regularly occurring growth reduction that most likely has been caused by the cockchafer (*Melolontha melolontha*) (Schweingruber, 1988). The resulting signal (periodicity) in the ring widths made it impossible to date the measurements with any of the chronologies.

Table 2: Nr = number of measurements; r = average correlation coefficient within the cluster; Chron. = matching reference chronology; PV = Percentage of parallel variation ('Gleichlaufigkeit'); P = significance level of the found level of PV.

	Nr.	**First and last year**	**R**	**Chron.**	**St-value**	**PV**	**P**
Cluster1	11	1571-1660	0.554	Sax959	10.65	82.8	0.001
Cluster2	11	1368-1668	0.593	Wd400std	10.98	70.3	0.001
Cluster3	18	1435-1570	0.629	N/A	N/A	N/A	N/A
Rest	63	1174-1696	<0.55	N/A	N/A	N/A	N/A

After clustering, a group of 60 measurement series remained that did not contain sub-groups of measurements with an average correlation coefficient > 0,55. Assuming that this lack of common signal is not caused by measurement errors and/or incorrect dating, this implies that this group reflects extremely varied growth conditions. In other words, the series in this group originate from widely different regions.

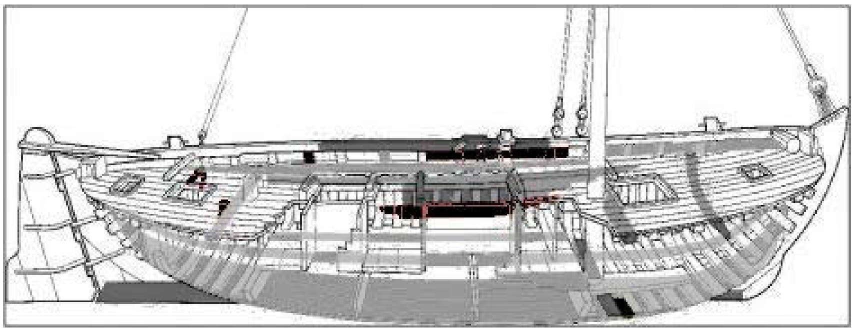

Figure 1: Distribution of the timbers from the three clusters. The timbers marked in black belong to cluster 1, the timbers marked with middle-grey are part of cluster 2 and the timbers marked with the two light-grey colours are part of cluster 3.

Figure 2: Map of the Netherlands and surroundings at the beginning of the 18th century. The area shaded in dark grey (without borderline) indicates the region of origin of cluster1. The area shaded in light grey (without borderline) indicates the region origin of cluster 2.

Discussion

Based on observations on indigenous bog oaks from Dutch sites (Jansma 1995), we assumed that an average correlation coefficient over 0,55 or higher between series indicates that these series represent trees from the same site. Obviously, this is a generalization and does not take into account the immense variety of relationships between annual tree growth and environmental factors. In addition, this approach is quite rude in comparison to other statistical methods.

When we compared the *ventjager* clusters with the measurements within existing chronologies, we again used 0,55 as a threshold value for determining whether the two groups of measurements (those of *ventjager* and those used to compile the chronology) originated in the same region or not. By doing so, we ignored the fact that the size of one cluster, when added to another cluster, will influence the average correlation coefficient of the combined group.

The latest end date we found for the timbers is AD 1696. Based on this date, we estimated the earliest possible construction date as AD 1705. This estimation should be treated with some caution, because of the following reasons:

We could not estimate the number of missing rings to the bark with any certainty, because no sapwood was present on this piece of wood. This means that 1705 should be regarded as *the year after which* the trees were felled. How much later this happened, cannot be established dendrochronologically.

A dendrochronological date tells us when a tree died, and not when its wood was put to use. When interpreting a dendrochronological date, one should take into account that timbers may not have been processed directly after cutting and that therefore the felling date me predate the construction date by some years. However, this last point does not weigh as heavily as one might think. Hollstein (1980) has shown that most oak timbers used in German buildings were processed within one year after felling. The reason is that when oak dries out, it becomes tough and therefore more difficult to saw or cut.

Our conclusion that the timbers in cluster1 originally grew in the area around Hannover (D) and the timbers in cluster2 in the area around Liege (B), is quite acceptable with regard to possible trade routes. Wood trade from the area around Hannover to the Netherlands was relatively easy to accomplish using respectively the Elbe river and the North Sea. The area around Liege is connected to the current Netherlands by the Meusse, and Jansma (1992; 1995) has already shown that oak from this area was used in the Netherlands in the 14th and 15th centuries.

Conclusion

Our study shows that comparisons with refined reference chronologies do indeed result in more detailed assessments of the origin of the timbers. The results clearly show the varying geographical origins of the different timbers in the ship.

Acknowledgements

We want to thank ir. Hans Polman (WUR) for his supervision at the university. A big hello and thanks goes out to the staff of NISA, Lelystad, who had to bear the brunt of our presence as well as to Morragon Software Development. A further acknowledgement is due to the people throughout Europe who helped us with our data, especially Hubert and Berbel Leuschner and Tomasz Wazny.

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Dating Flanders - towards a Flemish tree-ring chronology of oak

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Introduction

Dendrochronological dating can be applied on wooden remnants from the largest part of the Holocene. It presupposes that absolutely dated average tree-ring chronologies are available as a standard against which undated tree-ring patterns from the same or similar species can be matched. In northwestern Europe, however, for certain periods and regions such chronologies have not yet been developed. We have observed this to be the case especially in (some) coastal regions.

This phenomenon is caused, among others, by the fact that dendrochronology in Europe was first introduced in regions with a moderately continental climate (i.e., Central Germany), and only later became an accepted method in regions where maritime influences prevail. This means that in the latter regions less time and capacity has been invested in dendrochronology. The result is what can be termed a dendrochronological 'knowledge gap' regarding some coastal areas in northwestern Europe.

One of the regions that is badly represented in the dendrochronological data set, is western Flanders (North Belgium;). In 1989, Hoffsummer laid the foundation for tree-ring dating in Walonie (southern Belgium). His published Meusse chronology, which spans the period from AD 672 to 1986, was constructed from oak that grew in the vicinity of Liege. The chronology is similar to Hollstein's Central-German chronology (1980), due to the fact that Hoffsummer used Hollstein's chronology as the main standard for dating the Liege material. The common signal in the tree-ring patterns that contributed to the Meusse chronology, therefore, most likely reflect a response to relatively 'continental' weather conditions and a somewhat marked topography, rendering the chronology less suitable for the dating of (archaeological) oak felled in the flat coastal (maritime) region to the West.

Past Dutch efforts to develop dendrochronology likewise were not focussed on Flanders. In 1995, Jansma published a variety of chronologies that represent both indigenous oak (3rd millennium BC to 6th century AD) and oak brought in from current Germany (4th to 18th century AD) and eastern Belgium (Wallonie, 14th to 15th century AD). However, a relatively short chronology produced by Jansma for western Flanders and the adjacent part of the Netherlands (the province of Zeeland; AD 824 - 1251) remained unpublished, because of its low replication. This means that also in Dutch dendrochronology western Belgium remained out of the picture.

The aim of the current study is to remedy this situation. Since a few years, we have been systematically investigating oak from archaeological excavations in western Flanders. These series are well-suited for the production of a regional master chronology that can be used as a standard for dating. By presenting this chronology here, we hope to lay the foundation for further dendrochronological work in this region.

Material

In 1995, the Belgian Institute of the Archaeological Heritage (IAP) and the Municipal Archaeological Service (SAD) of Brugge started extensive archaeological research on the site of a future housing project behind the former Bruges prison for women, *the Refuge,* at Sint-Andries, which is a province in West-Flanders (Belgium; Hollevoet and Hillewaert 1997/1998). In 1996, excavations began at Sint-Andries, Molendorp, where land for a future housing project was prepared for building. Both investigations revealed settlement traces from Pre-Roman, Roman and Early Medieval periods. Initially, these traces were dated mainly by pottery. However, timber used in several buildings and (stave) wells offered excellent opportunity for a more precise dating of the structures. Further material was derived from a medieval settlement near the village center of Varsenare (Jabbeke), and from Damme, Oudenaarde and several other sites mainly in West Flanders.
The Dutch data set was derived from the RING-archive. It includes material that was dated by Jansma at Amsterdam University between 1985 and 1991, by Hanraets at the National Service for Archaeological Heritage Management between 1989 and 1991, and by Hanraets and Jansma at the latter institute since 1991. Part of the material was published by Jansma (1995).

Methods

General

In January 1998, we were able to date tree-ring series from an early-medieval water well excavated in the municipality of Breda (province of Noord Brabant; AD 428 – 670). The reference chronology we used was the German 'Ostfriesland' chronology (Leuschner, unpublished data). We were then able to date wood from a medieval well at Sint Andries (Flanders) against the dated Breda chronology (AD 462-539). We produced a mean Breda/St. Andries chronology, which was subsequently used to date other finds from Flanders. Using cross-dating techniques, we selected those measurement series from the RING-archive that agree well with the Breda/St. Andries chronology. We used these together with material from Flanders as the basis for our new chronology.

Estimating the chronology signal

The strength of the common signal in a chronology is indicative of its suitability for dating wood from the region represented by the chronology. Jansma (1995) showed that the Estimated Population Signal (EPS), which is commonly used in dendrochronology to assess the signal strength, has some characteristics that make it less suitable for the estimation of a chronology's signal. We therefore estimated the common signal of NLFlanders/1 by calculating the average running correlation between each individual measurement series and the average chronology of all other series in 50-year intervals, using COFECHA (Holmes 1984). Jansma (1995) has shown that, given sufficient replication, Dutch site chronologies of bog oaks are characterized by average correlations of about 0,5. We used this value as a rough threshold to discern between intervals with a sufficient (i.e. strong) and insufficient (i.e. weak) chronology signal.

We identified intervals where a weak chronology signal might be caused by low sample replication by straightforward comparison of the running correlation to changes of the number of individual tree-ring series included in the chronology. In this manner, we could discern between (a) intervals where a weak chronology signal in principle can be strengthened by inclusion of more dated time series, and (b) intervals where a weak signal is caused by other factors than sample depth and which therefore will not improve significantly when more series are added.

In order to assess the regionality of the chronology signal, we compared NLFlanders/1 to independent Belgian and German standard chronologies in the RING-archive, again using running correlation coefficients (50-year intervals).

Results and interpretation

The Dutch series that cross date well with the series from Flanders originate from excavations in different regions in the southeastern and eastern Netherlands (Fig. 1). The resulting average chronology, NLFlanders/1, runs from 218 BC to AD 1104 (Fig. 2). A separate Flanders chronology, comprised of the Flemish component of this data set, spans the intervals 218 BC to AD 208, AD 285 to 707 and AD 727 to 1051 (Fig. 2).

NLFlanders/1 has a low replication (n < 10) between 217 and 150 BC, AD 150-225 and AD 800-850 (Fig. 3). These are the intervals where a low internal correlation can be expected **if** replication plays a key role in the signal strength of these chronology intervals. However, between 217 and 150 BC the internal correlation in the chronology is higher than 0,5 (Fig. 4), meaning that the series in this interval have a strong common signal. This interval therefore does not need to be strengthened by including more series. The same holds for the interval AD 800 – 850. On the other hand, between AD 125 and 250 the average correlation in general remains below 0,5 (Fig. 4), meaning that in this interval replication indeed may be a factor of influence. If this is true, further inclusion of more dated series around this interval may well improve the reliability of this chronology interval.

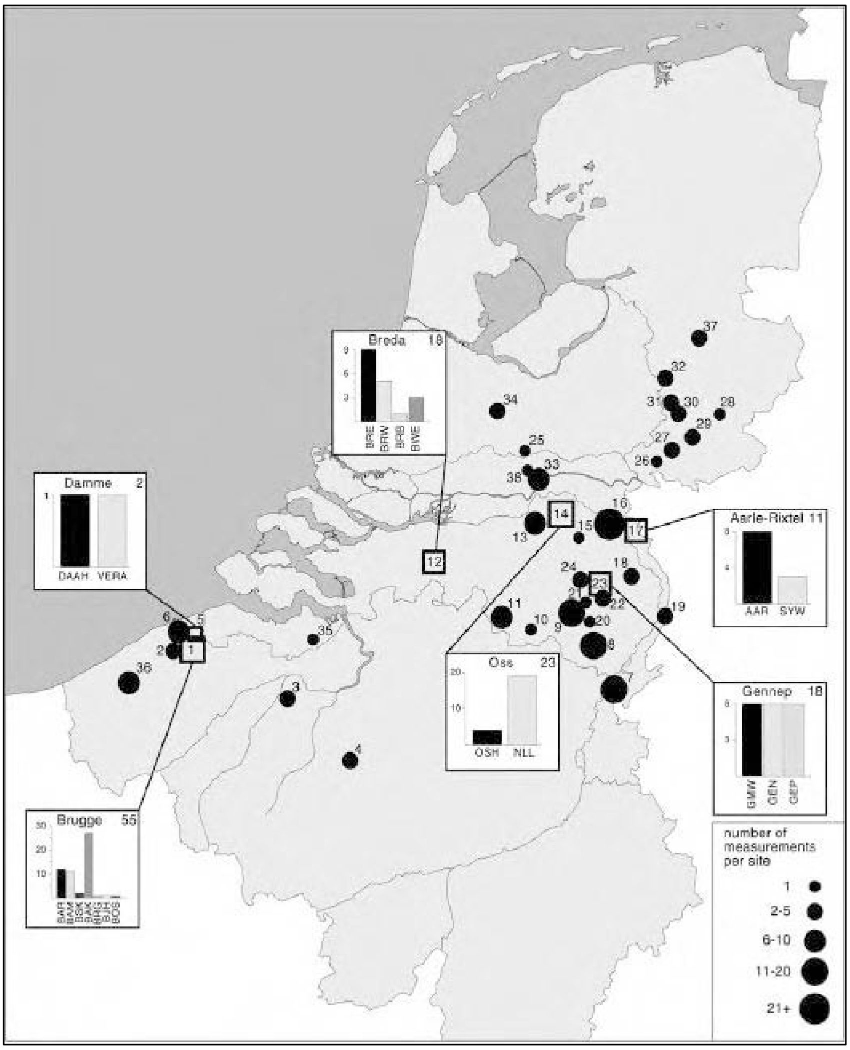

Figure 1: Map of archaeological sites represented by the NLFlanders/1 chronology. 1 = Brugge; 2 = Jabbeke; 3 = Merelbeke; 4 = Elewijt; 5 = Damme; 6 = Oudenburg Roksem; 7 = Stevensweert; 8 = Nederweert; 9 = Geldrop; 10 = Bergeijk; 11 = Reussel; 12 = Breda; 13 = Empel; 14 = Oss; 15 = Uden; 16 = Cuyk; 17 = Gennep; 18 = Venray; 19 = Venlo; 20 = Someren; 21 = Mierlo; 22 = Helmond; 23 = Aarle-Rixtel, Strijp; 24 = Lieshout; 25 = Wijk bij Duurstede; 26 = Didam; 27 = Wehl-Hessenveld; 28 = Borculo; 29 = Zelhem; 30 = Warnsveld; 31 = Eme; 32 = Deventer; 33 = Tiel; 34 = Utrecht; 35 = Hulst; 36 = Kortemark; 37 = Heeten Raalte; 38 = Malburg.

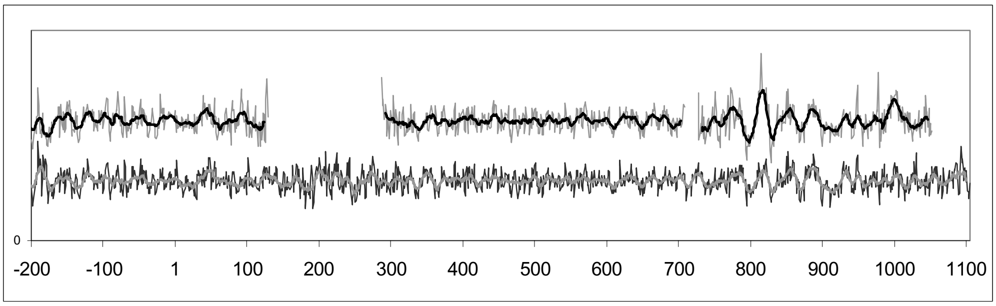

Figure 2: Average NLFlanders/1 (grey on black) and Flanders (black on grey) chronology

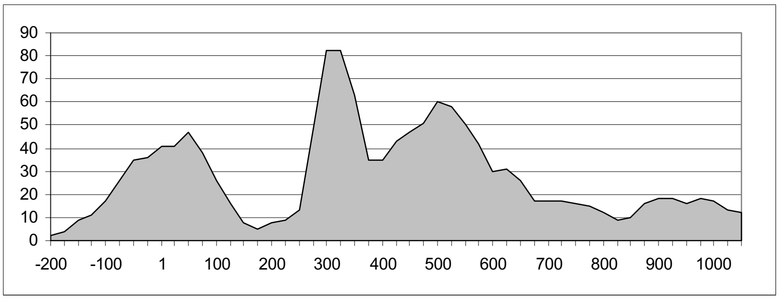

Figure 3: Replication of the NLFlanders/1 chronology. X-axis: years BC and AD; Y-axis: number of samples

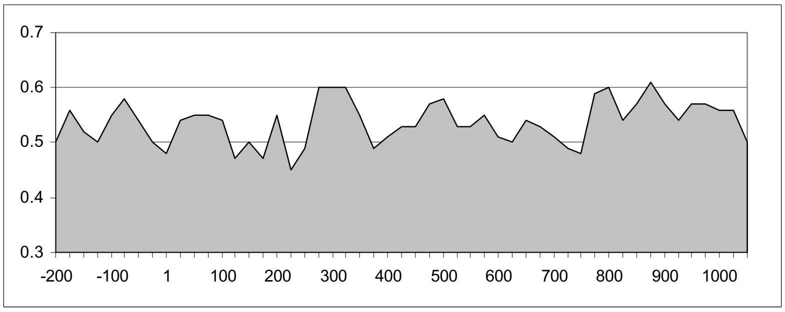

Figure 4: Internal correlation in the NLFlanders/1 chronology. X-axis: years BC and AD; Y-axis: average correlation per 50-year interval

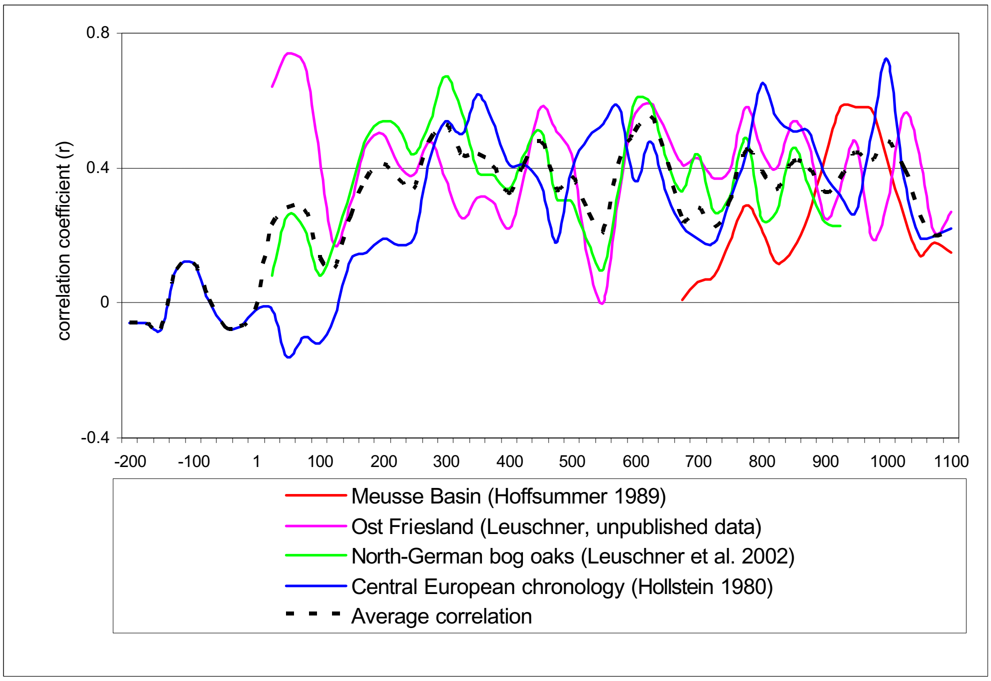

Figure 5: Running correlation with available master chronologies from Belgium and Germany

Between 218 BC and ca. AD 250, the average correlation between NLFlanders/1 and master chronologies from Germany is weak (Fig. 5). This is a consequence of the extremely weak correlation in this interval between NLFlanders/1 and Hollstein's Central European chronology (even negative correlations occur). Given the fact that the internal correlation in NLFlanders/1 is higher than 0,5 for most of this interval (Fig. 4), it is to be expected that NLFlanders/1 will prove useful for dating material from this interval that cannot be dated with the Hollstein chronology.

Most of the correlation series shown in Figure 5 dip to a minimum around AD 550 and AD 700 – 750. If climatic forcing played a role, these time intervals must have been characterized by a lack of predominant weather conditions over larger areas. However, for the period around AD 550 this conclusion is problematic, in view of the fact that around this time severe growth-reducing climatic factors, which may have been caused by a volcanic eruption or a meteor impact, influenced tree growth in larger parts of Europe (Baillie 1994). Other possible causes are (a) changing characteristics of the master chronologies themselves (i.e., lower replication, a different type of included material), and/or (b) increased felling activities in the relevant wood producing areas (which would have dampened the climatic growth signal in the tree-patterns of the remaining trees).

The weak average correlation with the available Belgian and German standard chronologies around 1100 (Fig. 5) could be caused by the decreasing replication of NLFlanders/1.

Hoffsummer's Meusse Basin chronology shows little agreement with NLFlanders/1 (Fig. 5). In view of the proximity of the Meusse Basin to both Flanders and the Dutch sites included in NLFlanders/1, one would expect higher correlations. However, Hoffsummer's chronology is built from material dated against Hollstein's more continental chronology (1980) and as a result probably reflects quite different weather conditions and a somewhat marked topography. Therefore its low correlation with NLFlanders/1 is not altogether surprising.

Discussion

The strong similarity between archaeological tree-ring series from Flanders and locations as far away as the central-eastern Netherlands (Fig. 1) is surprising. It was our first ntention to produce a Flanders chronology of indigenous oak. The distribution of sites, however, leads to the hypothesis that the oaks represented by NLFlanders/1 were brought in from an area at some distance from the spots where they were put to use. In this case, the Meusse and Rhine would have been the most likely route of transport. Given the fact that NLFlanders/1 includes series from river oaks found in the Meusse sediments at Stevensweert (Fig. 1), the Meusse is the more likely of the two. However, there are some arguments against this hypothesis:

Most series from Flanders were either dated against each other, or against chronology NLRom-R (Jansma 1995, updated version), which represents Dutch indigenous (bog) oaks from low, moist sites. Other important chronologies were the North-German Ostfriesland chronology by Leuschner (unpublished), and NLRom-W1, a Dutch chronology representing archaeological timber from the western coastal Netherlands (Jansma 1995). These three chronologies all represent oak from coastal, 'maritime' sites. They do not include oak transported along the Meusse or Rhine and, therefore, neither do the Flemish samples dated against them.

The later part of NLFlanders/1 is partly comprised of timbers from revetments at the Dutch town of Tiel. Dating these timbers was problematic, due to their lack of similarity to existing chronologies from this period. The average Tiel chronology proved useful in dating some Dutch ship wrecks that could not be dated otherwise (RING, unpublished data). This elaborate process in our opinion points to a local origin of the wood.

After completion of the study presented here, we were able to date oak posts from a farmhouse at Borsele (Zeeland) against NLFlanders/1 (RING 2002, unpublished data). The habitants of this site used local resources when building, which is illustrated by the fact that incidentally they even used Neolithic bog oaks that were preserved in the immediate surroundings (RING, unpublished data).

The question about the origin of the wood can not yet be solved. During future studies we will keep an open mind towards the possibility that (a) NLFlanders/1 represents indigenous oak from local, moist sites in the immediate surroundings of the archaeological sites where they were put to use, and/or (b) it represents oak transported over larger distances.

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Tree-ring research on Dutch and Flemish art and furniture

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Introduction

Between AD 1500 and 1700, in The Netherlands high-quality art and furniture was produced. The question of the historical meaning of these pieces is, among others, related to their exact age. Dendrochronology can contribute to the determination of their creation dates; usong cross-dating techniques, we can determine the calendar years during which the oak trees used for pieces of art and furniture were felled. Such dates provide a *terminus post quem* for the creation of these pieces. In addition, dendrochronology can be used to identify the provenance of the wood.

Dendrochronological research on Dutch panel and Flemish paintings is common since the 1970's (e.g., Eckstein *et al.* 1975; Fletcher 1978; Klein 1986). However, less attention has been paid to research on Dutch and Flemish furniture and sculptures. Our research on these types of objects is a response to the increasing demand from, among others, museums and art dealers in The Netherlands (Fig. 1).

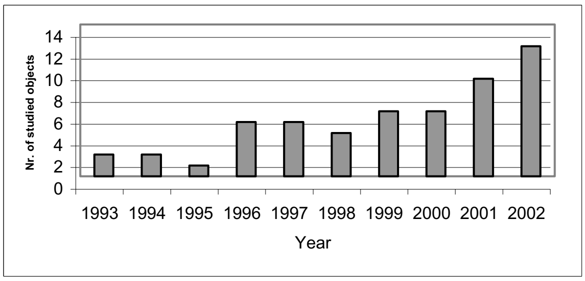

Figure 1 - Number of dating commissions on art and furniture per year

Material and methods

The 51 items we studied represent a variety of object types. They include 15 panel paintings (e.g. Fig. 2), 11 sculptures (e.g. Fig 3), 15 cabinets and chests, 3 desks and tables, an organ, a pulpit and a dolls house, and other items.

Figure 2: 17th century forgery (Museum Flehite, Amersfoort (NL)

Figure 3: 15th-century statuette

Research in most cases took place *in situ*, at the restoration workshop or museum where the pieces were held. Some relatively small sculptures were analyzed in the laboratory. We mostly used straightforward visual techniques to measure the wood. First, if necessary (and desirable), a narrow section of the wood (2 – 4 mm) was cut with a scalpel from the outer to the inner ring, in order to reveal the cell structure. When working for the Rijksmuseum in Amsterdam, restaurateur Paul van Duin prepared the wood using a small wood plane. Next, chalk was rubbed into the wood, in order to set off the ring boundaries. In some cases we had access to adjustable microscopes, but mostly we measured the ring widths using a simple lens. We measured relative ring width, meaning that we assigned a number (index) to each ring width in comparison to the surrounding ring widths, which is very much like the visual 'skeleton-plot' technique.[1] The essentials of our method are shown in Figure 4.

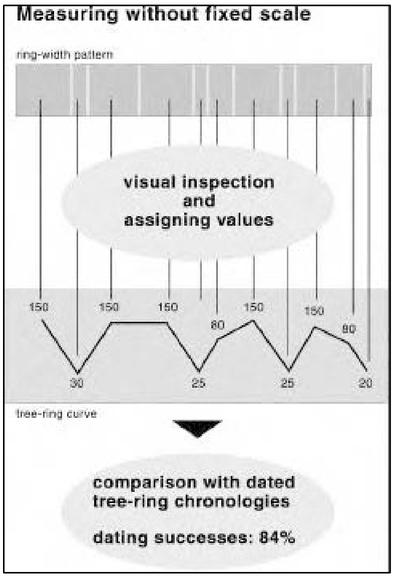

Figure 4: Schematic presentation of the visual measuring method

We dated the measurement series against the standard chronologies in the RING archive (the Baltic region, Belgium, France, Germany and the Netherlands; Jansma 1992) using standard cross dating methods. Based on the origin of the chronology that provided the best match, the most likely region of

[1] e.g., http://tree.ltrr.arizona.edu/skeletonplot/introcross date.htm

origin was deduced for each piece of wood. We then grouped the ring-width series according to this origin, detrended the series and calculated average chronologies using standard dendrochronological approaches (Dendrochronological Program Library DPL[2]; COFECHA (Holmes 1983); CRONOL default option (50% variance preserved at a wavelength of 128 yrs)).

Results and interpretation

Of the 185 measurement series, 159 could be dated against existing standard chronologies (Table 2) or, incidentally, by internal cross dating (Table 1, 2nd collumn). In this manner, 43 objects out of a total of 51 could be dated, which is a success rate of 84%. The chronological distribution of the end dates of the objects is shown in Figure 5.

Table 1 - Provenance of the studied wood

Provenance	**Chronology code**	**Author(s)**	**Chronology description**	**Nr. of matching samples**
Unknown	Internal match			16
Baltic	GBB1	Hillam and Tyers 1995; ibid., personal communication	Chronology of Baltic wood	65
Baltic	NLPP	Eckstein, Brongers and Bauch 1975	Chronology of Dutch paintings	22
Baltic	GBB2	Hillam and Tyers 1995; ibid., personal communication	Chronology of Baltic wood	4
Baltic	FRFP	Lambert and Lavier, personal communication	Chronology of Flemish paintings	3
Baltic	Eubig7	Leuschner, personal communication	EU-project ADVANCE 10-K, West Poland	2
Baltic	Polen	Wazsny, personal communication	Polish chronology	1
Baltic	Eubig8	Leuschner, personal communication	EU-project ADVANCE 10-K, East Poland	1
Total Baltic				**98**
German	DLSO	Hollstein 1965	South German chronology	22
German	DLCE	Hollstein 1980	Central German chronology	16
German	NLHist-1	Jansma 1995	Chronology of wood imported from central Germany	5
German	DLWF	Tisje unpublished data; De Vries, personal communication	Eastern Netherlands and adjacent Westphalia	2
Total German				**45**

[2] www.ltrr.arizona.edu/software.html

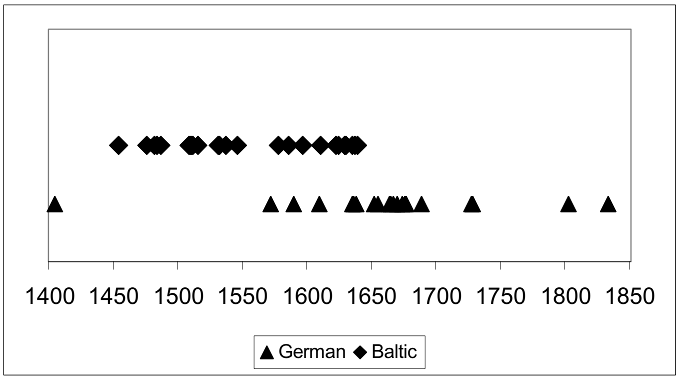

Figure 5: Chronological distribution of the end dates of the studied objects. German = series dated against German master chronologies; Baltic = series dated against Baltic master chronologies.

Most studied wood (98 series) was imported from the Baltic region (Table 2). This Baltic oak most often was used in art objects (paintings, sculptures, altar pieces; Fig 6a). The remaining wood (45 series) was obtained from South and central Germany and used mostly for cabinets, tables and such, less than 25% being used for paintings and altar pieces (Fig. 6b). Both groups of measurement series were detrended and, after removal of (parts of) series showing low correlation with the bulk of the material, compiled into average chronologies (Fig. 7). The new 'Baltic import' chronology covers the period from AD 1167 to 1637 (Table 2). The 'German import' chronology, from which one anomalously early object was excluded (Fig. 5, end date ca. 1400), covers the interval from AD 1360 to 1837 (Table 3).

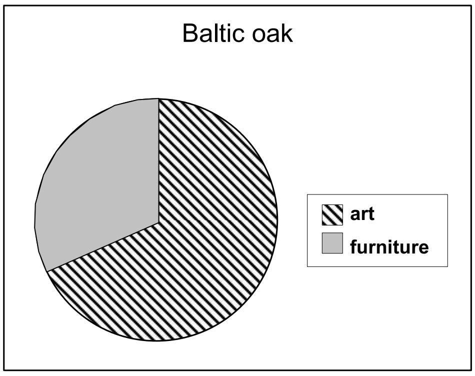

Figure 6a - The application of Baltic oak

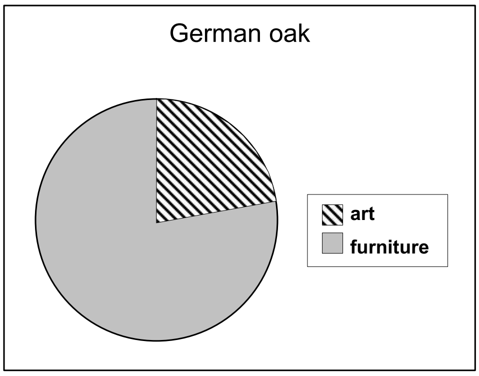

Figure 6b - The application of German oak

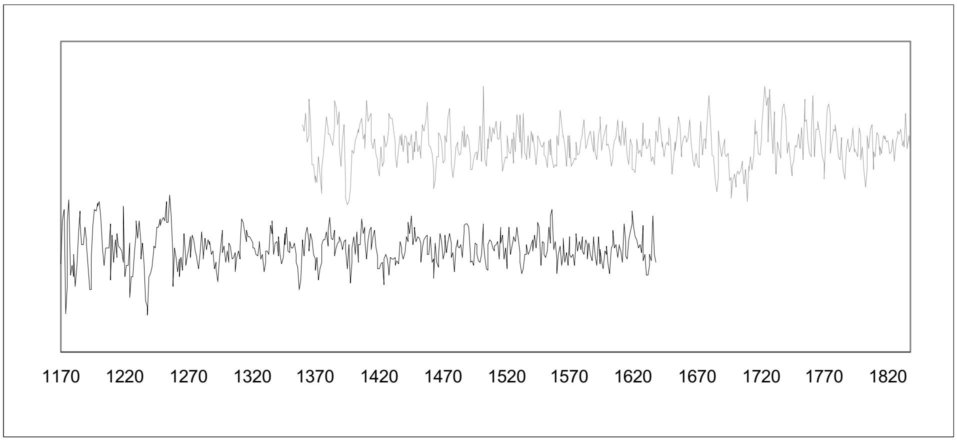

Figure 7: Average chronologies of imported Baltic (black) and German (grey) oak

The overlap between the end dates of the studied material (AD 1576 – 1637; Fig. 5) can be used to infer the decennia during which in Belgium and The Netherlands both Baltic and German wood was used by carpenters and artists. When calculating this interval, we should keep in mind the minimum number of missing sapwood rings (ca. 20) and minimum aging period of the wood (4 years)[3]. The correction for these factors shifts the overlapping interval to ca. 1600 - 1660. Our data before ca. 1600 point to a preference of Baltic timber, after ca. 1660 only German wood was used. The switch to German oak coincides with the British Navigation Acts, a series of laws which, in 1651 and 1660, successfully restricted Baltic trade by the Dutch.

[3] Only dry oak was used for art and furniture, in order to prevent morphological deformations of the end products.

Table 2 – Average annual-growth indices in the 'Baltic import' chronology of oak

Year	year+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
1167	159	48	63							
1170	85	127	137	37	63	126	147	74	84	73
1180	94	63	84	115	136	125	104	104	120	109
1190	104	83	60	61	91	122	138	136	144	140
1200	145	130	99	84	84	100	101	101	123	70
1210	113	86	108	91	115	102	100	97	86	140
1220	73	83	83	105	53	73	73	97	114	127
1230	110	127	105	90	105	85	50	44	35	72
1240	76	82	99	102	101	120	121	128	122	127
1250	130	127	145	125	125	152	131	91	63	101
1260	92	78	89	73	92	79	114	90	83	93
1270	101	112	92	113	108	98	92	90	80	96
1280	116	95	89	110	99	109	103	107	94	98
1290	81	86	80	68	88	104	117	96	102	87
1300	97	87	105	102	89	92	96	78	92	98
1310	90	102	128	126	115	106	118	111	111	109
1320	105	100	101	95	93	104	107	90	95	78
1330	87	97	98	95	122	114	127	94	105	106
1340	93	112	94	85	92	114	104	120	97	96
1350	107	100	100	105	94	86	82	60	70	108
1360	106	93	114	121	106	98	115	109	94	89
1370	79	91	69	80	86	103	108	109	116	102
1380	118	130	110	108	118	93	101	105	106	112
1390	107	99	106	108	99	81	104	67	87	100
1400	111	95	116	86	103	104	129	115	121	109
1410	90	109	118	120	99	112	118	101	93	81
1420	81	85	87	65	89	94	90	77	74	91
1430	90	89	91	83	88	85	106	101	96	89
1440	96	111	107	126	115	132	103	113	120	106
1450	112	110	105	86	100	109	112	113	94	94
1460	111	86	89	71	105	87	82	93	115	107
1470	89	97	113	96	106	115	105	91	96	77
1480	100	109	102	100	103	92	116	122	123	123
1490	120	93	86	88	84	105	103	94	88	86
1500	94	123	106	91	80	79	103	109	106	100
1510	98	102	103	107	90	120	105	113	89	100
1520	81	96	120	95	102	110	111	106	121	108
1530	96	86	76	80	94	94	104	95	97	104
1540	108	97	113	101	117	126	120	84	107	105
1550	95	91	98	121	105	131	137	99	107	89
1560	76	95	102	83	94	110	87	96	84	111
1570	95	91	95	84	106	115	97	107	99	111
1580	98	95	108	103	90	105	95	88	111	108
1590	93	83	112	85	99	88	80	98	94	102
1600	85	76	100	104	117	100	104	91	103	102
1610	98	86	123	106	93	89	108	116	124	136
1620	121	111	108	108	100	103	96	122	88	95
1630	75	75	83	94	88	131	94	87		

Table 3: Average annual-growth indices in the 'South- and central-German import' chronology of oak

Year	year+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
1360	119	114	131	103	109	144	122	81	81	64
1370	70	64	89	71	53	78	90	109	127	115
1380	110	110	104	99	118	143	136	119	132	100
1390	80	106	119	63	48	43	45	57	93	95
1400	92	104	108	115	112	121	126	105	111	97
1410	143	123	128	130	104	96	106	90	86	80
1420	70	98	80	84	108	98	102	116	130	126
1430	126	114	103	91	78	96	109	100	111	94
1440	109	107	83	102	100	110	85	102	94	114
1450	94	100	87	93	120	113	122	139	142	99
1460	98	92	76	57	65	89	88	112	109	102
1470	83	85	109	102	128	135	88	82	68	80
1480	98	102	96	90	92	113	98	118	98	111
1490	105	88	77	77	85	91	94	86	95	118
1500	84	139	156	85	79	106	96	118	103	116
1510	111	114	122	105	105	122	108	74	83	88
1520	87	109	94	91	105	83	112	94	129	118
1530	102	129	87	130	92	89	86	108	87	114
1540	102	111	96	81	96	109	106	100	98	102
1550	90	89	78	104	90	106	87	78	81	79
1560	108	100	133	119	107	108	100	79	108	87
1570	109	80	83	87	85	103	90	91	104	111
1580	114	125	97	101	103	108	113	101	94	113
1590	91	86	111	116	128	95	106	114	120	99
1600	101	95	79	87	95	104	107	124	102	108
1610	99	123	99	116	110	88	81	105	100	77
1620	77	73	95	106	92	95	89	121	100	106
1630	96	98	104	106	84	89	81	114	113	103
1640	128	114	98	103	88	99	102	99	117	105
1650	71	87	102	95	109	127	119	88	97	105
1660	108	106	103	105	124	101	89	85	80	91
1670	81	78	95	122	90	106	105	97	122	148
1680	123	94	90	89	66	55	69	113	99	88
1690	100	105	92	89	92	65	68	48	65	72
1700	60	69	74	71	76	84	78	62	77	46
1710	80	74	88	76	89	125	111	114	91	90
1720	107	117	137	156	138	146	103	153	123	92
1730	132	108	72	103	94	87	102	135	140	126
1740	128	91	103	86	70	79	84	100	98	111
1750	110	96	116	85	144	123	125	103	91	88
1760	111	147	89	115	115	122	113	102	89	83
1770	67	104	135	140	129	92	104	115	114	119
1780	109	89	86	107	98	76	67	96	105	103
1790	94	99	117	93	97	94	89	116	108	86
1800	98	73	60	77	108	97	115	119	76	94
1810	89	112	108	90	98	91	108	105	109	102
1820	104	91	94	93	105	84	102	109	113	110
1830	115	99	104	98	131	97	109	94		

Conclusion

The data set we studied is small, and general inferences based on small data sets are necessarily shaky. However, if our data are correct, they indicate that before ca. 1600 artisans and artists in the Netherlands mainly used oak derived from the Baltic, and that around 1660 a switch occurred to oak from South and central Germany.

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The role of Dendrochronology in the protection of the Cultural Heritage.
Progress report of the dendrochronological analyses for BACPOLES

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Introduction

In Europe over the last ten years there has been a strong interest in active heritage management, because of ever increasing building activity and the treaty of Valletta (Malta)[1]. We, for instance, have become aware of the need to monitor protected archaeological sites, because the soil, as an environment for cultural heritage, is far from stable. In the EC-funded project BACPOLES[2] experts in heritage management, wood and soil research as well as bacteriology from Italy, Great Britain, Sweden, Germany and The Netherlands work together. They study the causes of degradation of waterlogged wood from terrestrial and marine archaeological sites as well as of foundation piles from historical buildings. Dendrochronology was used to determine the felling date and the origin of the trees that were used as building timber. This paper deals with the preliminary dendrochronological results of the ongoing BACPOLES project.

A great part of the above ground cultural heritage in north-western Europe is built on wooden piles. This technique was applied roughly since the Middle Ages when towns started to expand and new habitation areas had to be found on wet and unstable ground. These foundations were formerly considered safe from decay due to the waterlogged conditions where oxygen is absent until in the nineteen-eighties when it became clear that wooden foundations can be seriously damaged by bacteria (Fig. 1). In some cities even whole quarters are threatened by collapse.

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[1] For the English text of the treaty of Malta go to http://www.archis.nl

[2] *Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites* (duration: 2002-2005; contract number EVK4-CT-2001-00043); http://www.bacpoles.nl

Figure 1: Collapsed foundation (Photo: Fugro)

Figure 2: Cross-section of pine with bacterial degradation (Liese 1955).

Unlike soft rot, a fungal infection that occurs in the transition zone between wet and dry conditions, bacterial decay can also occur below the groundwater table, where the concentration of oxygen is low or even zero. The same holds true for waterlogged wood in archaeological sites. The bacterial degradation of waterlogged wood (Fig. 2) is a slow process. None the less it is a great danger, especially in the case of protected, not yet excavated archaeological sites. The problem is not only the deterioration of the wooden constructions but also the loss of important information about traces of woodworking or natural traits like sapwood and bark. There is already a vast amount of literature on degradation processes in waterlogged archaeological and historical wood (for an overview and further literature, see Kars & Smit 2003 or the BACPOLES website[3]).

When investigating the causes of degradation it is important to assess the time span in which these processes take place. Dendrochronology can provide the exact felling dates and the time period between felling and timber use in case of recent (nineteenth, twentieth century) historical buildings, where the building date is mostly documented.

Besides dating, dendrochronology offers the possibility to trace the origin of the trees used (=dendroprovenancing). Timber import and transportation have consequences for the time period between felling and use. It also offers the possibility of studying possible relationships between the origin and the quality of the wood, which again can affect its susceptibility to bacterial degradation.

Material

To be able to keep an overview of the large amount of samples and the variety of sampling contexts and wood species, we decided to include all information about the samples as well as the results of the dendrochronological analysis in five tables, which you'll find below.

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[3] http://www.bacpoles.nl

Figure 4: Excavated foundation piles in Amsterdam (Photo: Fugro).

Figure 5: Archaeological wood: central pile of Roman farmhouse (Photo: ROB/RING).

Although BACPOLES is a European research project, most of the sampling of foundations of historical buildings has taken place in The Netherlands, where the problem of rotten piles has been recognized for some time and where the idea for the project originated. Until now the foundations of six houses in Amsterdam (Fig. 4), Rotterdam, Haarlem, Dordrecht, Leeuwarden and Koog aan de Zaan (The Netherlands) as well as the Parliament of Stockholm (Sweden) and a palace and bridge in Venice (Italy) have been sampled (Table 1).

Table 1: Historical foundations sampled within the BACPOLES project and the preliminary results of dendrochronological dating and provenancing of the wood samples.

Country	**Name of site and building date**	**Building date**	**No. and type of samples**	**Wood species**	**Dating result**	**Provenance of the wood**
NL	Amsterdam	AD 1918	4 complete stem discs	*Picea abies*	Not dated yet	-
NL	Dordrecht-Anna Paulownastraat	AD 1931	11 complete stem discs	*Picea abies*	AD 1816-1929	South Germany
			1 complete stem disc	*Pinus sylvestris*	AD 1875-1929	Lithuania
NL	Rotterdam-Joubertstraat	AD 1901-1905	1 complete stem disc	*Picea abies*	Not dated yet	-
			2 complete stem discs	*Abies alba*	Not dated yet	-
NL	Koog a/d Zaan-Irisstraat	AD 1937	3 complete stem discs	*Pinus sylvestris*	Not dated yet	-
NL	Haarlem-Jan Nieuwenhuizenstraat	c. AD 1900	(6 complete stem discs)	(*Populus* spec.)	(Not analyzed)	-
I	Venice, Ponte Balbi	16th century AD	3 stem discs	*Larix spec.*	Not dated yet	-
			1 core sample	*Quercus robur/petraea*	Not dated yet	-
I	Venice, Palazzo Balbi	9th-10th century AD	4 complete stem discs	*Pinus sylvestris*	Not dated yet	-
S	Stockholm, Parliament	AD 1895-1905	2 complete stem discs	*Pinus sylvestris*	AD 1748-1890	Nemdeö, Southwest Sweden
NL	Leeuwarden	19th-20th century AD	1 complete stem disc	*Pinus sylvestris*	AD 1849-1901	Nemdeö, Southwest Sweden

A list of the archaeological sites that have been sampled for BACPOLES so far -nine in The Netherlands and five abroad (Germany, Sweden)- is given in Table 2. At the terrestrial sites the aim was to sample so-called structures (i.e. houses, fences, wells) instead of mobile objects, but this wasn't always possible. Where possible, wood used for building foundations (Fig. 5) was sampled, because it provides an analogue to the foundation piles of historical houses. Another advantage of sampling foundation wood is that one might assume it was used when it was still quite fresh, so the felling date of the tree approximates the building date of the structure. In addition, there is less chance of sampling re-used wood.

Table 2: Archaeological sites sampled within the BACPOLES project and the preliminary results of dendrochronological dating and provenancing of the wood samples.

Country	**Name of site**	**Type of object**	**No. + type of samples**	**Wood species**	**Dating result**	**Provenance of the wood**
NL	Dokkum-Koningstraat	Well from town site	5 stem-disc fragments	*Quercus robur/petraea*	AD 1378-1479	Central-Southern Netherlands/Central-South Germany
NL	Dokkum-Koningstraat	Barrel from town site	5 stem-disc fragments	*Quercus robur/petraea*	AD 1128-1375	Baltic/East Pommern (Germany), Poland
NL	Borsele-Ellewoutsdijk	Rural house site	2 complete stem discs	*Quercus robur/petraea*	AD 22-99	Western Netherlands /Roman road near Utrecht (Netherlands)
NL	Vleuten-De Meern 4	Shipwreck on land	1 stem-disc fragment	*Quercus robur/petraea*	AD 35-99	Roman road near Utrecht (Netherlands)
		Embankment	1 complete stem disc	*Ulmus spec.*	AD 7-98	Central Germany
NL	Burgzand-Noord 3	Shipwreck, marine	1 stem-disc fragment	*Quercus robur/petraea*	AD 1503-1608	Netherlands/Central-North Germany
			1 stem-disc fragment	*Pinus sylvestris*	AD 1513-1626	Southeast Norway
NL	Burgzand-Noord 15	Shipwreck, marine	2 stem-disc fragments	*Quercus robur/petraea*	AD 1370-1628	Central-South Germany/Lower Saxony (Germany)
			1 stem-disc fragment	*Pinus sylvestris*	No date	-
G	Travenhorst	Castle site	4 complete stem discs	*Quercus robur/petraea*	No date	-
S	Stora Sofia	Barrel from shipwreck	3 stem-disc fragments	*Quercus robur/petraea*	AD 1487-1614	Wollin (Poland)/East Friesland (Germany)
S	Lidan	Shipwreck, marine	2 stem-disc fragments	*Quercus robur/petraea*	AD 1085-1384	Netherlands/Central-North Germany /Central Poland
N	Bryggen	Town site	1 complete stem disc + 2 fragments	*Pinus sylvestris*	No date	-
S	Mollösund	Shipwreck, fresh water	1 complete stem disc	*Quercus robur/petraea*	No date	-
NL	Elst-St.Maartenstr.	Temple site	6 stem-disc fragments	*Quercus robur/petraea*	58 BC-AD 86	Central-North Germany/ Netherlands
NL	Flevoland, plot no. GZ-80	Shipwreck on land	4 stem-disc fragments	*Quercus robur/petraea*	AD 1416-1533	Twente (Eastern Netherlands)/West Falia (Germany)
NL	Flevoland, plot no. KZ-47	Shipwreck on land	2 stem-disc fragments	*Quercus robur/petraea*	AD 1438-1503	Central Netherlands and Twente (Eastern Netherlands)

Because of the importance of studying the quality of archaeological wood in many different contexts, shipwrecks on land and under water were also included in the sampling. However, the period of time between the ships being built and sinking in many cases remains uncertain or unknown, as do the exact conditions the ships have been subjected to before they sank and became buried.

Methods

Sampling strategy

Standard requirements for dendrochronological sampling include collecting several samples from the same context or building phase that have an ample number of rings and, if possible, sapwood or waney edge.

Our aim was to collect at least four dendro samples per site. Some of the pre-selected (archaeological) sites did not yield more than one or two dendro samples. This was due to difficult sampling conditions (for instance under water), rarity of (suitable) wood in that particular site, or because the site proved to be of significant archaeological importance and it was decided not to continue excavating to find appropriate samples.

Where possible, complete stem discs were collected. For instance, at a number of the historical sample sites foundation piles are seriously affected and have to be replaced, which creates very good opportunities for sampling. In case of double rows of piles it was possible to extract complete piles too. In case of single rows of piles it was sometimes possible to replace a sampled part of a pile with different material. Otherwise radial slices or increment cores (diameter 1 cm) were taken. The quality of cores from waterlogged wood was less in comparison to the other samples. They tended to twist or compress and broke relatively easy.

Sample preparation and measurement

To prepare a radial trajectory to detect and measure ring widths razor blades or surgical blades (for the discs) and a Stanley knife (for the cores) were used. To visually enhance the cell structure powdered chalk was rubbed onto the surface of the wood. On conifer samples four radials were measured on each sample whereas for oak one or two were sufficient to establish a reliable tree-ring sequence for dating.

Dendrochronological dating and provenancing

To absolutely date the samples, regional standard chronologies of oak (*Quercus robur*/*petraea*), Scots pine (*Pinus sylvestris*), European spruce (*Picea abies*) and silver fir (*Abies alba*) from different European countries are available in the database of RING, The Netherlands Centre for Dendrochronology (Jansma *et al*., 2002).

Although conifers were extensively imported from Scandinavia and Germany for piling on a large scale, as in The Netherlands between approximately 1875 and 1960, the cultivation of Dutch Scots pine for coal mines and houses cannot be ruled out (Buis, 1993). Some experts (René Klaassen, SHR Foundation for Wood Research and Herman Keijer, Fugro Engineers, personal communication) believe that foundation piles encountered in nineteenth- and twentieth-century houses in The Netherlands measuring over thirteen metres are mostly imported (German, Scandinavian) European spruce and those measuring up to seven metres are usually local (Dutch) Scots pine. Up to now no standard chronologies for *Pinus sylvestris* from The Netherlands are available. In previous attempts to date coniferous wood from historical buildings in The Netherlands (Sass-Klaassen, 2000), the same problem was encountered.

Results

From a total of over one hundred wood samples from historical buildings and archaeological sites that have been sampled for BACPOLES so far, 77 samples were selected for dendrochronological analysis (Tables 1, 2 and 3). The quality of the sample material and the results of the analyses are discussed below. Furthermore, Table 3 summarises some basic characteristics of the samples such as number of rings and the presence/absence of waney edge.

Table 3: Basic characteristics of the dendrochronological samples analyzed for BACPOLES.

Type of site	No. of samples	Wood species	No. of rings			Form of sample	No. of samples with	
			Min.	Max.	Average		Sapwood	Waney edge
Archaeological	38	Oak	20	294	91	(Part of a) disc	21	9
	1	Elm	82	82	82	Disc	-	1
	5	Scots pine	22	155	79	(Part of a) disc	?	3
Total	44							
Historical	1	Oak	55	55	55	Disc	1	1
	16	European spruce	39	113	62	Disc	-	16
	11	Scots pine	12	147	61	Disc or core	?	11
	3	Larch	43	52	48	Core	-	1
	2	Silver fir	53	98	76	Disc	-	2
Total	33							
Total from all sites	77							

Evaluation of sample material: historical wood samples

It appears that four different species of conifers were used for foundations: European spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), silver fir (*Abies alba*), and larch (*Larix* spec.) (Tables 1 and 3). Sometimes more than one conifer species was found in the same foundation. In one case the foundations consisted entirely of poplar (*Populus* s*pec.*) and no suitable sample material for dendrochronology was retrieved. A piece of oak (*Quercus robur*/*petraea*) came from the bridge sampled in Venice, Italy.

The overall preservation of the pile samples is such that the cell structure of the wood is intact and tree-ring boundaries are clearly delineated. On most piles the waney edge is present, but on some samples the outer rings of the discs have broken off along the tree-ring boundary. The cored samples, which were fragmented, were reconstructed before measuring.

Evaluation of sample material: archaeological wood samples

Most samples from the terrestrial archaeological sites, including two buried shipwrecks on reclaimed land, are oak (*Quercus robur*/*petraea.*) (Tables 2 and 3). One elm sample (*Ulmus* spec.) was taken from a Roman river embankment near Utrecht, The Netherlands. Bryggen, the terrestrial site in Bergen, Norway, yielded only Scots pine. The underwater-shipwrecks yielded oak samples as well as some Scots pine samples.

The preservation of the archaeological samples ranged from (visually) very good to “acceptable”. In the latter cases sapwood or waney edge were lacking, even if they could have been present earlier, the heartwood was partly degraded, or degradation caused discoloration and disappearance of the tyloses from the earlywood vessels in part of the heartwood so that itcould be falsely interpreted as sapwood. On the other hand, the central piles of a Roman farmhouse near Borsele, The Netherlands (Table 2), were perfectly preserved. They had clearly distinguishable sapwood as well as waney edge all around. Also worthy of mention are the foundation piles of the medieval castle Travenhorst, Germany, on which even the bark was still present.

Assessment of dating percentage

The success rates of the dendrochronological dating done so far are given below (Table 4). A distinction again is made between the archaeological sites (mostly oak) from which 75% of the analyzed samples were dated and the historical sites (mostly conifers) from which 39% of the analyzed samples were dated:.

When looking at the number of dated sites (Tables 1 and 2) instead of the number of dated samples (Table 3) we see different success rates: eleven out of fourteen (= 79%) for the archaeological sites and three out of nine (=33%) in case of the historical sites.

Table 4: Success rates of the dendrochronological dating of samples from archaeological sites and historical buildings for the BACPOLES project.

Type of site	No. of samples	Wood species	No. of samples		
			Undated	Dated	(%)
Archaeological	38	Oak	10	28	(74)
	1	Elm	0	1	(100)
	5	Scots pine	4	1	(20)
total	44		14	30	(75)
Historical	1	Oak	1	0	(0)
	16	European Spruce	7	9	(56)
	11	Scots pine	7	4	(36)
	3	Larch	3	0	(0)
	2	Silver Fir	2	0	(0)
total	33		20	13	(39)
Total	**77**		**34**	**43**	**(56)**

Age and provenance of the wood

The age (i.e. the ages of the oldest and youngest measured ring per site) of the analyzed wood samples is given in tables 1 (historical sites) and 2 (archaeological sites). The last column of each table also lists the region(s) of the standard chronologies that yielded the best matches. It shows the origin of the wood used to *comprise* these chronologies (see also Table 5), but it's difficult to say something about the *true* origin of the sampled wood (i.e. where did it grow?). For instance, in case of the terrestrial Roman sites in The Netherlands (Table 2) the wood in theory could be of "local"[4] origin or "imported" -rather: transported- from adjacent Germany (Table 5). The period between felling and use of the trees may have been longer for transported wood than for more local wood. This may have had implications for the quality of the wood. To draw any conclusions about the marine sites, one would have to know when and where the ships were built and when they sank. Were they built of local wood? How long had they been in use?

The youngest date given for the samples from historical buildings is also the felling date of the trees, because all foundations provided samples with waney edge. When comparing the felling dates of the pile samples with the documented building dates, a difference of several years was found in some cases. This may be due to necessary treatment and transportation time (in case of imported wood) or storage time (local/imported wood). For example, the trees for the foundation piles of the Parliament in Stockholm (Table 1) were cut in 1890 in the vicinity of Stockholm, five years before the actual construction (1895-1905, Charlotte Björdal, Lundt University, Department of Wood Science, personal communication), so they may have been *stored* for five years. The trees for the foundation of a house in Dordrecht (AD 1931), The Netherlands were also cut two years in advance (1929), in Germany.

[4] The meaning of the words *local* and *imported* in this case is relative. It is not our intention to discuss the regional validity of the chronologies that were used for dating in this paper. To be able to do so, more research is needed.

Table 5: Chronologies that were used for the dating of oak and conifer samples for BACPOLES and (roughly) indicate the provenance of the timber.

Chronology	Author(s)	Species	Country	Region/Description
0500029M	Bitvinskas, unpublished	*Pinus sylvestris*	L	Lithuania
3NEM0001	Eggertson, unpublished	*Pinus sylvestris*	S	Isle of Nemdeö (Southwest Sweden)
DHFIS300	Friedrich, Spurk & Becker, unp.	*Picea abies*	G	South Germany
DV1272MM	De Vries, unpublished	*Quercus robur/petraea*	NL	Twente (Eastern Netherlands)
EUBIG1ST	EU Contr.nr. ENV4-CT95-0127	*Quercus robur/petraea*	G	Netherlands, Central/North Germany
EUBIG2ST	EU Contr.nr. ENV4-CT95-0127	*Quercus robur/petraea*	G	Central/South Germany and Limburg (The Netherlands)
FLESBERG	Eidem 1959	*Quercus robur/petraea*	N	Southeast Norway
GBBALTI1	Hillam & Tyers 1995	*Quercus robur/petraea*	(UK)	Panel paintings from the Baltic in the UK
NLMIDDEN	Jansma 1995	*Quercus robur/petraea*	NL	Wood found in the Eastern Netherlands
NLZUID	Jansma 1995	*Quercus robur/petraea*	NL	Wood found in the South-eastern Netherlands and adjacent Germany (river Rhine import)
NLROMR9	Jansma 1995, extended version	*Quercus robur/petraea*	NL	Roman wood from wet Dutch sites + bog oaks
NLWF1040	Tisje, unpublished	*Quercus robur/petraea*	NL	Twente (Eastern Netherlands)/West Falia
NSSUB5HL	Leuschner, unpublished	*Quercus robur/petraea*	G	An area within Lower Saxony
OFR18MMM	Leuschner, unpublished	*Quercus robur/petraea*	G	Bog oaks from East Friesland/North Germany
POL457MM	Wazny, Eckstein (1987)	*Quercus robur/petraea*	P	Wollin
POL996MM	Wazny 1999	*Quercus robur/petraea*	P	East Pommern
POLWSTDM	Krapiec, unpublished (1996)	*Quercus robur/petraea*	P	Central Poland
ROMWEG	RING, unpublished	*Quercus robur/petraea*	NL	The Roman road near Vleuten, Utrecht (wood from Germany?)
WD400STD	Hollstein 1980	*Quercus robur/petraea*	G	Germany

Discussion

There are several reasons why some of the oak samples (mainly archaeological wood) could not be dated: a) the limited number of samples per archaeological context impedes the suppression of individual tree-ring patterns (by averaging with other trees); b) the sample exhibits too few rings so that no statistically reliable match with a standard chronology (or any other measurement series) is possible; c) tree-ring patterns are disturbed as a result of infestation by the cockchafer (*Melolontha melolontha*). Reasons why many of the conifer samples could not be dated a) inability to detect and then compensate for missing rings so that a match with a chronology becomes possible; b) the preponderance of so-called juvenile wood with no strong common tree-ring signal in discs from young trees; and c) last but not least, no chronology available for a certain area or period.

The felling dates (AD 97 and 100) of two piles from a Roman farmhouse in Borsele, The Netherlands (Table 2) differ by three years. Was one of them stored for three years and the other used fresh? It may have something to do with the Roman custom to strip off the bark of living trees, leaving them to dry until the next year, when they would be cut (Vitruvius). Some of these dead trees might have been “forgotten” for several years or maybe left on purpose: a form of storage. Of course oakwood is easier to work when still “green”, but in this case the stems of the trees were used whole.

Conclusions

Dendrochronological dating worked very well for the archaeological samples, which were almost exclusively oak, because of the many standard chronologies of oak (*Quercus robur*/*petraea*) that are available for Europe: 30 out of 44 samples (75%) and 11 out of 14 sites were dated. Finding a match for the mainly coniferous samples from foundations of historical buildings was less successful: only 13 out of 33 samples (39%) or 3 out of 9 sites were dated. The limited number of tree rings on the samples and the variety of possible origins complicates dendrochronological dating.

From the felling date and provenance of the dated samples some provisional conclusions about transport or storage of the wood can be derived: 1) considering the most likely provenance found for the samples through matching them with standard chronologies, the dated archaeological material probably consist of samples from transported as well as more local wood and the dated historical material mostly of imported wood; 2) the differences that were found between the felling dates of the trees used for foundations of historical houses and their documented building date mean we can conclude that the wood may sometimes have been stored for several years.

As for the preservation of the analyzed samples: damaged or degraded sample material in some cases may have prevented dating to the year, especially in the case of archaeological wood.

Expectations & future activities

Having successfully dated only part of the conifer samples with chronologies from -as expected- Germany and Scandinavia, the possibility still remains that some of the other Scots pines that were used as foundation piles in Dutch historical houses originated from forests in The Netherlands. A further research of the existing literature on this subject will be carried out. In the meantime an effort is being made to construct new chronologies of Scots pine for The Netherlands. Only few studies on living pine trees from The Netherlands have been undertaken (with different research questions) some of which are included in the International Tree-Ring Database (ITRDB; http://www.ngdc.noaa.gov/paleo/treering/html). Some of these data may be used, but only after careful checking and provided they don’t derive from trees that are *too young* for the purpose of dating. Besides that, we intend to use wood samples from old living pines (*Pinus sylvestris*) at ten other locations in The

Netherlands. This part of the research is still ongoing. Possibly more pine samples from foundations of houses of the nineteenth and early twentieth century can be dated with these local[5] chronologies that can go back as far as AD 1750. The trees that were used as foundation piles usually have less than 155 rings, meaning that they will be largely covered by most of the newly constructed chronologies.

Whether or not the period of transportation and/or storage has implications for the quality of the wood samples -as is currently being studied by other participants in the project- still remains to be seen. The effect may be minor in comparison to that of the burial circumstances the wood has been subjected to for hundreds of years (Hans Huisman, ROB National Service for Archaeological Heritage, Research Department Soil & Degradation of Archaeological Materials, personal communication).

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[9] Unofficial English title: A handbook for the physical preservation of the archaeological heritage. Mechanisms of degradation encountered in features and materials. Monitoring the condition of the archive in the soil.

[10] Unofficial English title: Dendrochronological research of coniferous wood from Dutch monumental buildings.

[11] Unofficial English title: The development and use of dendrochronology for Oakwood in Poland.

[12] Unofficial English title: Dendrochronological dating of the early Middle Age Slavic settlement at Wolin.

SECTION 7

NEW APPLICATIONS

Malacochronology, the application of dendrochronological methods on marine bivalve (shell) growth

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Introduction

In the temperate marine environment the seasonality in water temperature and primary production results in a strong seasonality of biological processes, both in the water column and at the sea floor. For bivalves living at the seafloor and growing by accretion of calcium carbonate, this results in the deposition of annual growth layers (Jones, 1980; Witbaard *et al.*, 1994) comparable to those in trees (Fig. 1). Like for trees, it is assumed that environmental conditions during the period of shell growth manifest themselves in the deposited material, as a result of which both the compositional differences and the ring width itself contain information.

While for short-lived species the growth lines are often visible on the external shell surface, for long lived species the growth lines are - especially during the later phases of life - too narrow to be recognised on the external shell surface. By application of the acetate peel method (Kennish et al; 1980, Ropes, 1985) this problem can be overcome.

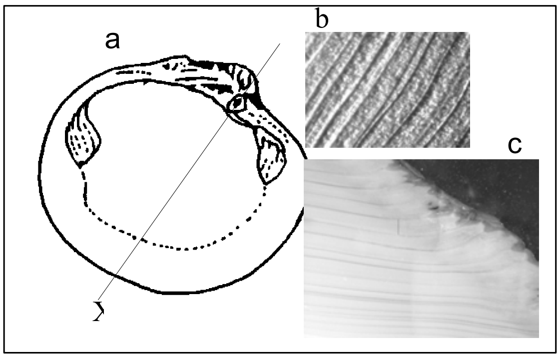

Figure 1: Schematic drawing of Arctica islandica. Line X indicates direction of sectioning and line of maximum growth. Photo insets show internal growth lines in the etched hinge section (b) as well as in a polished section of the valve (c).

Application of this method to a number of bivalve species revealed that many of them have a longevity which surpasses earlier ideas (Heller, 1990). Various species can reach ages of decades rather than years. With maximum ages exceeding 200 years, *Arctica islandica* is the most illustrative and best known example (Jones, 1983). This approximately 10 cm high bivalve has a widespread distribution in the shelf seas of the North Atlantic. In the North Sea it can be found north of 53°30'N. Population densities may range from 0.1/m² to over 200/m² (Witbaard & Bergman, 2003). *Arctica* is a filter feeding species, i.e. it is dependent on small organic particles which are suspended just above the seafloor and which were produced in the illuminated surface waters.

Growth experiments with *Arctica islandica* demonstrated that shell growth of this species is mainly controlled by ambient seawater temperature and food supply (Witbaard *et al.*, 1997b; Kraus *et al.*, 1992). With this in mind the growth record is supposed to reflect rather basic ecosystem properties like water temperature and productivity. For many of the sites where *Arctica* can be found, no idea on long term variations of such environmental conditions exists. A study of *Arctica*'s shell growth could thus possibly reveal long-term trends in these variables retrospectively. In this paper we report on the shell growth of *Arctica* from the northern North Sea, with the aim to explore the relationship between biological functioning and climate in this area.

Material and methods

Shells of living specimens of *Arctica islandica* were collected in the Fladen Ground (northern North Sea), which is located about 100 miles North-East of Aberdeen (Scotland) and is 100 and 150 meter deep (Basford & Eleftheriou, 1988) (Fig. 2). The area is located just South of the major water inflows of Atlantic Water into the northern North Sea (Turrell, 1992a; Turrell, 1992b).

Three batches of living *Arctica* were collected and in total 103 shells were measured and used for the construction of a chronology of annual shell growth. The specimens originated from approximately 59° 20'N 00° 30' E. and were collected by boxcorer, trawl and dredge in 1983, 1991 and 2000.

To apply the acetate-peel method, shell cross-sections (Fig. 1a) were obtained by cutting the left hand valve along the axis of maximum growth. The surface of the exposed cross section was ground and polished (Fig. 1c) before it was being etched in a weak solution of HCl. The growth banding is based on a compositional difference of organic matrix and the size of the inorganic crystals. After etching this results in a relief in which the organic-rich and or larger crystals are visible as small ridges (Fig 1b). In the next step, this surface was transferred to a sheet of acetate by using a few drops of acetone. The "imaged growth bands" obtained in this way were counted and measured by means of a microscope.

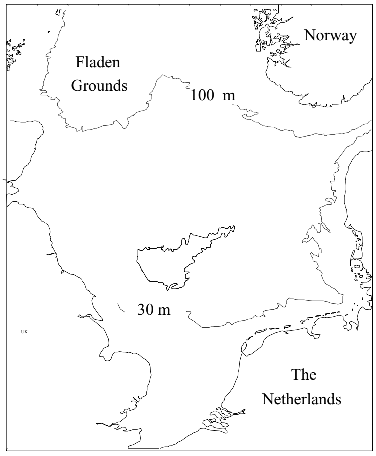

Figure 2: Location of the Fladen Grounds in the northern North Sea.

Because all specimens were caught alive, it was assumed that the outermost increment was formed in the year of sampling. By counting backwards, each measured growth increment could be assigned to a particular calendar year. For each specimen this resulted in an absolutely dated time series of ‘shell-ring’ widths. These time series were cross-dated with the programs COFECHA (Holmes, 1983; Grissino-Mayer, 2001) and PAST (http://www.sciem.com/main.html). The ontogenetic growth trend was removed by double detrending, using a negative exponential function in combination with a 66-year spline fit to remove the remaining low-frequency variation (Cook, 1985). For young specimens (~30 years old) we used a more flexible 15-year cubic spline to remove the ontogenetic trend. For each shell this detrending procedure resulted in an index series that for each year reflected whether growth was below or above the expected rate. From these detrended and cross-dated time series a standard chronology was constructed using the program ARSTAN (Cook, 1985) (http://www.ltrr.arizona.edu). Calibration of the standard chronology with environmental variables was done with principal component analyses and response function analyses (Fritts *et al*., 1971; Fritts and Shashkin, 1995). We used monthly climatic data as well as monthly data on food availability, *i.e.* total phytoplankton, diatoms and copepod abundance from a sub-area enclosed by the corners at 57°30’N 02°00’E and 60°00’N 02°00’W obtained by the CPR survey (Colebrook *et al.*, 1991; SAHFOS, http://192.171.163.165/). The climatic indices tested were the North Atlantic Oscillation index (NAO) (Hurrell, 1995, (http://www.cgd.ucar.edu/ ~jhurrell/nao.html#monthly) and precipitation data for northern Scotland obtained from Jones and Conway (1997) (http://www.met-office.gov.uk/research/hadleycentre/ CR_data/Monthly/HadNSP_act.txt)

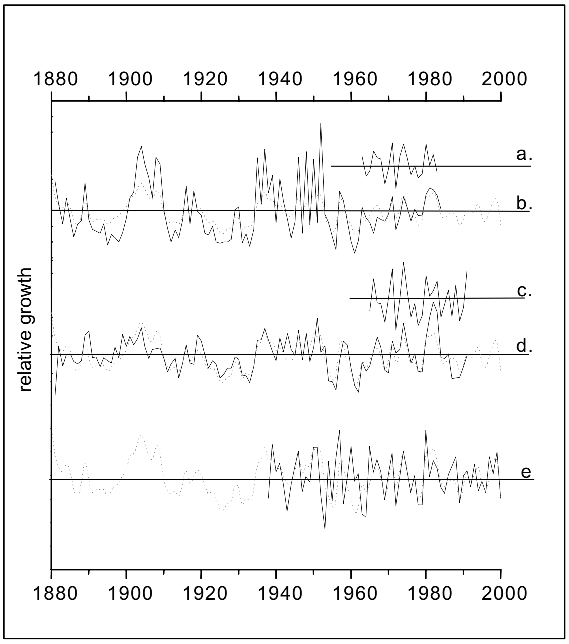

Figure 3: Chronologies of shell growth in Arctica islandica from the northern North Sea. Grey dotted line is the spline-fitted average chronology with superimposed the chronologies obtained from one of the subsamples. (a) young shells collected in 1983, (b) old shells collected in 1983, (c) young shells collected in 1991, (d) old shells collected in 1991, (e) young shells collected in 2000. Horizontal lines denote expected growth. Chronologies for young shells are displaced in upward direction for clarity.

Results

The average chronology of shell-growth variations in *Arctica islandica* is characterised by alternating periods in which growth is above or below expected growth. All different sub-samples, of both old and young shells as well as of the samples collected in the different years, show statistically similar patterns, which supports the idea that shell growth is the result of a common forcing factor (Fig. 3). Because the bottom water temperature in the area is almost constant, the attempts to explain the observed growth-rate variations focus on data indicative of food supply and food availability to the benthos community. These are the spring bloom production (diatom abundance), total algal production (phytoplankton colour) and copepod abundance, since the latter might compete for the same food source by intercepting food particles from the surface waters on their descent to the sea floor.

The response functions expressing the relationship between shell growth and the abundance of diatoms or total phytoplankton (expressed as phytoplankton colour units) explained only minor parts of the total variance in the average chronology (14% and 24%, respectively). The results, however, suggest the existence of a time lag between phytoplankton abundance and shell growth. The phytoplankton colour index of the autumn preceding growth correlated higher with the chronology of growth rate variations than the spring phytoplankton colour values of the calendar year in which the growth increment was terminated.

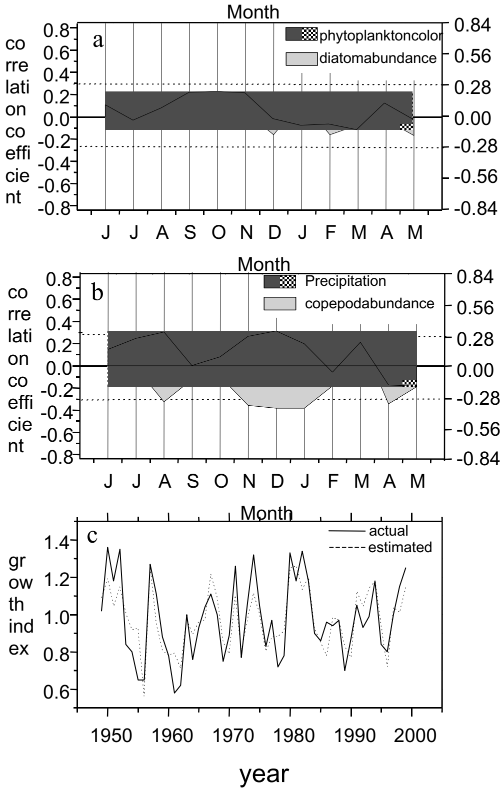

Figure 4: Lagged correlations of monthly variables and the average annual shell growth indices for the period 1949-1999. Dotted lines indicate the significance level (p<0.05). (a) Correlation with monthly average phytoplankton colour and total diatoms, (b) correlation with monthly precipitation over northern Scotland and total copepod abundance in the northern North Sea, (c) comparison of the actual shell growth rate variations and predicted variations on the basis of a response function model with copepod abundance and precipitation as predictor variables.

While the correlations between shell growth and phytoplankton data were insignificant, shell growth was significant negatively correlated with the lagged copepod abundance (Fig. 4b). The response function based on copepod abundance in the prior autumn and the following spring period could explain about 48% of the variance of the inter-annual variation in shell growth. Copepod abundance in the northern and central North Sea has been shown to be related to the NAO index (Fromentin and Planque, 1996). During the wintermonths of studied period (1949-1999) the shell growth showed a positive correlation to the NAO index altough that correlation never reached significance. Alternatively, we used the average monthly precipitation over northern Scotland as a descriptor for more local hydrographical conditions in the Fladen Ground because it most likely reflects factors that are important in the determination of benthic food supply such as wind stress, stratification, river run-off and the start and length of the spring-bloom. We found a positive relationship between shell-growth and the amount of rainfall in the preceding winter and an negative correlation with precipitation during spring (April-May) (Fig. 4b).

The combination of copepod abundance and the precipitation over Scotland for a 12 month period explained 66% of the variance in the growth rate chronology of *Arctica* (Fig. 4c). A reduction of the number of months to the winter period exclusively, did not lead to a great loss of explained variance in the response function. The combination of precipitation and copepod abundance for the period between November and May still explains 61% of the total variance, suggesting that conditions during autumn and following spring are important for shell growth.

Discussion

With the exception of temperature, climate will affect shell growth indirectly by changing ecosystem properties like primary production, sedimentation and the length of the period in which primary production takes place. The documented inter-annual variations in bottom-water temperature in the Fladen Ground (Ellet and Blindheim, 1992) as well as the recently reported anomalies in Sea Surface Temperature (SST) for the northern North Sea (Reid *et al*., 1998) seem to be too small to explain the observed *in situ* shell growth variations in view of the results obtained from experiments (Witbaard *et al.*, 1997b). Therefore, the most likely remaining factor to explain these growth rate differences would be the supply of food.

A significant relationship between shell growth and phytoplankton colour or diatom abundance was however absent (see also; Witbaard, 1996; Witbaard *et al*., 1997a). Apparently there is only a weak direct link between primary production in the surface waters and shell growth 140 meters below. One possible reason could be the rapid development of a dense copepod population in early spring.

Particle-flux measurements in the Fladen Ground indeed show that in spring only small amounts (10–25%) of the primary production sink to the seafloor (Davies & Payne, 1984). Cadee (1986) even estimated that most of the primary produced material ended up in the pool of dissolved organic matter. Hence benthic food availability seems to be depressed.

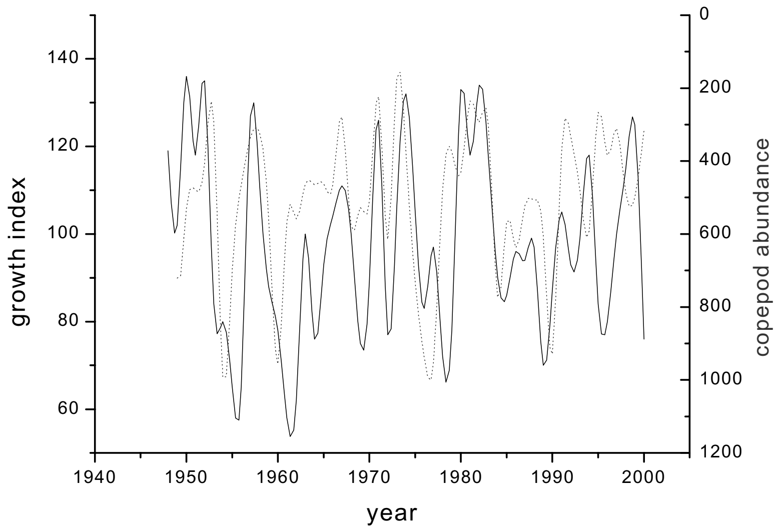

Figure 5: Observed correspondence between shell-growth indices (continue line) and 6-month lagged copepod abundance (dotted line) as obtained from the CPR data base. Copepod abundance scale (righ side) is reversed.

In the northern North Sea the downward particle flux seems to be controlled by the cold water copepod *Calanus finmarchicus.* In early spring, a seed population of this species is advected into the northern North Sea from its deep overwintering sites in the neighbouring Atlantic (Bryant *et al*., 1998; Gallego *et al*., 1999; Madden *et al*., 1999). The population develops rapidly in March and peaks in April-May (Planque and Fromentin, 1996) i.e. the period of the spring bloom. This timing together with a grazing capacity of 40-90% of the daily primary production (Radach et al, 1984), not only controls the magnitude of the spring phytoplankton bloom but also the subsequent export flux towards the bottom. Therefore the observed negative correlation between shell growth and copepod abundance reflects a competition for the same food source which is depicted in Figure 6.

Weather conditions have a large influence on the advection and population development of *C. finmarchicus* in the northern North Sea (Gallego *et al*., 1999; Harms *et al*., 2000; Madden *et al*., 1999). To explain the interannual variations in the abundance of *C. finmarchicus,* Fromentin and Planque (1996) summarised a possible climate-foodweb structure which explains the interannual variation in shell-growth rates of *Arctica* as well.

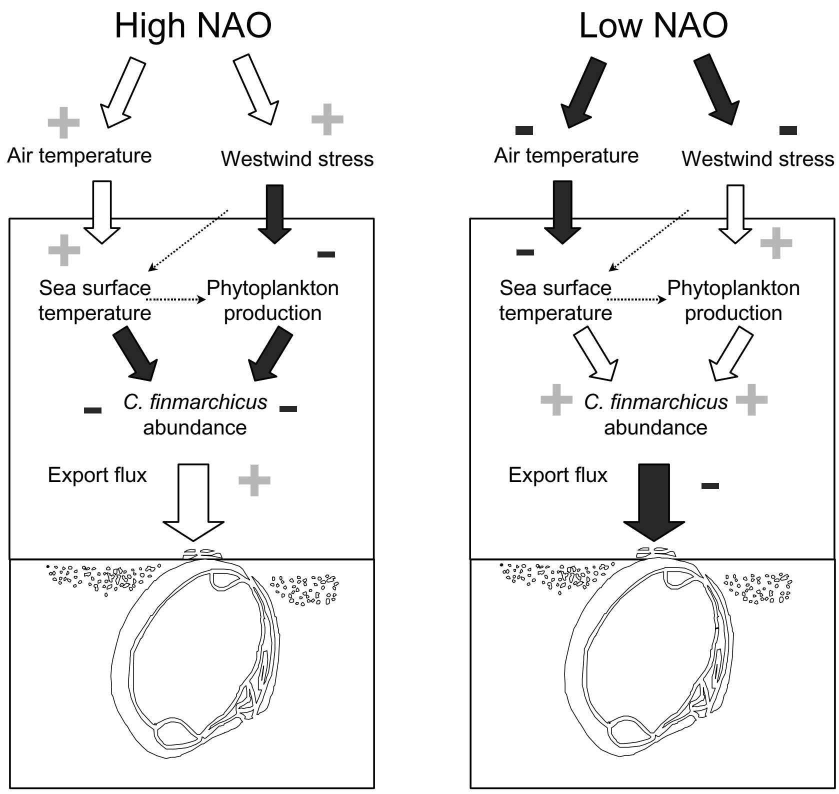

Figure 6: Graphical representation of the model as proposed by Fromentin and Planque (1996). The two extreme states of the NAO are given. "+" sign indicates a positive and "-" indicates a negative feedback to the controlling factor.

During winters with a predominant high NAO index, west-wind stress and precipitation increases over north-west Europe and Scotland. As a consequence, stratification of the water column is delayed and phytoplankton production will start late and is low (see Dickson et al, 1988 for a discussion of the mechanism). The subsequent development of the copepod population is depressed which leads to high fluxes of phytoplankton to the seafloor resulting in high shell growth rates. In winters with a low NAO index; lower temperatures, less wind and early stratification promotes the rapid development of *C. finmarchicus* populations which matches the onset of the spring bloom and therefore depresses the downward flux of phytoplankton material which ultimately results in low rates of shell growth.
This is in line with our observations which show a significant positive relationship between shell growth and rainfall amounts and the NAO index. However, although precipitation rates in northern Europe strongly depend on the NAO index, thepositive relationship between the NAO index and growth record remained statistically weak. This does not exclude the NAO as

an underlying mechanism but demonstrates that local conditions have a larger impact on shell growth and modify the NAO signal to such an extent that it cannot always be recognised clearly.

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