GFZ
Helmholtz-Zentrum
POTSDAM

HELMHOLTZ-ZENTRUM POTSDAM
DEUTSCHES
GEOFORSCHUNGSZENTRUM

TRACE
Tree Rings in Archaeology, Climatology and Ecology

Volume 11

Proceedings of the DENDROSYMPOSIUM 2012
May 8th – 12th, 2012 in
Potsdam and Eberswalde, Germany

Edited by:
Gerhard Helle, Holger Gärtner,
Wolfgang Beck, Ingo Heinrich,
Karl-Uwe Heußner, Alexander Müller
and Tanja Sanders

Scientific Technical Report STR13/05

www.gfz-potsdam.de

HELMHOLTZ
GEMEINSCHAFT

Imprint

Helmholtz Centre Potsdam
GFZ German Research Centre
for Geosciences

Telegrafenberg
D-14473 Potsdam

Printed in Potsdam, Germany
September 2013

ISSN 1610-0956

DOI: 10.2312/GFZ.b103-13058
URN: urn:nbn:de:kobv:b103-13058

This work is published in the GFZ series
Scientific Technical Report (STR)
and electronically available at GFZ website
www.gfz-potsdam.de > News > GFZ Publications

TRACE
Tree Rings in Archaeology,
Climatology and Ecology

Volume 11

Proceedings of the DENDROSYMPOSIUM 2012
May 8th – 12th, 2012 in
Potsdam and Eberswalde, Germany

Edited by:
Gerhard Helle, Holger Gärtner,
Wolfgang Beck, Ingo Heinrich,
Karl-Uwe Heußner, Alexander Müller
and Tanja Sanders

Scientific Technical Report STR13/05

Preface

This publication is a result of the 11th TRACE conference (Tree Rings in Archaeology, Climatology and Ecology) organized by the GFZ German Research Centre for Geosciences, Deutsches Archäologisches Institut (DAI), Berlin and the Thünen Institute of Forest Ecosystems, Eberswalde, on May 08th – 12th 2012 in Potsdam and Eberswalde, Germany.

TRACE is an initiative of the 'Association of Tree-Ring Research' (ATR) and seeks to strengthen the network and scientific exchange of scientists and students involved in the study of tree rings. The annual conference provides a scientific platform for young scientists at high level.
More than 200 scientists, among which 96 students, working on tree-ring related topics participated in the conference coming from Austria, Belgium, Canada, Czech Republic, France, Germany, Iran, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Russia, Spain and Switzerland.
A total number of 45 oral and 107 poster presentations highlighted the various aspects of tree-ring research: wood anatomy & seasonal dynamics, dendroecology & dendrogeomorphology, archaeology and climatology.
A total of 29 manuscripts were submitted. After review 25 short papers are published in this volume giving an overview of the wide spectrum of fields in tree-ring research.
We would like to thank the authors for contributing to this TRACE-volume, and the reviewers for their valuable comments on the manuscripts. The organizers of the conference also wish to thank the sponsors of TRACE 2012
Beta Analytic Ltd. (United Kingdom), COX Analytical Systems (Sweden), Ecomatik, (Germany), Grube (Germany), Häglof, (Sweden), Regent Instruments Inc. (Canada), Rinntech (Germany), ThermoFisher (Germany), ZEISS (Germany) for their financial support.

Gerhard Helle
Holger Gärtner
Wolfgang Beck
Ingo Heinrich
Karl-Uwe Heußner
Alexander Müller
Tanja Sanders

CONTENTS

SECTION 1 CLIMATOLOGY

SECTION 2 ISOTOPES

SECTION 3 ECOLOGY

SECTION 4 ARCHAEOLOGY

SECTION 5 WOOD ANATOMY

SECTION 6 GEOMORPHOLOGY

In Memoriam

Klaus Felix Kaiser

1947-2012

Klaus Felix Kaiser before this last flight, July 2012

Promoting science at and sometimes even beyond its interdisciplinary boundaries requires lots of enthusiasm, vision, creativity and stamina, as well as strong charisma and a sufficient amount of self-confidence. Klaus Felix Kaiser, who unexpectedly died July 20th, 2012, certainly commanded a great quantity of all these characteristics.

For more than 35 years of his professional career, he incessantly worked on the development and improvement of tree-ring records from the Late Glacial and Early Holocene periods. His productive life-task consequently resulted in the oldest floating tree-ring chronology from nearly 150 individual pines collected in Switzerland. This annually resolved and millennium-long paleo-environmental archive reaches back to ~14’000cal BP. It remains worldwide unique.

By approaching the climatological enigma of the Bølling, Allerød and Younger Dryas at the transition from the Late Glacial into the Early Holocene episode, Felix operated at a cross-disciplinary interface, stimulating methodological forefronts in dendrochronology, paleoclimatology/ecology, and radiocarbon dating.

His exceptional pine compilation did enhance accuracy of the global ^{14}C calibration curve, and will allow high-resolution terrestrial and marine proxies to be linked. National and inter-national collaboration, together with the supervision of students and PhDs resulted in a rich body of literature, peaking in a most recent review article on the entire range of Late Glacial ring width chronologies across Europe (Kaiser et al. 2012). Felix is bequeathing a fascinating dendrochronological playground for us, thanks.

Undoubtedly, Felix was an outstanding scientist, honored with a Professorship at the University of Zurich, nonetheless, he was also a dedicated teacher in Geography, and his wealth of experience, great sense of humor and social skill motivated a whole generation of students. Moreover, Felix was a passionate pilot and widely familiar with good cuisine and wine. In liaison with his wife, he travelled all over the globe.

Those who spent time with him at WSL will warmly remember Felix as a friend, colleague and advisor, but also as a critical mind and demanding lateral thinker. Sharing his scientific passion for more than ten years brought me the privilege to frequently learn from him about tree rings and life. Joining Felix on a flight over the Alps was memorable.

– Contributed by Ulf Büntgen

Swiss Federal Research Institute WSL

SECTION 1

CLIMATOLOGY

Relationships between ring width and maximum latewood density – an example from southeast Tibet

P. Hochreuther, J. Münchow, J. Grießinger & A. Bräuning

Institute of Geography, University of Erlangen-Nuremberg, Kochstr. 4/4, D-91054 Erlangen, Germany
E-mail: philipp.hochreuther@fau.de

Introduction

Tree-ring data from forests close to the altitudinal growth limit are subject to dendroclimatological research, since the growth of such trees is usually limited by temperature. Following Douglass' statement, 'stressed is best', it makes these specimens to valuable archives for paleoclimate research. In recent years an increasing number of climate reconstructions from tree-ring chronologies of high- elevation sites in the Himalayan region and on the Tibetan Plateau have been established (e.g. Zhu et al. 2013, Liu et al. 2012, Griessinger et al. 2011). Of all parameters which can be extracted from wood, total ring width (RW) and maximum latewood density (MXD) are the ones most commonly used to reconstruct the climatic variability of the past (Hughes 2002). It was also mentioned that both parameters seem to carry, at least in the extratropical northern hemisphere, a common variable for climatic variables (Kirdyanov et al. 2007). This suggestion is based on the high similarity between inter-annual variations of RW and MXD. In our study conducted on the Tibetan Plateau, this has also been found true. However, we found that the approach applied by Kirdyanov et al. (2007) can be adjusted to better fit the data from southeast Tibet. Here we present a modification of this approach using the statistics program R.

Material and methods

Site and species

RW and MXD data originate from samples of Sikkim larch (*Larix griffithii*) collected in 2004 near Bomi situated on the southeastern Tibetan Plateau (Bräuning 2006). These trees are pioneers growing on lateral and terminal moraines of recent glacier advances. From a total of 33 cores, 24 were analysed, with tree ages ranging from 40 to 220 years.

Climate

The regional climate is strongly influenced by the Asian summer monsoon. However, in contrast to the unimodal precipitation maximum from July to August, which is typical for summer monsoon climate, the local precipitation pattern is bi-modal, characterized by an early onset of pre-monsoonal rainfall and a second precipitation peak during an autumn rainy period. This has been described as typical for parts of the Longitudinal Range-Gorge Region in western China (He et al. 2007). The climate station at Bomi, operated since 1961, records an annual mean precipitation of 836mm and annual mean temperatures of 8.3°C.

Data treatment

Ring widths were measured using a LINTAB II measuring system with a resolution of 0.01 mm and then the tree ring series were crossdated using standard dendrochronological practices (Stokes & Smiley 1968). For densitometric measurements, samples were glued on wooden carriers and then processed with a Lignostation densitometry system (Rinntech, Germany; Rinn 2006). Relative density variations were measured along smoothed wood surfaces using a high-frequency dielectric scanner with a spatial resolution of ca. 30 µm (Schinker et al. 2003). The density series were crossdated with the ring width series using the program TSAP (Rinn 2003).

Biological growth trends in the RW and MXD raw time series were removed with a cubic smoothing spline with a 50% frequency response cut-off equal to 2/3 of the series length. The tree ring series were then standardized to dimensionless indices using the statistics program R (www.r-project.org) of the dplR library. While building the MXD chronology, it became apparent that the younger trees carry a different signal than the old ones (Fig. 1); therefore two MXD chronologies were developed, one for old trees (222-year chronology, N = 7) and one for young trees (59-year chronology, N = 9).

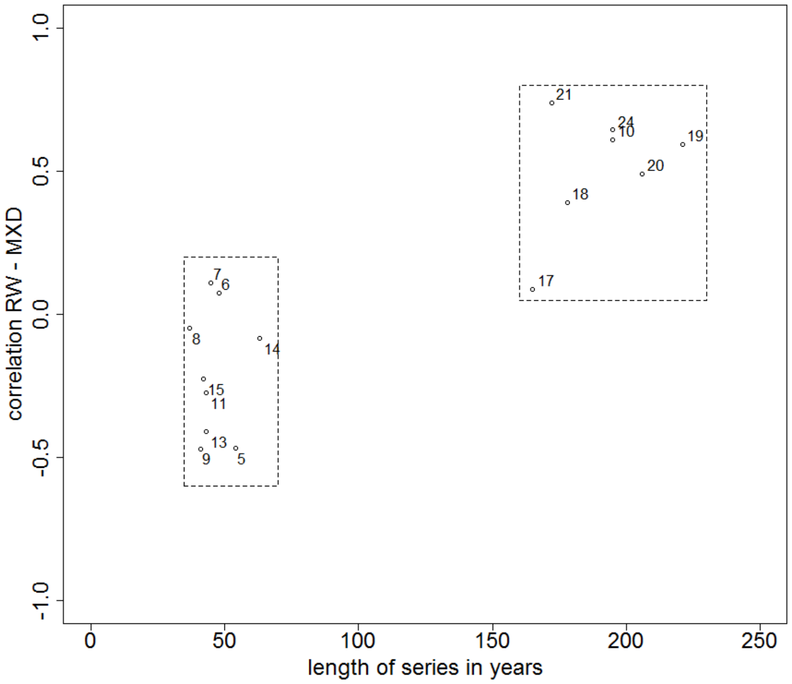


Figure 1: Correlation between RW and MXD versus the lengths of individual tree-ring series;dashed lines frame short and long series.

Long RW and MXD chronologies correlate significantly with each other (0.60, p<0.001; Fig. 2); for six of the seven long series, the correlations between RW and MXD varied from 0.58 to 0.63 (p<0.001). Those cores were used for further analysis.

As the strong relationship between both parameters in the long series is apparent, even in the raw data, the approach introduced by Kirdyanov et al. (2007) was chosen as a starting point for further exploration of the correlations.

Figure 2: Long RW (grey) and MXD (black) index chronologies. The striking differences prior to 1830 are probably due to the reduced sample depth (EPS for whole period: 0.796, > 1830: 0.875).

According to Kirdyanow et al. (2007), the signal contained in RW and MXD can be separated using:

$$MXD = MXD_{Min} \ x \ (MXD_{AS} - MXD_{Min}) \ x \ (1 - exp^{-axTRW})$$

The parameter MXD_{AS} is the MXD of tree rings wider than 1 mm. MXD_{Min}, represents the theoretical minimum of MXD for RW approaching zero. In the original paper, these parameters were determined using a least-squares method. In our case, three modeling approaches were tested: a second-order polynomial function, a generalized additive model (GAM) and one with gamma distribution (see Fig. 3). A linear relationship was rejected due to Ramsey's RESET (37,28>qf(0.99,1,219).

In order to account for the autocorrelation, the GAM was modified taking the time parameter into account in the way:

gam2 <- gam(MXD ~ s(RW) + s(year))

Results

The relationship between RW and MXD appears linear whereas RW stays below 0.7 mm, for wider rings the incremental increase of MXD is reduced. For rings wider than 2 mm (only 36 rings in total) an asymptote seems to be reached. This is consistent with findings by Kirdyanov et al. (2007), although borders in the latter are at a much lower level.

Comparing the models without removal of autocorrelation, the gamma prediction model (R^2 = 0.58) explains less variance than the 2nd order polynomial (R^2 = 0.65) or GAM (R^2 = 0.65. It also introduces the highest values of autocorrelation. Since both the other methods produce similar results (Fig. 3a), the authors would suggest applying Occam's razor and preferring the simpler model.

In removing the autocorrelation, the modified GAM reveals good results (Fig. 3b), while even increasing the amount of explained variance (R^2) to>0.7 for all samples.

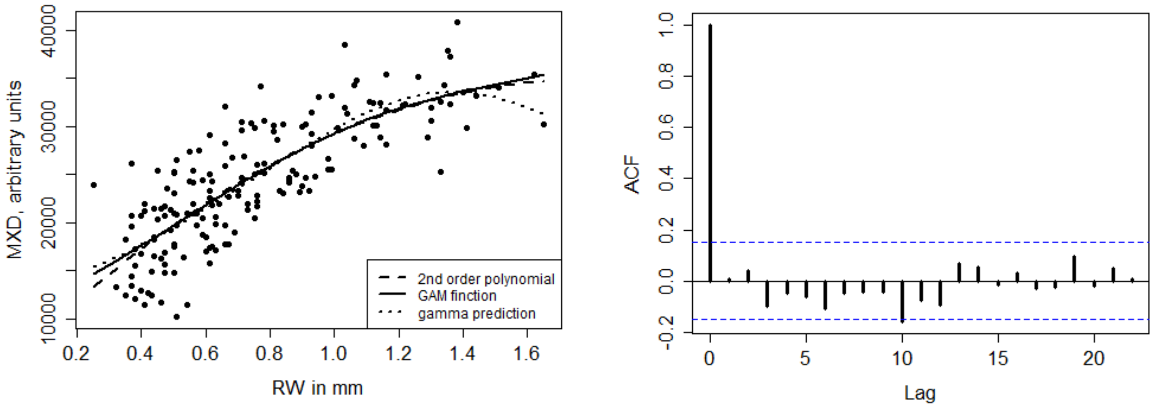

a) b)

Figure 3: a) Output for all three methods modeling the relationship between RW and MXD for one core. b) Autocorrelation function of the modified GAM approach for the same core. Dashed lines represent significance levels.

Discussion

Although the study is based on a limited number of samples, the models applied show similar results in each case. Therefore we recommend trying a GAM including the time parameter when the similarities between RW and MXD are ovious and require analysis. As the methods applied are compatible the approach by Kirdyanov et al. (2007), we also assume that it can be applied at lower latitudes. The residuals gained from the GAM approach furthermore seem to yield cyclicity, which points towards climatic influence. However, the aptitude for modeling density and the validity of the modeled parameter (MXD') for temperature reconstruction has not been proven in this study. the definitive value of this approach still requires completion of the method and thus should be regarded with caution.

References

Bräuning, A. (2006): Tree-ring evidence of 'Little Ice Age' glacier advances in Southern Tibet. *The Holocene* 16: 369-380.

Grießinger,J., Bräuning, A., Helle, G., Thomas, A., Schleser G. (2011): Late Holocene Asian summer monsoon variability reflected by δ18O in tree-rings from Tibetan junipers. Geophysical Research Letters 38, art. no. L03701.

He, D., Li, S. & Zhang, Y. (2007): The variation and regional differences of precipitation in the Longitudinal Range-Gorge the Region. *Chinese Science Bulletin* 52: 59-73.

Hughes, M.K. (2002): Dendrochronology in climatology - the state of the art. *Dendrochronologia* 20: 95–116.

Kirdyanov, A.,Vaganov, E. & Hughes, M.K. (2007): Separating the climatic signal from tree-ring width and maximum latewood density records. *Trees* 21: 37-44.

Liu, J., Yang, B., Huang, K. & Sonechkin, D.M. (2013): Annual regional precipitation variations from a 700 year tree-ring record in south Tibet, western China. Climate Research 53 (1): 25-41

Rinn, F. (2006): Lignovision. Scanning of wood and tree-ring recognition – user reference. Frank Rinn. Heidelberg.

Rinn, F. (2003): TSAP-Win Professional – Zeitreihenanalyse und Präsentation für Dendrochronologie und verwandte Anwendungen. Frank Rinn. Heidelberg.

Schinker, M.G., Hansen, N., Spiecker, H. (2003): High-frequency densitometry-a new method for the rapid evaluation of wood density variations. *IAWA Journal* 24: 231–239.

Stokes, M. & Smiley, T. (1968): An Introduction to Tree-Ring Dating. University of Arizona Press. Tucson.

Zhu, H., Xu, P., Shao, X. & Luo, H. (2013): Little Ice Age glacier fluctuations reconstructed for the southeastern Tibetan Plateau using tree rings. Quaternary International 283: 134-138.

Tree growth under climatic and trophic forcing - A nutrient manipulation experiment in Southern Ecuador

S. Spannl [1], O. Ganzhi [2], T. Peters [1] & A. Bräuning [1]

[1] Institute of Geography, FAU Erlangen-Nuremberg, Germany; ² National University of Loja, Ecuador
E-mail: susanne.spannl@fau.de

Introduction

Tropical mountain forests are strongly affected by environmental and anthropogenic impacts, e.g. by climate change, an expanding land use and an increasing use of nitrogen fertiliser in agriculture (Galloway et al. 2004, 2008). Thus, higher atmospheric nitrogen and phosphorus depositions as well as an intense frequency of drought-events are expected in the future (Hietz et al. 2011; Rozendaal & Zuidema 2011). Tree-physiological processes (e.g. diameter tree growth, foliage production, water consumption) are strongly influenced by these changes and could respond to fertilisation controversially (Cavellier et al. 2000; Homeier et al. 2012; Lewis et al. 2004; Tanner et. al 1990).

Within the framework of an interdisciplinary **nu**trient **m**anipulation **ex**periment (**NUMEX**) in Southern Ecuador we test the hypothesis that N-fertilization of different tropical tree species stimulates tree growth and affects the trees' water status especially during climatic extreme events like dry spells.

Material and Methods

Study site

The study site of NUMEX (2000 m a.s.l.) is situated in the protected research area "Reserva Biológica San Francisco (RBSF)", close to the Podocarpus National Park (3°58'S, 79°04'W) between the Ecuadorian provinces Loja and Zamora-Chinchipe (Figure 1). The area is characterised by a humid climate with an annual mean rainfall of about 2176 mm and an annual mean temperature of 15.5°C (Emck 2009; Richter & Peters 2011).

NUMEX is designed (Figure 2) in four main blocks (1-4); three with a northern and one with a south-western exposition. Within each block four plots consisting of the different treatments *Control (C), Nitrogen (N), Phosphorus (P)* and a combination of *Nitrogen and Phosphorus (N/P)* were set up randomly. Since February 2008 fertiliser have been added annually (50 kg N ha^{-1}; 10 kg P ha^{-1}) (Homeier et al. 2012; Homeier et al. 2013, in press).

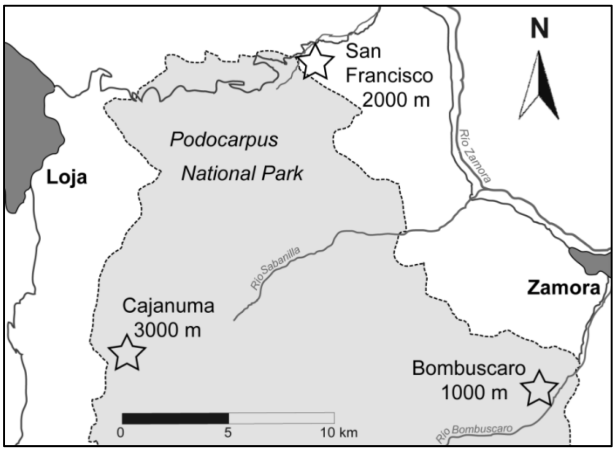


Figure 1: Location of the study area San Francisco [Homeier et al. 2013, in press]

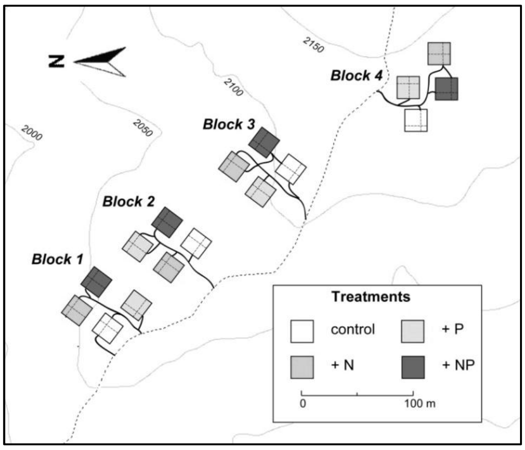


Figure 2: NUMEX plot design [Homeier et al. 2013, in press]

Methodological approach

To register radial stem diameter variations of tropical tree species we installed eight high resolution dendrometers (since July 2010; measurement interval: every 30 min, 5 µm resolution). Because of the high costs of our measurements only one N-fertilised and one non- fertilised tree of the tree species *Graffenrieda emarginata* Ruiz et Pavon (Melastomataceae), *Podocarpus oleifolius* D. Don ex Lamb. (Podocarpaceae), *Prunus* sp. (Rosaceae) and *Alchornea lojaensis* Secco (Euphorbiaceae), were investigated. Based on these measurements the parameters daily amplitude of diameter growth (dA), daily radial change (dR) and cumulative radial growth (cum dR) of the trees were calculated and analysed (Deslauriers 2007, Bräuning et al. 2009, Spannl et al. 2011, Volland-Voigt et al. 2011). For more details refer to Figure 3.

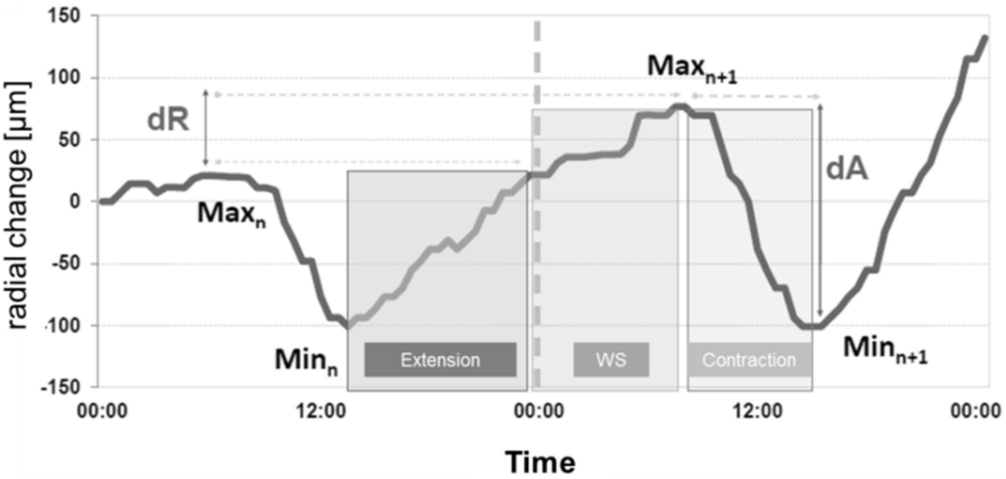


Figure 3: Schematic illustration of the calculation of the variables daily radial change (dR), water saturated phase (WS) and daily amplitude (dA) [Bräuning et al. 2009; Volland-Voigt et al. 2011, modified].

Despite the strong variability of precipitation within this area there is also a little dry period between October and November, the so called 'Veranillo del Niño" (Emck 2007, Bendix et al. 2006, Bendix et al. 2008, Rollenbeck 2011) mainly influencing tree growth patterns.

According to previous studies in Southern Ecuador (Bräuning et al. 2009, Volland et al. 2011) calculations of the daily sums of precipitation as well as the daily atmospheric vapour pressure deficit (VPD) (equation of Schönwiese 2003) were made from July until December 2010. During this time period we defined short climatic drought events as periods with at least four consecutive days without any rainfall.

Results

These short drought conditions are already sufficient to detect changes in tree growth or tree water status, respectively. In consequence nine dry spells with a range from four up to eleven rainless days were determined. In total there were 48 days without rainfall during the observed period (N=48) (Figure 4).

Although different tree species have been investigated, variations in radial stem diameter in relation to drought events showed a synchronous course over the monitored time period (Figure 4). But, the close up look within the nine dry spells visualises species specific differences regarding the total cumulative growth and the daily amplitudes of radial stem diameter variations (Figure 4 and Table 1). Except for the dominant tree species of this altitudinal belt *G. emarginata*, nitrogen fertilised trees showed a higher cumulative growth than trees growing on control plots (measured on December 1st 2010).

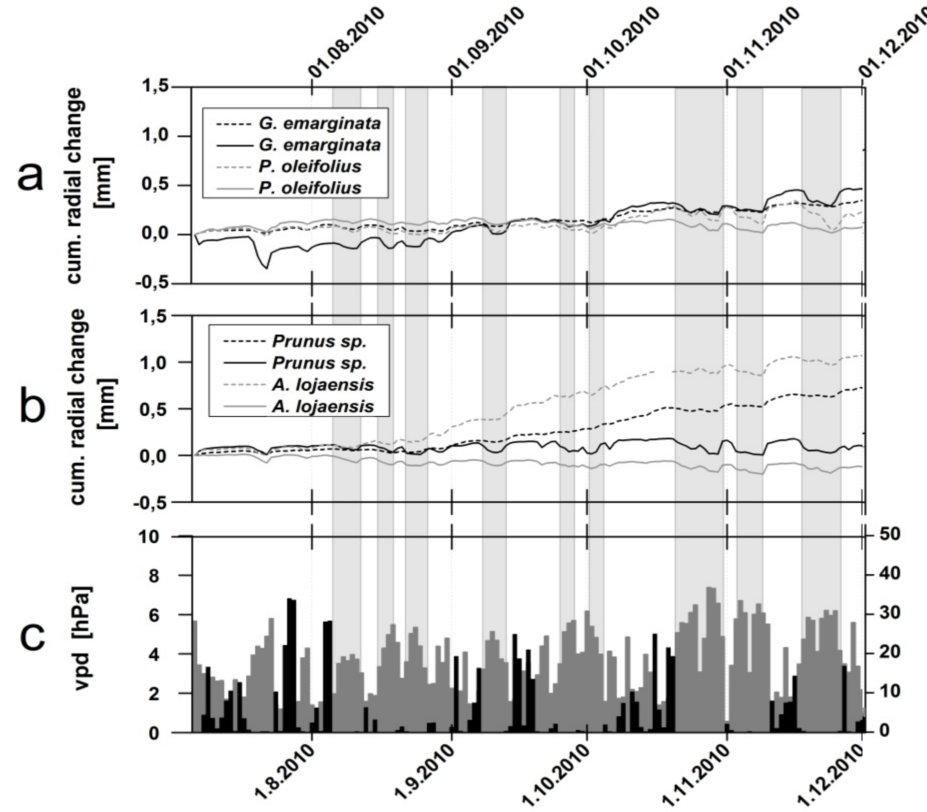


Figure 4: Linkage between tree growth and climatic patterns at 2000 m a.s.l. from July 2010 until December 2010. a. Cumulative daily radial change of Graffenrieda emarginata and Podocarpus oleifolius and b. Prunus sp. *and Alchornea lojaensis. Tree individuals growing on N-manipulated plots are depicted with dashed lines. Individuals growing on non-manipulated plots are depicted with continuous lines. Data gaps are highlighted with grey hatched boxes. c. Daily totals of precipitation (black columns) and vapour pressure deficit (grey columns). Dry spells are highlighted in light grey (modified from Homeier et al. 2013, in press.).*

Tab.1:
Cumulative growth value [mm] measured on December 1st 2010

	+N	**C**
G. emarginata	**0,35**	**0,47**
P. oleifolius	**0,23**	**0,08**
***Prunus* sp.**	**0,73**	**0,11**
A. lojaensis	**1,00**	**-0,12**

+N= nitrogen fertilised trees
C= control trees

While the mean dA (Figure 5) of *P. oleifolius* showed a highly significant increase after the fertilisation, *G. emarginata* and *Prunus sp.* reacted contrarily. Trees of *A. lojaensis* revealed no significant difference and the daily amplitudes remained fairly constant. Thus, the results might indicate that increasing accumulations of nitrogen deposited via wind transport from Amazonia might change the species composition and the competitive behaviour of the tree species (DFG Research Unit 816 2013; Homeier et al. 2013, in press).

Independent of the treatment and the tree species the statistical correlations were highly positive between dA and VPD (Figure 6). Whereas the nitrogen fertilised tree of *P. oleifolius* revealed a higher correlation than the non-fertilised one, all other tree species showed opposing reactions. These findings possibly indicate that besides climatic conditions additional transpiration control mechanisms might have an impact after the fertilization.

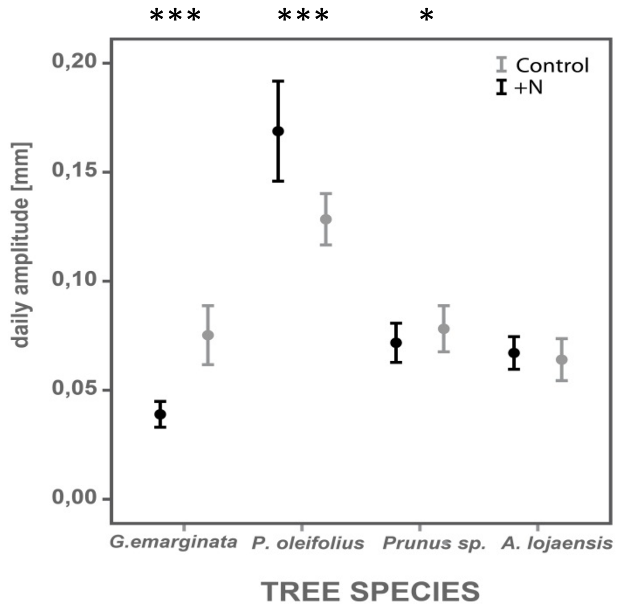


*Figure 5: Mean values (+ two standard errors) of the daily amplitude of radial stem diameter variations during nine dry spells (N=48) in the period between July and December 2010 of the different tree species Graffenrieda emaginata, Podocarpus oleifolius, Prunus sp. and Alchornea lojaensis (nitrogen fertilised and non-manipulated individuals). Significant differences between fertilized and non-manipulated individuals of each tree species are marked with asterisks (*** p < 0.001; * p < 0.05).*

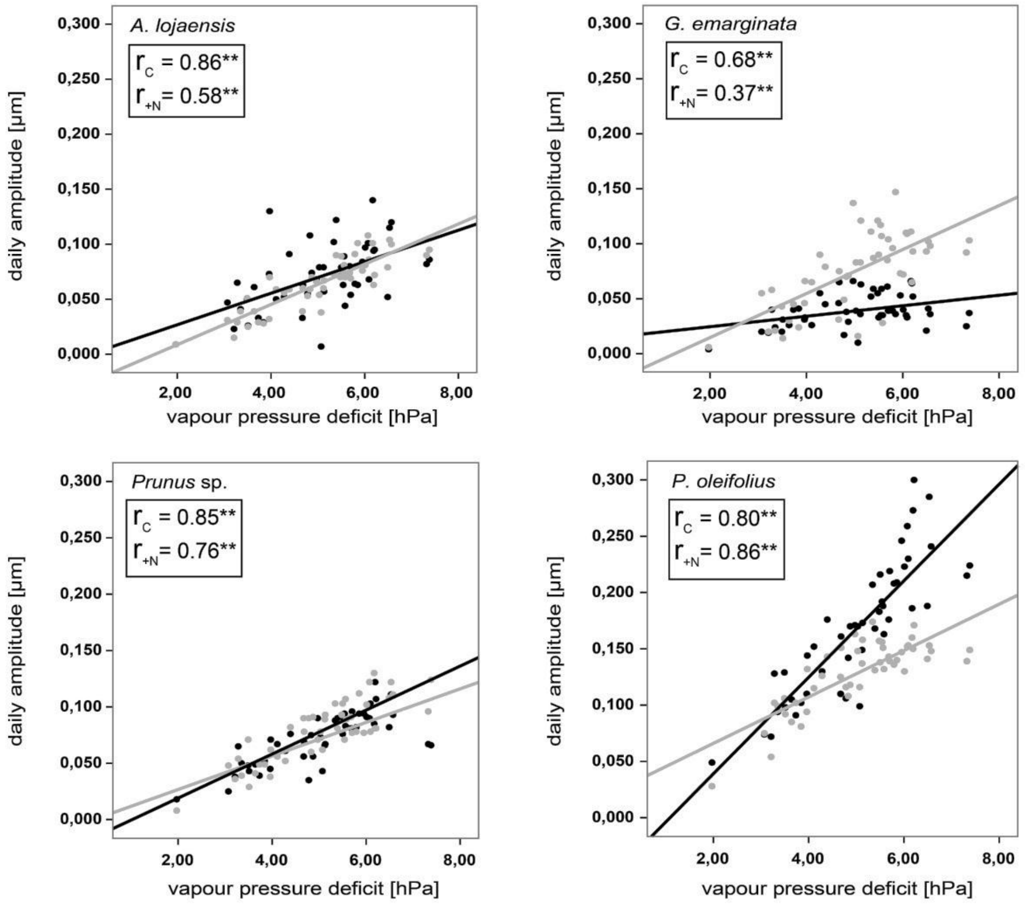


*Figure 6: Correlation between daily amplitude and vapour pressure deficit (black dots: nitrogen fertilised tree; light grey dots: control tree; r_C : Pearson correlation coefficient of the control tree; r_{+N} : Pearson correlation coefficient of the nitrogen fertilised tree). Asterisks mark significant correlations (** p < 0.01).*

Discussion

These first results indicate that tree growth variations during dry periods are species specific. *G. emarginata* shows least positive effects of fertilization on growth and revealed strongest reactions of climatic control on daily radial stem variations. That indicates that this species is well adapted to the nutrient-poor conditions of the upper montane forest belt.

The long-term fertilization effects of tree growth dynamics and physiological behaviour need to be continuously studied for a longer time period. The first preliminary results present a significant and species-specific influence of fertilization on competitive ability of trees under higher influx of nutrients and an increasing frequency of drought periods.

Acknowledgements:

The authors are indebted to the German Research Foundation (DFG) for financial support of the projects BR 1895/14-1 und BR 1895/14-2 (FOR 816).

References:

Bendix, J., Rollenbeck, R., Richter, M., Fabian, P., Emck, P. (2008a): Climate. In: Beck, E., Bendix, J. Kottke, I. , Makeschin, F. , Mosandl , R. (Eds.): Gradients in a Tropical Mountain Ecosystem of Ecuador. *Ecological Studies* 198: 1-13.

Bendix, J., Rollenbeck, R., Göttlicher, D., Nauss, T., Fabian, P. (2008b): Seasonality and diurnal pattern of very low clouds in a deeply incised valley of the eastern tropical Andes (South Ecuador) as observed by a cost effective WebCam system. *Journal of Applied Meteorology* 15: 281–291.

Bräuning, A., Homeier J., Cueva, E., Beck E., Günter, S. (2008): Growth dynamics of trees in tropical mountain ecosystems. In: Beck, E., Bendix, J., Kottke, I., Makeschin, F., Mosandl, R. (eds.): Gradients in a Tropical Mountain Ecosystem of Ecuador. *Ecological Studies* 198: 291-302.

Bräuning, A., Volland-Voigt, F., Burchardt, I., Ganzhi, O. , Nauss, T., Peters, T. (2009): Climatic control of radial growth of *Cedrela montan*a in a humid mountain rain forest in southern Ecuador. *Erdkunde* 63: 337-345.

Cavelier, J., Tanner, E., Santamaría, J.(2000): Effect of water, temperature and fertilizers on soil nitrogen net transformations and tree growth in an elfin cloud forest of Colombia. Journal of Tropical Ecology 16 (1): 83-99.

Deslauriers, A.; Rossi, S.; Anfodillo, T. (2007): Dendrometer and intra-annual tree growth: What kind of information can be inferred? *Dendrochronologia*, (25) 2: 113-124.

DFG Research Unit 816 (2013): TMF Newsletter, Issue 19. Laboratory for Climatology and Remote Sensing (LCRS), University of Marburg, Marburg, Germany. DOI:10.5678/lcrs/for816.cit.1233.

Emck, P. (2007): A climatology of South Ecuador. PhD-Thesis. University of Erlangen-Nuremberg. http://www.opus.ub.uni-erlangen.de/opus/volltexte/2007/656/(29.03.2013).

Galloway, J.N., Dentener, F.J., Capone, D.G., Boyer, E.W., Howarth, R.W., Seitzinger, S.P., Asner, G.P., Cleveland, C.C., Green, P.A., Holland, E.A., Karl, D.M., Michaels, A.F., Porter, J.H., Townsend, A.R., Vörösmarty, C.J. (2004): Nitrogen cycles: past, present, and future. *Biogeochemistry* 70: 153–226.

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z.C., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., (2008): Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. *Science* 320: 889–892.

Hietz, P., Turner, B.L., Wanek, W., Richter, A., Nock, C.A., Wright, S.J. (2011): Long-Term Change in the Nitrogen Cycle of Tropical Forests. *Science* 334: 664-666.

Homeier, J.; Hertel, D.; Camenzind, T.; Cumbicus Torres, N.; Maraun, M.; Martinson, G.; Poma, N.; Rillig, M.C.; Sandmann, D.; Scheu, S.; Veldkamp, E.; Wilcke, W.; Wullaert, H. & Leuschner,

C. (2012): Tropical Andean Forests Are Highly Susceptible to Nutrient Inputs? Rapid Effects of Experimental N and P Addition to an Ecuadorian Montane Forest. *PLoS ONE* 7 (10), 1-10.

Homeier, J.; C. Leuschner, C.; Bräuning, A.; Cumbicus, N., Hertl, D. Martinson, G. Spannl, S.; Veldkamp, E. (2013): Effects of increased nutrient deposition on the productivity of South Ecuadorian montane forests and implications of the carbon cycle. In: In: Bendix J, Beck E, Bräuning A, Makeschin F, Mosandl R, Scheu S and Wilcke W (eds): Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador. Ecological Studies Vol. 221, Springer, Berlin, Heidelberg, New York. (in Press).

Lewis, S.L., Malhi, Y., Phillips, O.L (2004): Fingerprinting the impacts of global change on tropical forests. *Philosophical Transactions of the Royal Society B: Biological Sciences* 359, pp. 437-462.

Richter M., Peters, T. (2011): Klimavielfalt, Klimawandel und Klimafolgen in den tropischen Anden. *Passauer Kontaktstudium Geographie* 11: 159-174.

Rozendaal, D.M.A., Zuidema P.A. (2011): Dendroecology in the tropics: a review. *Trees* 25: 3-16.

Schönwiese,C.D. (2003): Klimatologie. 2. Aufl. Stuttgart.

Spannl, S., Günter, S. Peters, T, Bräuning, A. (2011): Which factors control tree growth in a tropical mountain forest? The case of *Cedrela Montana* in Southern Ecuador. TRACE 11: 106-105.

Tanner, E.V.J., Kapos, V., Freskos, S., Healey, J.R., Theobald, A.M. (1990): Nitrogen and phosphorus fertilization of Jamaican montane forest trees. *Journal of Tropical Ecology* 6: 231-238.

Volland-Voigt, F., Ganzhi, O., Bräuning, A. (2010): Stem growth and wood anatomy in tropical trees in Southern Ecuador. *Trace* 9: 13-17.

Volland-Voigt, F., Bräuning, A., Ganzhi, O., Peters, T., Maza, H. (2011): Radial stem variations of *Tabebuia chrysantha* (Bignoniaceae) in different tropical forest ecosystems of southern Ecuador. *Trees* 25: 39-48.

Wullaert, H.; Homeier, J.; Valarezo, C. & Wilcke, W. (2010): Response of the N and P cycles of an old-growth montane forest in Ecuador to experimental low-level N and P amendments. Forest Ecology and Management 260: 1435-1445.

Radial growth and climate signals of *Picea schrenkiana* at different elevations in the Sary-Chelek Biosphere Reserve, Kyrgyzstan

M. Magnuszewski [1], A. Orozumbekow [2] & M. Zasada [1]

[1] Warsaw University of Life Sciences – SGGW, Faculty of Forestry, Nowoursynowska 159, 02-776 Warsaw, Poland.
[2] K.I. Skryabin Kyrgyz National Agrarian University
E-mail: Michal.Magnuszewski@wl.sggw.waw.pl, Michal.Zasada@wl.sggw.waw.pl

Introduction

Kyrgyzstan is a Central Asian Republic located in the north of the Tian Shan mountains massif. Most of these territories (93%) is located between the alltitudes of 800 to 3000 m a.s.l. The territory of Kyrgyzstan was divided into eight different climate regions. Spruce occupies almost all of the regions. In the Fergana-Chatkal region (third Kyrgyz Forest Region), Schrenk spruce reaches its south range (Gan 1970, Grisa et al. 2008). Most of the forests here are situated in the Sary-Chelek Biosphere Reserve. This Reserve is one of the most interesting and unique places in the Fergano–Chatkal forest region, recognizes a UNESCO Biosphere Reserve (Grisa et al. 2008). Except spruce forest, in the Sary-Chelek there are also walnut-fruit forests and juniper forests, which are included in the Red Book of Kyrgyzstan (Antonia et al. 2009).

In the Sary-Chelek Reserve Schrenk spruce found good growing conditions, but spruce stands are very fragmented and grow at different elevations, where climate factors create diversified growing conditions. The altitude of spruce stands in Sary-Chelek varies from 1300 to 2500 m a.s.l. (Grisa et al. 2008).

The objective of this study was to answer the question about climatic factors influencing radial growth of spruce trees at different elevations: 1350-1400, 1500-1600 and 1900-2000 m a.s.l. in the Sary-Chelek Biosphere Reserve.

Material and methods

The study was conducted in the Sary-Chelek Biosphere Reserve (Fig. 1), which is situated on the southern slopes of Chatkal massif in the western mountain ranges of the Tian Shan. The climate at Sary-Chelek station, located at 1100 m asl., is classified as dry continental, with hot summers (type DS according to Köppen 19xx; Grisa et al. 2008). The average annual temperature is 7.9°C. The hottest month is August, with a mean temperature of 19°C. The coldest month is January, with the average temperature of -5.3°C. The average annual rainfall is 993 mm. Most of the rain falls in spring (March-May), when monthly precipitation reaches 120-150 mm. The least rainfall occurs in August and September (average 37 mm per month).

Increment cores were collected in 2010 during field campaign organized within the Erasmus-Mundus External Cooperation Window Asia programme. The study plots were located at various altitudes: 1350-1400, 1500-1600, and 1900-2000- m a.s.l., with north slope ranging from 35 to 50 degrees. The lowest study plots were established near the Sary-Chelek village, while the most upper site was located next to the Sary-Chelek lake, which is located about five kilometres from the village. Increment cores (one per tree) were sampled from dominant and co-dominant trees perpendicularly to the slope to minimize the effects of slope on the tree ring width. There were 15-20 trees sampled in each plot, depending on the number of trees located in the area.

Tree-ring widths were measured using the CooRecorder 7.3 software, and verified using CDdendro 7.3 (www.cybis.se). After COFECH analyses samples with low cross-correlation results were eliminated based on results (Holmes 1983). After COFECH analyses were eliminated samples with low cross-correlation. To build residual chronology all samples from the lower site were used, 17 samples from the middle one and only 13 samples from the upper.e The ARSTAN

DOI: 10.2312/GFZ.b103-13058

software was used (Cook and Holmes 1986; Cook and Kairiukstis 1990) to develop residual chronologies by detrending method (negative exponential curve with straight line). The residual chronology was used for comparison of the radial increment of spruce in the analysed area. The following basic statistical measures of ring widths were calculated: arithmetic mean, maximum, minimum and median values, standard deviation, coefficient of variation, and mean sensitivity (Tab. 1).

In addition, pointer years were identified for years where ≥ 80% of all trees indicated synchronous growth intervals (Tab. 2). A minimum replication criterion of 10 trees was used in this procedure (Elling 1966, Huber 1970). The residual chronologies were employed to assess growth-climate relationships using the response function model described in details by Fritts (1976) with the monthly temperature and precipitation data from the Sary-Chelek meteorological station over the 1966-2009 period.

Figure. 1. Map of Kyrgyzstan with Sary-Chelek Biosphere Reserve (large black point)
(source: https://www.cia.gov/library/publications/the-world-factbook/maps/maptemplate_kg.html)

Results

The longest chronology, reaching back to 1773 AD, was created from the spruce site located at 1900-2000 m asl. (236 years). The chronologies from 1350-1400 and 1500-1600 m a.s.l are shorter, spanning 105 and 188 years, respectively (Tab. 1).

The mean tree ring width is similar among the spruce sampling sites, reaching from 0,97 mm (low), to 0,97 mm (middle) and 0,99 mm (upper site). However, differences in other statistical parameters were observed, such as maximum, minimum, and median tree ring width, as well as standard deviation and variability. At the lower and middle elevations a very high diversity exists between the minimal and maximal tree ring widths (Tab.1). The highest variability was observed in the middle elevation, with a coefficient of variation reaching about 23% (Tab.1). The pointer years were similar between low and high elevation sites (Tab.2).

Influence of weather conditions on the creation of Schrenk spruce growth were different at three elevations (Fig.1 and 2). Significant and positive correlations between tree ring width and monthly temperatures were observed at the upper elevation site for January, February and November in the year of ring formation. Significantly negative correlations were observed at the lowest elevation site for June and July in the year preceding tree ring formation, and at the middle elevation site for March, April, May, July, June, September in the year of ring formation and for August, September, November prior to the year of tree- rings formation (Fig. 1).

The monthly precipitation data shows mostly positive association with the tree ring growth on all the sites. Positive correlations were found with winter, spring and summer precipitation prior to the year of ring formation at the lower (January, February, March, April, Mai, June, July) and upper (January, February, April, June, July, August) elevation (Fig. 2). The middle elevation site showed significantly positive correlations between winter, spring and summer (January, March, April, Mai, June July, August) precipitation in annual year of ring formation In the upper site has founded positive correlation between tree rings growth and spring (March) of current year.

Table 1: Characteristic of residual chronology from the study plots in Sary-Chelek Biosphere Reserve.

	Site 1	**Site 2**	**Site 3**
Elevation m a.s.l	1350-1400	1500-1600	1900-2000
Chronology length	1904-2009	1821-2009	1773-2009
Mean tree ring width	0.97	0.97	0.99
Max. tree ring width	1.51	2,05	1.94
Min. tree ring width	0.55	0.22	0.06
Median tree ring width	0.96	0.96	0.98
Standard delevation	0.18	0.22	0.19
Variability	19%	23%	19%

Table 2: Pointer years.

1350-1400m a.s.l	**1500-1600m a.s.l**	**1900-2000m a.s.l**
Positive pointer years		
1999		1999
1997		1997
1987	1987	
1980		1980
1973		1973
		1958
	1958	
Negative pointer years		
2008	2008	2008
2001		2001
	2000	2000
1998		1998
1995	1995	1995
	1994	1994
1989		1989
1979		1979
1976		1976
1974		1974
1971		1971

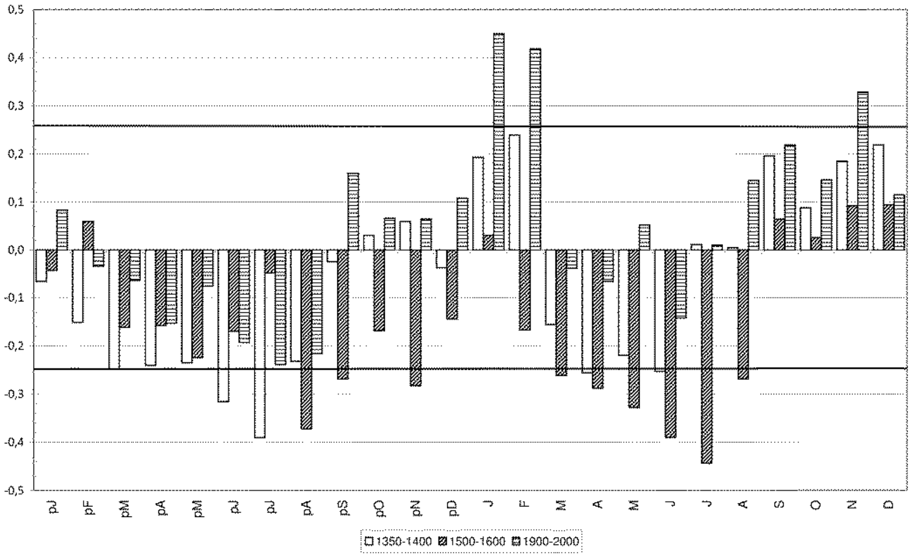


Figure 1: Correlation between Picea Schrenkiana residual chronologies from different elevations and monthly temperatures in the Sary-Chelek Biosphere Reserve. Horizontal lines indicate correlations at p < 0.05.

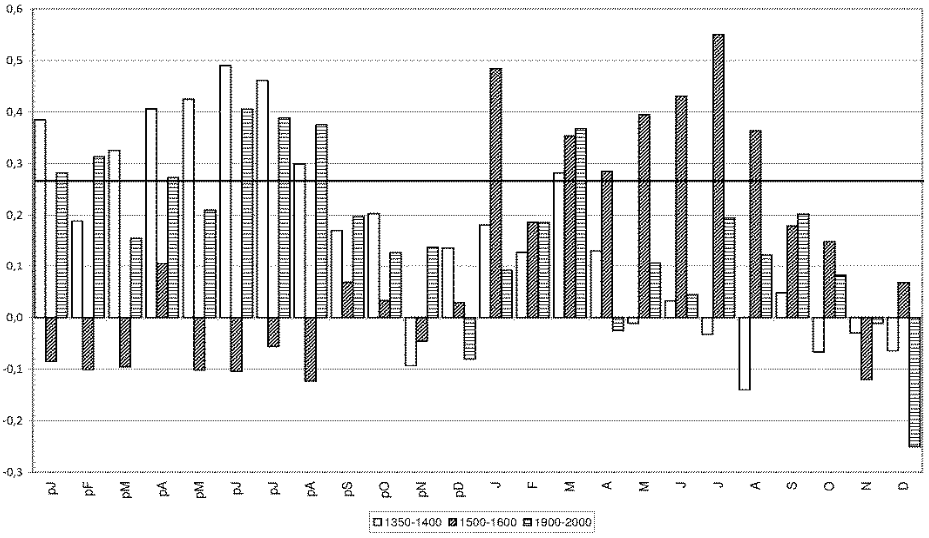


Figure 2: Correlation between tree rings width of Picea Schrenkiana trees and mean monthly precipitation in Sary-Chelek Biosphere Reserve. Horizontal lines indicate correlations at p < 0.05

Discussion

The growth of Schrenk spruce from the Sary-Chelek Reserve is more dependent on rainfalls than temperature in all analysed plots (Fig. 1 and 2). Vertical distribution of spruce forests depends on the availability of moisture and the temperature conditions (Grisa et al. 2008).Thus in the Kyrgyz Tian-Shan the lower border of spruce forests depends on limited availability of moisture, and the upper border on the availability of the heat (Orlow 1989).

In the Sary-Chelek Biosfere Reserve on three studied sites at different altitudes, the relationship between climate and tree ring growth was totally different. The limiting factor in the upper site should be limitation of temperature, but in this investigation it isn't.. Positive correlation between tree rings growth and the coldest months (January, February) on the upper sites (1900-2000) could be caused by local conditions which are created by the Sary-Chelek lake. On the other hand, in the lower sites the limiting factor is stock of water, what was confirmed by positive correlation between precipitation in the prior year and tree ring width (winter, spring is the season when precipitation in Sary- Chelek is the highest). If the previous season is filled with moinsture, trees can use it in the next growing season. However if the temperature is hight during the rainfall season, it can result in reducing water in the soil and therefore hence the stress. This occurs particularly in the continental climate at the lower altitudes. The same strategy was observed by Wang et al. (2005) during investigation of Schrenk spruce located in the Xinjiang reserve in Uygur, an autonomous region of China. A positive correlation between the tree ring width in the annual rainfall and also in August of the year preceding the altitude gradient in the central part of the Tian Shan mountains in China was a common feature connecting all tree areas.

One of the most important sources of water in a continental climate could be melting of the snow, which can be a moisture stock in the high mountains during spring and summer. That can explain the positive correlation between the precipitation in winter and tree rings width (Fig. 1 and 2).

Conclusions

- The researched stands are characterized by similar tree-ring width values, but different variability of tree rings width through the entire altitude gradient.
- For all plots a positive correlation between precipitation and tree-ring widths was observed:
  - On the lower one positive influence of precipitation were in winter, spring and summer prior year of tree rings formation,
  - On the middle one, it was observed with positive influence on precipitation in winter, spring and summer of current year of the tree ring growth.
  - On the upper plots positive influence of precipitation was observed? in winter, spring and summer prior to the year of tree rings formation and also in March of current year of tree rings formation
- The influence of temperature at all elevations is negative. The only exception is plot from the upper elevation, where temperature in winter and spring months of the current year is positively correlated with the tree ring widths.
- The number of pointer years was a similarity between lthe lower plot (1350 – 1400 m a. s. l) and the upper plot (1900–2000 m a. s. l.).

Acknowledgements

The study was funded by Erasmus- Mundus External Cooperation Window Asia Lot 9. Many thanks to the Rector of Kyrgyz National Agrarian University for his invaluable support. Many thanks to the foresters from Sary-Chelek Biosfere Reserve, especially to Toko Bajke Toktonaly Junusov, who helped in searching and accessing the study plots. Thanks also to all Kyrgyz friends, who helped in collection of the data, especially Kannat Musuraliev, Nurlan Kasmaliev, Mahzat Kalmanbetov, and Bolot Tagaew.

References

Antonia, E., Lazkov, G., Newton, A. (2009): The Red List of Trees of Central Asia. Fauna & Flora International, Cambridge . United Kingtom

Cook, E.R., Holmes, R.L. (1986): User manual for program ARSTAN. In: Holmes RL, Adams RK, Fritts HC (eds) Tree-ring chronologies of western North America: California, eastern Oregon and northern Great Basin. Chronology Series VI: S. University of Arizona, Tucson, pp 50–56

Cook, E.R., Kairiukstis, L.A. (1990): Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, Netherlands

Elling, W. (1966): Untersuchungen über das Jahrringverhalten der Schwarzerle. Flora 156B:155-201

Fritts, H.C. (1976): Tree rings and climate. Academic Press, New York

Gan, P.A. (1970): Lesa SSSR v pyati tomakh. Tom 5: Lesa Kazakhstana,sredneaziatskykh respublik i yugo vostoka evropeyskoy chasti SSR (in Russian) [The forests of the SSSR in Wve volumes, vol 5:

Grisa, E., Venglovsky, B., Sarymsakov, Z., Carraro, G. (2008): Forest typology in the Kyrgyz Republic. Practice oriented document for field assessment and sustainable management of forest stands. Bishkek

Holmes, R. (1983): Computer-assisted quality control in tree-ring dating and mearesurement. Tree-Ring Bull 43:69–78

Huber, B. (1970): Dendrochronologie. [in:] Handbuch der Mikroskopie in der Technik 5,B.1.Umschau Verlang, Frankfurt,S.171-211

Orlow, W,P. (1989): Kultury eli Tian-Szanskoj. Akademia Nauk Kirgijskoj CCP, Instytut Biologii, Otdel Lesa. Frunze

Wang, T., Ren, H., Ma, K. (2005): Climatic signals in tree ring of Picea schrenkiana along an altitudinal gradient in the central Tianshan Mountains, northwestern China. Springer-Verlag 19: 735-741

The influence of pluvial conditions on the radial increment of the Douglas fir and eastern white pine in north-eastern Poland

Ł. Ludwisiak & M. Magnuszewski

Department of Dendrometry and Forest Productivity, Faculty of Forestry,
Warsaw University of Life Sciences-SGGW
E-mail: lukasz.ludwisiak@wl.sggw.pl

Introduction

Since the time of great geographic discoveries many tree species, new to our continent, have been brought to Europe. Eastern white pine (*Pinus strobus* L.) and Douglas fir (*Pseudotsuga manziesii* var. *viridis* Franco) were among those species that found their place in Polish forests the earliest (Senet 1973; Fabijanowski et al. 1980). The first Polish studies on the acclimatization of Douglas fir in Poland date back to the 1920s (Suchocki 1926). Initial attempts to determine the impact of climatic and soil conditions on growth of that tree species were made by Borowiec (1965). More recent studies (Cedro 2006, Wilczyński and Feliksik 2007) confirm the relevance of further investigations. Surveys dedicated to Eastern white pine are less numerous, however this species is considered to play a significant role in Polish forests (Ważynska 1969, Król 1988, Kochańska 2006)

In Poland, both eastern white pine and Douglas fir find good opportunities for growth and development, corresponding to the climate conditions in the central regions of their natural range (Jaworski 1995). Under local growing conditions productivity of Douglas fir can reach more than 500 m^3ha^{-1} at the age of 50, making this species the most productive one in the country (Chylarecki 2004). In Poland, more than 3000 hectares is estimated to be occupied only by Douglas fir. Despite their large productivity and other advantages, the future of Douglas fir and eastern white pine in Polish forests is uncertain, due to latest international and country level legal regulations.

The objective of this study was to construct a local tree-ring width chronology of the two introduced species growing in the same locality and compare their growth pattern with pluvial conditions.

Study site

The study was performed in the Lidzbark Forest District (Fig. 1) in the province of Warmia and Mazury (north-eastern Poland). Study material originates from two sample plots located in stands characterised with similar habitat conditions. Both, eastern white pine (mixed with Norway spruce) and Douglas fir (mixed with Scots pine) were planted as an experimental plots to investigate the characteristics of alien species in Polish forest.

Sampling plots were located in two stands located 500 meters from each other. Douglas fir constituted more than 50% of the species structure and average breast height diameter of this species reached 55 cm. Eastern white pine constituted circa 25% of the species structure and mean dbh equalled 52 cm. According to the classification used in Polish forestry, both stands grow on fresh deciduous (Lśw) forest habitat types (Plan Urządzania Lasu). Precipitation in that region is rather not profuse, ranging 540-610 mm annually. During the vegetation period (lasting for 181 days), 340-360 mm of rain is noted on average.

DOI: 10.2312/GFZ.b103-13058

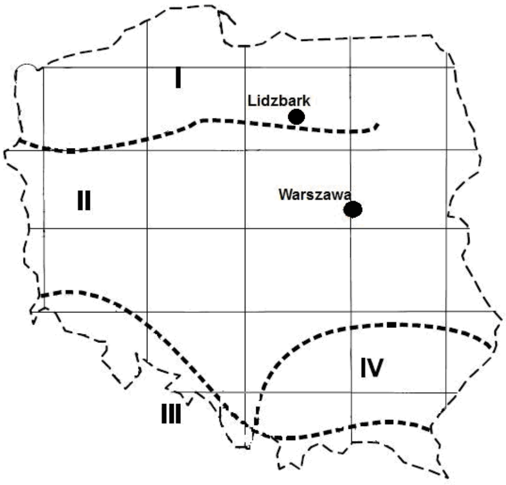


Figure 1: Study site and dendroclimatic regions for Douglas fir in Poland (Wilczyński 2007)

Material and methods

On each study plots 20 dominant, healthy and undamaged trees were sampled. Increment cores were collected in 2011 just before the final felling of the stands. One increment core from the breast height per tree was taken with Pressler borer from dominat and co-dominat trees.

Cores were sanded with finer grade until the tree-ring boundaries became easily distinguishable and then scanned with the flat-blatt scanner. CooRecorder image analysing program (www.cybis.se) was used for measuring tree-ring widths to the nearest to 0.01 mm. Individual series were cross-dated visually with the CDendro (www.cybis.se) software. The synchronization was checked with COFECHA program (Holmes 1999, Grissino-Mayer 2001). Series that showed highest dissimilarity of growth pattern were excluded from the further analysis in order to prevent limitation of the common signal exhibited by the chronologies. In total, 36 individual tree-ring width series were used in the chronology forming. Chronologies were constructed according to the conventional procedures (Cook & Kairiukstis 1990). Residual chronologies were computed for individual study plots with ARSTAN software used detrending method negative exponetial curve with straight line (Holmes 1999).

According to the previous research, the lack of water has a significant impact on native species (Bijak 2010) and alien (Wilczyński and Feliksik 2007) tree species in Polish forests. Having valuable local information data authors decided to focus on pluvial records which were collected in satisfactory long period of time. Climate data used in this study originate from Kostkowo station (1988-2011 period) located within 10 km range from the sites. Correlation analysis was used to study relationship between annual ring width and precipitation. Each chronology was correlated with monthly values starting from June of the year prior to ring formation to December of the year of cambium activity.

Results

Chronologies cover the period of 1906-2011 for eastern white pine and 1909-2011 for Douglas fir (Fig. 2). There were no missing rings found in analyzed tree-ring series and the investigated species are characterized by similar ring-width variations. Table 1 shows the characteristics of standard chronologies of studied species from plots in Lidzbark Forest District.

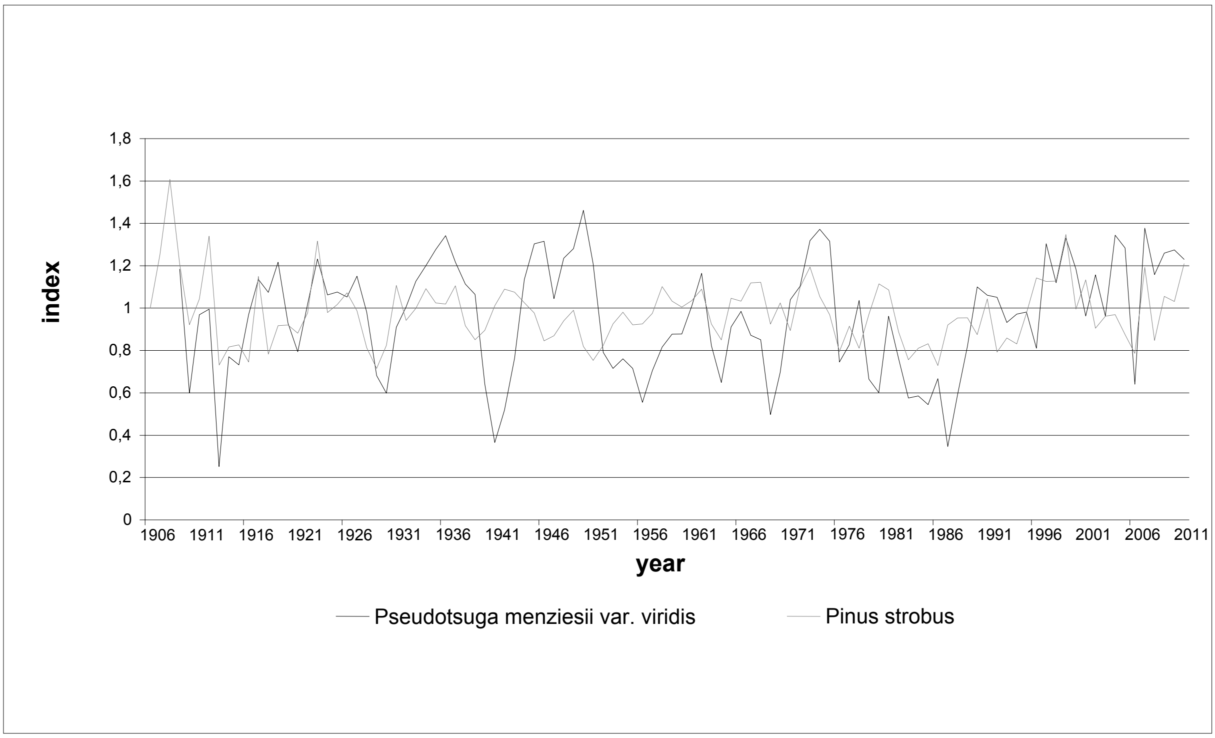


Figure. 2: Residual chronologies of analysed species

Table 1: Characteristics of residual chronologies of studied species from plots in Lidzbark Forest District

	Pinus strobus	*Pseudotsuga menziesii*
Time span	*1906-2011*	*1909-2011*
Mean tree ring width	*0,980*	*0,958*
Max. tree ring width	*1,608*	*1,462*
Min. tree ring width	*0,715*	*0,225*
Median tree ring width	*0,976*	*0,0982*
Standard deviation	*0,149*	*0,265*
Variability	*9,25%*	*18,09%*

Pluvial conditions are important factors for shaping radial increment of both species (Fig. 3). The analyzed species respond slightly different to precipitation. Eastern white pine reacted positively to intensive precipitation in previous year of tree ring growth with March, August and November and between tree rings growth and current June and July. Negative correlation was found in previous June and current November of tree ring growth. Douglas fir suffered from the limited amount of precipitation in March and September of the prior year to ring formation. Positive correlation was found between previous August and November and January and February and July current year of tree rings grow.

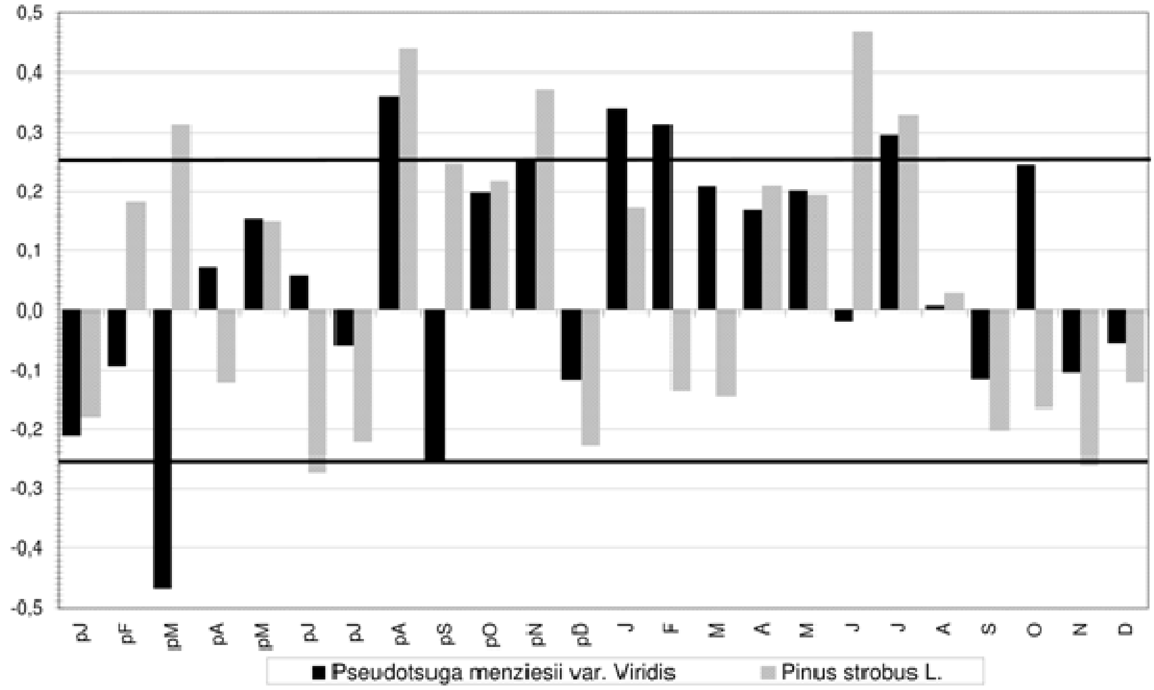


Figure 3: Correlation between Pseudotsuga menzesii var. viridis and Pinus strobus residual chronologies from Lidzbark Forest District and mean monthly precipitation in Kostkowo meteo station. Horizontal lines indicate significance level at $p < 0.05$.

Discussion

Drought is recognised as a one of the most important factors limiting growth of trees (Bronisz et al. 2009, Bijak 2010) Our study shows that pluvial conditions have a significant influence on growth rates of both studied species. According to Cedro (2006) the most limiting climate for Douglas fir in northern Poland is an air temperature. In SW Canada, however, the correlation of climatic parameters and ring width for Douglas fir demonstrated the predominating role of precipitation for tree-ring formation (Watson and Luckman, 2002). The growth reaction of eastern white pine depending on different factors. For example in America is very well known (Barton et al 1997, Hudson 2007, Pickarda et al 2011). However in Poland, due to their non-native origin and relatively low percentage of share in Polish forests, the characteristic of their radial growth is still unrecognized (Ważynska 1969). It seems to be more and more important to know the dependence of those species on pluvial conditions as numerous native species suffer from lack of water (Bijak, 2010, Koprowski and Zielski, 2006, Okoński and Koprowski, 2012). This article shows the influence of pluvial condition of two aliens species in Polish forest. The investigation demonstrates that in Polish forest pluvial conditions are very important for introduced species. However, this research did not give an answer why two aliens species can react differently to the pluvial conditions in the similar habits and climates conditions. To answer it more studies need to be conducted in the future.

Conclusions

Both of the studied species have similar tree age and rings width characteristic, however in the Lidzbark Forest District Douglas fir's better productivity was observed.

Hence, pluvial conditions are important and significantly correlated with tree rings growth for both studied alien species.

Therefore the two investigate aliens species have different reaction for pluvial conditions growing under the similar habitats and climates conditions in the Lidzbark Forest District.

References

Barton B., Elliott K. J., Swank W. T. (1997): Response of Planted Eastern White Pine (Pinus strobus L.) to Mechanical Release, Competition, and Drought in the Southern Appalachians. *The Southern Journal of Applied Forestry*, Vol. 21, No. 1 ;19-23.

Bijak Sz., (2010): Tree-ring chronology of silver fir and its dependence on climate of the Kaszubskie Lakeland (Northern Poland), *Geochronometria* 35 (2010), pp 91-94

Borowiec S. (1965). Ocena warunkow makroklimatycznych i glebowych w Polsce do hodowli daglezji (*Pseudotsuga taxifolia* Britton), *Sylwan* 1: 27-34.

Bronisz A., Bijak Sz., Bronisz K. and Zasada M. (2009)., Dendroclimatological investigation on radial growth of silver fir from inside and outside distribution range in Poland, *TRACE* Vol. 8, p 6-13.

Cedro A., (2006). Influence of thermic and pluvial conditions on the radial increments of *Pseudotsuga menziesii* Franco from Western Pomerania, Poland, *TRACE* Vol. 61, p. 132 – 140.

Cook, E., Kairiukstis, L. (1990). Methods of dendrochronology: applications in the environmental sciences, IIASA, *Kluwer Academic Publishers*, Boston

Chylarecki, H. (2004). Daglezja w lasach Polski. Potencjał produkcyjny, wymagania ekologiczne, biologia. *Bogucki Wydawnictwo Naukowe*

Fabijanowski, J., Jaworski, A., Jezutek, A. (1980). Ocena hodowlana gatunków drzew rodzimych i obcych prowadzonych na powierzchniach doświadczalnych w Zawoi. *Acta Agr. Et. Silv.*, ser Silv., Vol. 19.

Grissino-Mayer, H.D. (2001): Evaluating cross-dating accuracy: a manual and tutorial for the computer program COFECHA. *Tree Ring Research* 57: 205-221.

Holmes, R.L. (1999): Dendrochronology Program Library (DPL) User's Manual. *LTRR University of Arizona*, Tuscon

Hudson L. (2007): Limber Pine Sensitivity to Climatic and Biological Stressors: Evidence from Dendrochronology and Carbon Isotopes. Master thesis, Colorado

Jaworski, A., (1995). Charakterystyka hodowlana drzew leśnych. Kraków*, Gutenberg*

Kochańska, A, (2006). Egzotyczne drzewa Zielonej Góry, *Rocznik Lubuski* vol 32, cz. 1.

Koprowski M., Zielski A. (2006): Dendrochronology of Norway Spruce (Piecea Abies (L.) Karst) from two range centers In lowland Poland. Trees 20. s. 383-390.

Król, S., (1988).Synantropizacja fitocenoz leśnych przez introdukcję obcych gatunków drzew *Wiadomości Botaniczne*, vol. 2, p 115-124.

Okoński B., Koprowski M. (2012): Zależność przyrostów promieniowych dębu szypułkowego oraz jesionu wyniosłego od opadów atmosferycznych na stanowisku położonym na terasie zalewowej doliny rzecznej Warty *Studia i Materiały CEPL w Rogowie*, R. 14. Zeszyt 1 (30)

Pickarda F., Robichaudb A., Colin P. L. (2011): Using dendrochronology to date the Val Comeau canoe, New Brunswick and developing an easternwhitepine chronology in the Canadian Maritimes. *Dendrochronologia,* Volume 29, Issue 1, Pages 3–8

Plan Urządzania Lasa dla Nadleśnictw Lidzbark

Seneta, W., (1973). Dendrologia. Warszawa, PWN.

Suchocki, S. (1926). Kilka uwag o zarastaniu ściętych pni u daglezji zielonej (*Pseudotsuga Douglasii*). *Rocznik Polskiego Towarzystwa Dendrologicznego*: 111-112, Lwow.

Watson, E., Luckman, B. (2002): The dendroclimatic signal in Douglas-fir and ponderosa pine tree-ring chronologies from the southern Canadian Cordillera. *Can. J. For. Res*. 32: 1858-1874

Ważyńska, J. (1969). Badania nad aklimatyzacją sosny wejmutki (*Pinus strobus* L.) w Polsce. Arb. Kórnickie 14: 133-217.

Wilczyński, S., Feliksik, E., (2007). Local chronologies and regional diversity of dendrochronological of Douglas fir in Poland. *Geochronometria* 26, pp 69-80.

www.cybis.se

Growth response of sessile oak to climatic variability at two sites in West and Northeast Germany

K. Fregien [1], I. Heinrich [1], G. Helle, [1], I. Dorado Liñán [1] & B. Neuwirth [2]

[1]*GeoForschungsZentrum (GFZ) Potsdam - German Research Centre for Geosciences, Section 5.2 Climate Dynamics and Landscape Evolution, Telegrafenberg, 14473 Potsdam, Germany*
[2]*Department of Geography, University of Bonn, Meckenheimer Allee 166, 53115 Bonn, Germany*
E-mail: heinrich@gfz-potsdam.de

Introduction

Oaks have been comprehensively investigated dendroclimatologically, in order to assess the direct and indirect factors influencing tree growth (e.g., Gray & Pilcher 1983, Briffa et al. 1986, Lévy et al. 1992, Hartmann & Blank 1992, Baillie 1994). Previous investigations revealed that above average temperature and below average precipitation and associated parameters, e.g. soil moisture, were responsible for limiting tree growth (Garzía-González & Eckstein 2003, van der Werf et al. 2007, Mérian et al. 2011), and identified that above average precipitation in autumn of the previous year presumably supporting the additional storage of carbohydrates. Drought events have been considered to be one of the main predictors causing extreme negative growth reactions in oak (Kelly et al. 1989; Bréda et al. 1993; Lebourgeois et al. 2004, Michelot et al. 2012).

While most of the aforementioned dendroclimatic oak studies have been conducted at sites with significant growth limitations, the site selection of the current study was already pre-set by the fact that, for better comparability, the tree-ring records had to be collected near two lakes which have recently been sampled for lake sediment cores. The two lakes are part of a network of Terrestrial Environmental Observatories (TERENO) in Germany as an interdisciplinary research program (Zacharias et al. 2011). For a better understanding of the long-term hydrological dynamics TERENO (Terrestrial Environmental Observatories) focuses on precisely dated and synchronized long-term data from lake sediments and tree rings to reconstruct environmental parameters throughout the Holocene. The two lakes, Lake Holzmaar in the Eifel (TERENO West) and Lake Großer Fürstenseer See in the Mecklenburg lakes district (TERENO Northeast) and the surrounding forests have been selected for comprehensive analyses. In order to address the dynamic interactions of environmental systems, tree-ring analyses are highly suitable for palaeoclimatic studies (Speer 2010). Sessile oak (Quercus petraea [MATT.] LIEBL.) from surrounding forests were chosen for sampling and developing two new robust site chronologies. Sessile oak (Quercus petraea [MATT.] LIEBL.) from surrounding forests were chosen for developing two new robust site chronologies and for assessing their dendroclimatological potentials.

Since climate and soil conditions are generally poorer at the site in NE Germany, we hypothesise that trees at this site will be more drought-sensitive than at the western site. In order to test this we investigate the major growth-limiting parameters, temperature, precipitation as well as drought, to explore their effects on tree-ring widths of sessile oak at the two sites in W and NE Germany, which to our knowledge is the first east-west comparison of oak in this regard. Furthermore, we aim to estimate the driving factors of site-specific extreme growth reactions with regard to extreme climatic deviations.

Material and Methods

Study sites

The two study sites represent different geographical regions in Germany: the Eifel mid-range mountain region of West Germany (W Germany), and the Müritz National Park in the Northeast German lowlands (NE Germany) (Fig. 1).

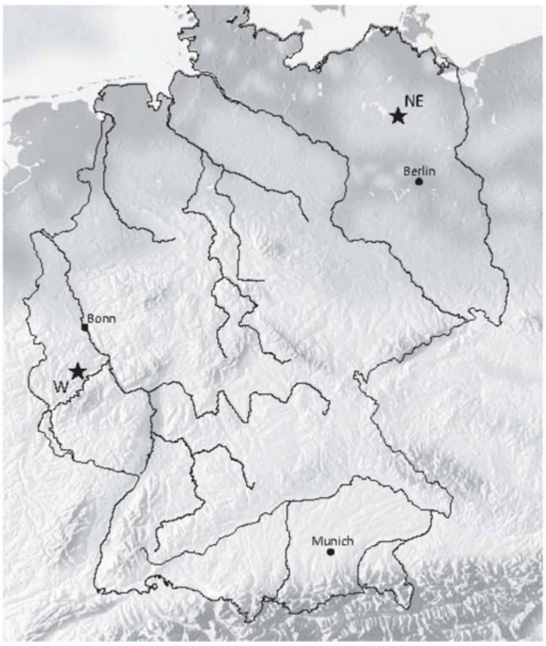


Figure 1: Location of the study areas in W and NE Germany.

The climatic situation of W Germany is dominated by moist oceanic conditions with milder winters and annual precipitation of approximately 800 mm. The soil is a well-drained and moderately developed dystric cambisol, and the soil texture varies from stony to sandy loams. In contrast, NE Germany generally experiences colder winters and less precipitation (approximately 600 mm). The annual mean temperatures in the two regions show only little differences, however, the rainfall variability is most pronounced during the summer month (Fig. 2).

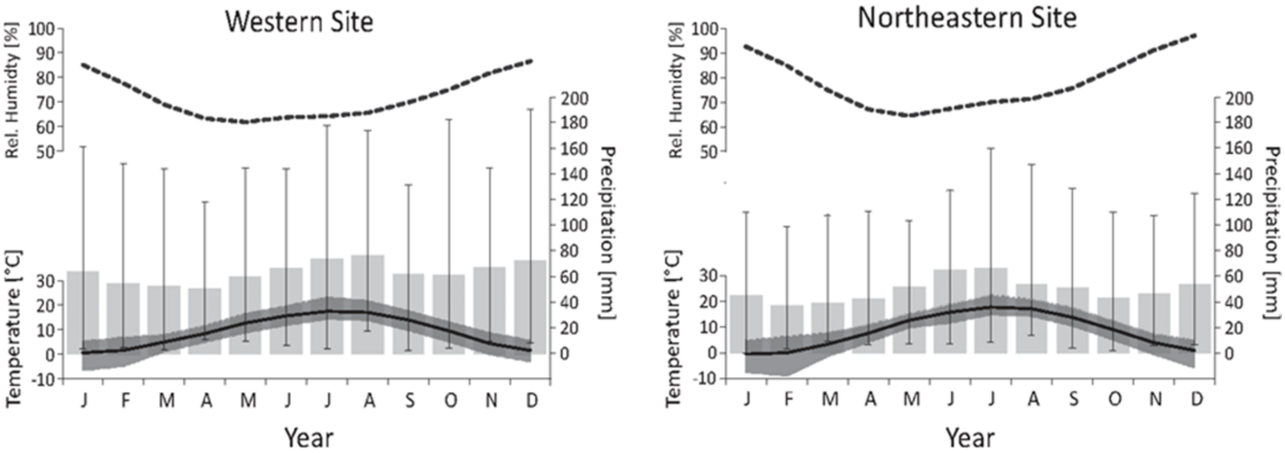
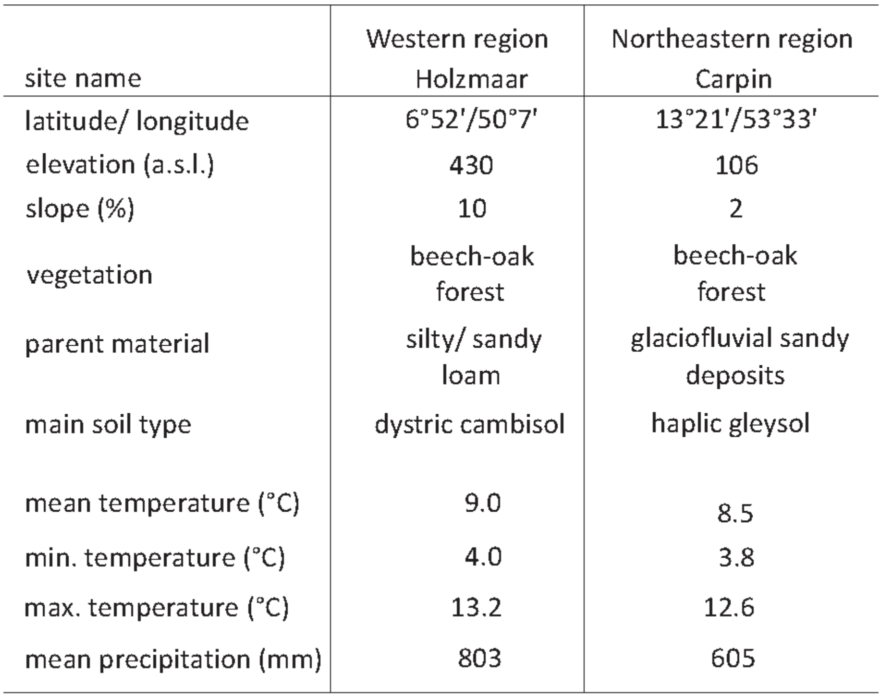


Figure 2: Climate diagrams for the sites in W and NE Germany. Monthly mean temperature (solid line), monthly precipitation sums (bars) and their absolute deviations (min/max) as well as monthly mean relative humidity (dashed line) for the period 1901 to 2006.

At the site in NE Germany, the main parent material for soil development is glaciofluvial sandy deposits and loamy ground moraines. The resulting soil types range from haplic gleysols to eutric cambisols, characterized by generally lower water-holding capacities (Soil Atlas of Europe 2005). Overall, the sites in W and NE Germany mainly differ concerning the rainfall regimes and soil moisture availability. Further details of the site conditions, which are, altitude, slope and elevation are given in Table 1.

Table 1: Site description and characteristics of the oak chronologies investigated in W and NE Germany.



site name	Western region Holzmaar	Northeastern region Carpin
latitude/ longitude	6°52'/50°7'	13°21'/53°33'
elevation (a.s.l.)	430	106
slope (%)	10	2
vegetation	beech-oak forest	beech-oak forest
parent material	silty/ sandy loam	glaciofluvial sandy deposits
main soil type	dystric cambisol	haplic gleysol
mean temperature (°C)	9.0	8.5
min. temperature (°C)	4.0	3.8
max. temperature (°C)	13.2	12.6
mean precipitation (mm)	803	605

Tree-ring data

Sampling of *Quercus petraea* (MATT.) LIEBL. was carried out at two sites in closed canopy forests of W Germany and NE German during the autumns of 2005 and 2009, respectively. From each of the 30 trees, two cores were taken with an increment borer at breast height. Tree-ring width chronologies were developed for each site following standard dendrochronological techniques (Fritts 1976; Cook & Kairiuktis 1990). Annual rings were measured and visually cross-dated with TSAP Win (Rinn 2007) and WinDENDRO (2006). The accuracy of the cross-dating and measurements were verified using the computer program COFECHA (Holmes 1983). Core samples poorly correlated with the master chronology (correlation less than 0.5) were discarded and excluded from the final chronology. Detrending and indexation of each tree was conducted to remove non-climatic trends due to increasing tree age, size, and the effects of stand dynamics. Mean indexed chronologies were developed from the cross-dated ring-width series by applying the ARSTAN program (Cook 1985). For the raw ring-width series, the variance of the radial growth was stabilized using an adaptive power transformation (Druckenbrod & Shugart 2004). In order to keep the inter-annual to multi-decadal variability, each tree-ring series was detrended by fitting a cubic smoothing spline with a 50% frequency cut-off of 30 years of the length of the series (Cook & Peters 1997). After detrending, indices were calculated and individual series averaged by calculating bi-weight robust means resulting in mean site chronologies (Cook et al. 1990). Chronology qualities and signal strengths were estimated using the inter-series correlation (Rbar) and the expressed population signal (EPS) (Wigley et al. 1984). The mean site chronologies used for calibration and climate reconstruction purposes was then cut off at a critical EPS of 0.85.

For the analysis of the climate-growth relationships we used monthly resolved gridded (0.5 x 0.5°) precipitation sums, temperature means (CRU TS 3.1, Mitchell & Jones 2005), and the self-calibrating Palmer Drought Severity Index (scPDSI, van der Schrier et al. 2006). The relationship between oak growth and regional climate was examined using Pearson´s simple correlation coefficients, which were computed between the climate data of the previous and current year and the tree-ring series for the period 1901-2002. The correlations were calculated from March of the year prior to ring formation to September of the current year as well as seasonal averages.
Pointer years were determined using the approach of Cropper (1979) to detect the intensity of single extreme years and the growth-limiting factors, in order to better understand the link between extreme climate events and anomalous tree growth (Neuwirth et al. 2004). These Cropper values were calculated for the period 1901-1996, and individual years were considered as positive or negative pointer years, if the normalized Cropper-value exceeded a threshold of Z_i = ± 1000, respectively. For selected pointer years exhibited by most sampled trees, climate data of the associated years were selected to search for extreme climatic events or disturbances possibly leading to the recorded anomalous tree growth. The long-term monthly means were subtracted from the extracted climate data of the extreme years and the resulting residuals were plotted over a 24-month window starting from January of the previous year and ending in December of the current year (Heinrich et al. 2008).

Results

Chronology characteristics

For both chronologies, important statistical parameters such as the mean EPS values, which constantly stay above 0.85, the chronology replications, the mean series inter-correlations, and the mean segment lengths (MSL) are summarised in table 2.

Table 2: Summary statistics for the oak chronologies in W and NE Germany. MSL: mean segment length (years); AGR: mean radial increment (mm yr^{-1}); Rbar: inter-series correlation and EPS: expressed population signal (calculated for the max. common period).

Site name	Western region Holzmaar	Northeastern region Carpin
Chronology length	2004-1822	2009-1703
No. of trees	16	14
MSL (years)	174	272
AGR (mm year^{-1})	1.5	1.19
Rbar	0.63	0.67
EPS	0.92	0.94

The site chronology in W Germany covers the period 1822-2004, while at the site in NE Germany, the chronology covers the period from 1701 to 2009 (Fig. 3). The western chronology shows a marginally higher mean radial increment (AGR) of 1.5 mm yr^{-1} than the northeastern with 1.3 mm yr^{-1}, and also the values of Rbar are similar ranging from 0.6 (NE Germany) to 0.7 (W Germany). The mean Rbar and EPS values of more than 0.6 and 0.85, respectively, suggest that the chronologies are robust estimates of annual growth changes and that they are suitable for further dendroclimatic research.

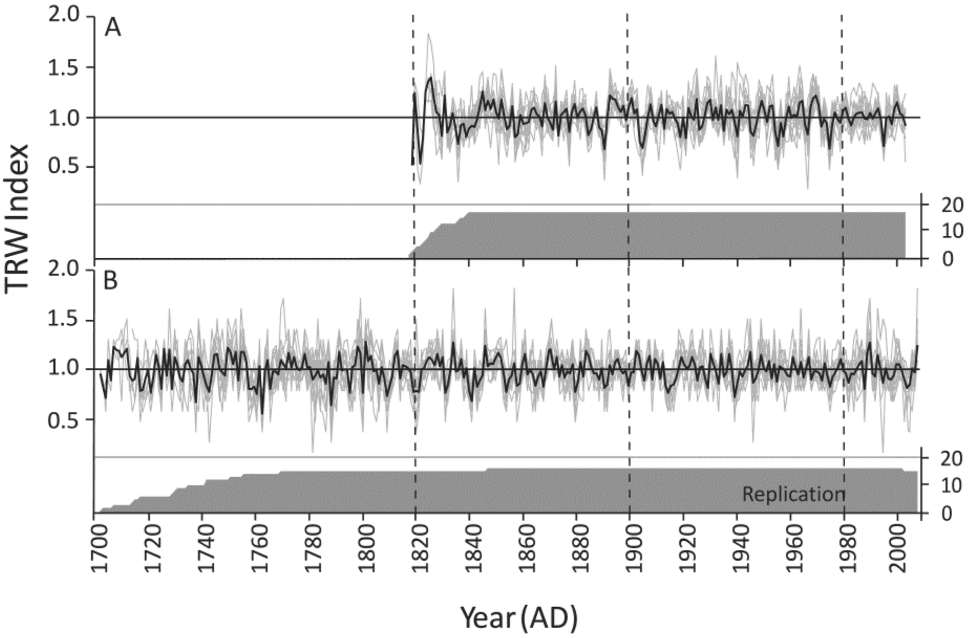


Figure 3: Plots of tree-ring (TRW) indices for W Germany (A) and NE Germany (B). Grey graphs represent indices of individual trees and the black graphs are the respective means. The grey-hatched graphs indicate the number of trees sampled through time.

Climate-growth relationships

Correlations with precipitation are mainly positive which indicates that the availability of water during spring and summer has a positive effect on the growth of oaks at both sites. At the site in NE Germany, annual tree-ring growth is significantly positive correlated to February (r = 0.32) and June (r = 0.34) precipitation sums and to seasonal precipitation sums during the early growing season (April to June) of the current year as well as to the summer precipitation sums of the previous year (July to September). The western oak chronology exhibits a significant positive correlation with June precipitation (r = 0.33). The correlation is stronger for the seasonal variables April to June and May to September suggesting cumulative effects of single months which lead to notably higher correlations with seasonal precipitation sums, whereas no significant correlations for the previous vegetation period exist (Fig. 4A).

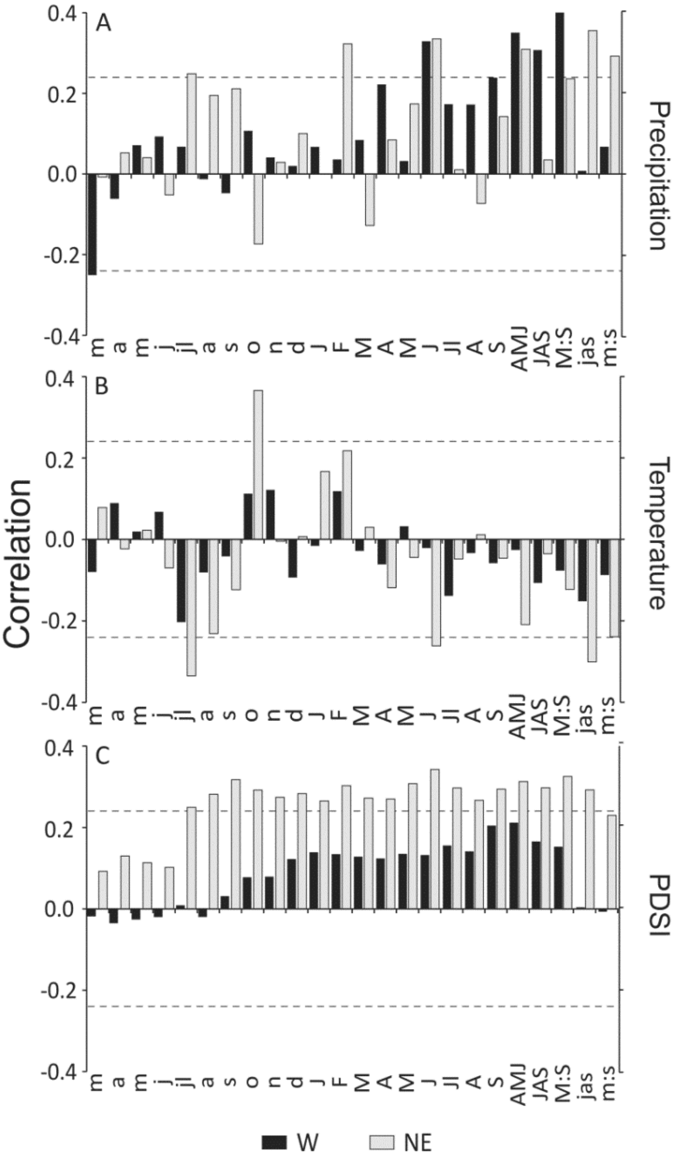


Figure 4: Climate-growth relationships of mean indexed chronologies with mean monthly precipitation (A), temperature (B) and scPDSI (C) (1901-2002), expressed by the coefficient of correlation. The black lines represent the 99% significance levels. Seasonal means are averaged for April to June (AMJ), July to September (JAS) and May to September (M:S) of the previous (small letters) and current (capital letters) year.

At both sites, correlations with temperature are mostly negative for both the current and previous summer month, however, significant values are only indicated for the site in NE Germany where correlations are negative for mean June temperatures (*r* = −0.26) of the current year and for the seasonal mean summer temperatures of July to September of the previous year. Significant positive correlations are only indicated for mean October temperatures (*r* = 0.37) of the previous year for the site in NE Germany (Fig. 4B).

At both sites correlations with scPDSI are positive, however, they are only significant for tree-ring indices from NE Germany. For tree-ring indices from NE Germany, strongest correlations are discernible for the mean June scPDSI (*r* = 0.34) of the current year, the mean September scPDSI of the previous year (*r* = 0.31) and for the seasonal mean summer scPDSI of May to September of the current year (Fig. 4C).

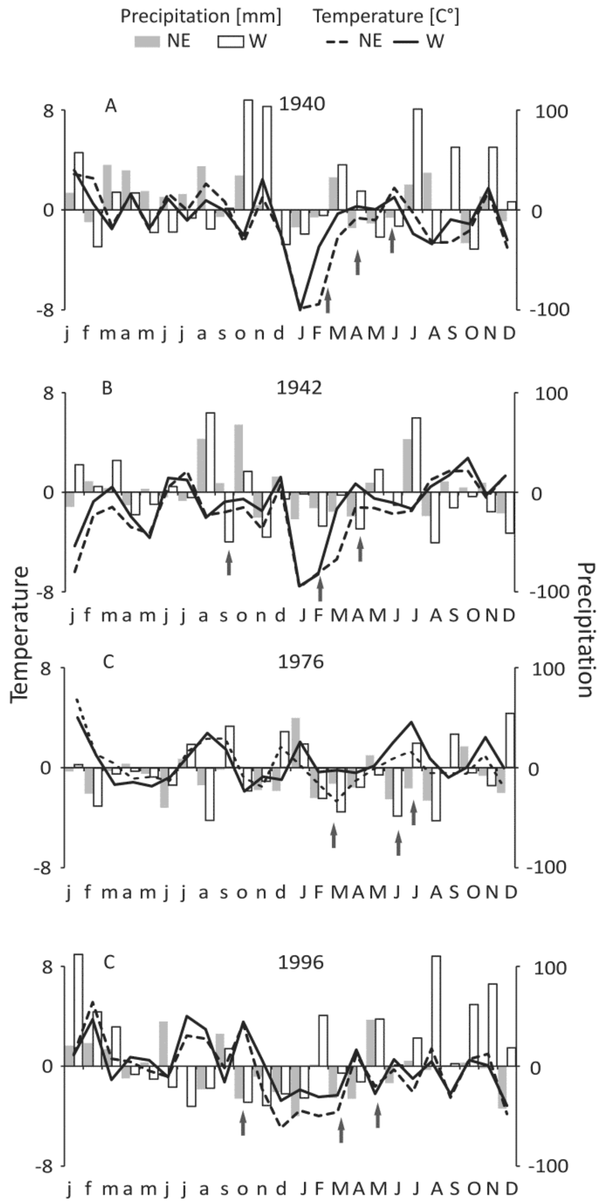


Figure 5: Representative negative pointer years detected only for site NE Germany (A), site W Germany (B), and for both sites (C). Values of temperature and precipitation were plotted as deviations from the long-term averages; small/capital letters mark the climate variables of the previous/current year before/during the pointer year (january to december/ January to December). Arrows indicate months of significant influence.

With the Cropper method 18 years of extreme growth anomalies were detected for the period 1901 to 1996. Oaks growing at the NE Germany site show more growth anomalies. At the NE Germany site, twelve pointer years were detected, six positive and six negative pointer years. At the W Germany site, eight pointer years were identified, two positive and six negative pointer years. In 1976 and 1996 only, both site chronologies exhibit significant negative pointer years simultaneously, but no common positive pointer years were found.

In order to compare growth anomalies in common and different pointer years, which may be induced by the same or dissimilar extreme climatic events at both sites, pointer years were compared to precipitation and temperature anomalies. Four negative tree-ring index pointer years, that is, 1940, 1942, 1976 and 1996 were selected for comparison (Fig. 5).

The year 1940 is a pointer year only at the NE Germany site, 1942 only at the W Germany site and 1976 as well as 1996 at both sites. The year 1940, the pointer year only found in NE Germany, is characterized by precipitation deficits in December of the previous year and January to March of the current year, and by temperatures much below average between December of the previous year and March of the current year. Interestingly, at the W Germany site only precipitations sums in November and December of the previous year were well above average. The year 1942, the pointer year only found in W Germany, is similar to 1940. However, monthly temperatures are not only below average between December of the previous year and March of the current year but also during most months of the previous year. Furthermore, monthly precipitation sums are mainly below average during the previous and current year, and only in August of the previous year and July of the current year can positive deviations from the long-term mean be found. Common negative pointer years found at both sites are indicated for the years 1976 and 1996. In 1976, the extreme negative growth reaction likely is the result of below-average precipitation during the growing season. In the same year the temperature was below-average in spring and high above-average from June to September. The year 1996 is characterised by above-average temperatures in July to October of the previous year, below-average temperatures between December of the previous year to March of the current year and markedly below-average precipitation sums from April of the previous year to April of the current year.

Discussion and Conclusion

At the site in NE Germany, precipitation of the previous late summer to autumn is more limiting for tree growth than at the site in W Germany, which indicates the importance of photosynthetic products obtained in the previous year for the tree growth of the current year. It is known that oak trees initiate their earlywood formation, just before photosynthetic activity starts, by remobilising stored reserves (Pilcher 1995). Less rainfall during times of carbohydrate storage in autumn has been reported to reduce the amount of reserves for the following year (García-González & Eckstein 2003; Michelot et al. 2012). Consequently, autumn precipitation may be important in determining the onset of the following growing season and the amount of earlywood formed with reserves from last year, particularly in drier environments such as the NE Germany site. Oaks growing at the site in NE Germany also show a positive correlation with February precipitation which suggests that early tree growth is likely to profit from higher soil moisture contents. Above-average snow accumulation in winter may also lead to a surplus of soil water (Kelly et al. 2002; van der Werf et al. 2007), positively influencing tree growth.

The highest correlations between oak growth and precipitation were found for the seasonal means (April to June and May to September). Both sites seem to be water-limited during summer, especially in June, which is supported by similar results from other studies (Menzel 2000; Rötzer et al. 2004). The importance of spring to summer water balance during the year of ring formation has been reported in several investigations (van der Werf et al. 2007; Čufar et al. 2008; Friedrichs et al. 2009). Water potential limitations within the root-to-leave system can induce stomata closure, and hence lead to radial growth decreases (Bréda et al. 1993; Bréda et al. 2006; Zweifel et al. 2006).

The correlations between tree growth and temperature values of the current vegetation period are generally low. The only significant correlation is exhibited for June, which negatively effects oak growing at the site in NE Germany. This negative correlation underlines the drier environmental character of the northeastern site where hot and dry conditions lead to limited growth in summer. Significant negative correlations were also found between tree growth and July to September temperatures of the previous year. The influence of hot conditions on oak growth patterns has been previously reported, especially with regard to the importance of vapour pressure deficits (Lövdahl & Odin 1992), and thus to decreasing photosynthetic rates (Lebourgeois et al. 2004). Furthermore, high air temperatures, which are associated often with low precipitation, have been reported to lead to significant inverse correlation signals in oak (Fritts 1976; Bednarz & Ptak 1990;

Pederson et al., 2004). These findings corroborate our results of mainly negative correlations between tree growth and temperature.

The correlation patterns between tree growth and scPDSI revealed significant correlations for most months at the site in NE Germany but no significant correlations for the site in W Germany, indicating disagreement in the growth responses at the two study sites in regard to drought conditions. It seems that at the site in NE Germany the stronger drought signal is a combination of generally lower amounts of precipitation, that is, approximately 800 mm versus 600 mm per year in W and NE Germany, respectively, and sandy soils with lower water holding capacities in NE Germany (Ruseckas 2006). These results suggest site-specific responses to differing soil moisture availability, which may be interpreted in terms of different soil texture and locally varying rainfall sums in particular (García-Suárez et al. 2009). These findings are also comparable to results reported by Wazny (1990) and Paltineanu et al. (2007) emphasising the influence of the soil conditions.

The pointer year analysis has helped to identify several years characterised by extreme positive or negative growth. Tree growth during the two common negative pointer years (1976 and 1996) was probably influenced by the same macroclimatic extremes occurring simultaneously at both sites. Likewise, previous studies have also shown that the negative pointer year 1976 was mainly linked to limiting hydrological conditions during the growing season throughout Europe (Kelly et al. 1989; Lévy et al. 1992; Briffa et al. 1998). Such studies found that deficient water balances negatively influenced annual growth as a result of low precipitation and high temperatures, which was also found in our study, in particular for the site in NE Germany. At the two sites in W and NE Germany, tree-ring growth in 1996 was extremely limited by below-average temperatures during late winter of the previous year to spring of the current and below-average precipitation during most of the previous year. Likewise, Lebourgeois et al. (2004) and Michelot et al. (2012) have shown that extreme hydroclimatic conditions especially at the end of the previous growing season as well as winter and current spring are likely to induce extreme growth. The only two pointer years found at both sites (1976 and 1996) seem to be only partly due to the same limiting factors but also due to different site-specific factors.

In contrast, extremely cold winter to spring temperatures occurred at both sites in 1940 and 1942 but 1940 is a pointer year only at the site in W Germany and 1942 only at the site in NE Germany. Frost effects have also been recorded by Tyree & Cochard (1996). Their results suggest that frozen soil may prevent oaks from absorbing soil water during the early part of the season and thus delay growth. In comparison, common negative pointer years due to such very cold winter-to-spring conditions were not identified in our study. It seems likely, that at our two study sites site-specific conditions were favourable enough to buffer such prolonged cold conditions at one site in 1940 and then at the other site in 1942. For example, in 1940, such a year with cold winter-to-spring conditions only the site in NE Germany exhibits a pointer year. The difference between the sites is that only W Germany received above-average precipitation in October and November of the previous year, which might have been sufficient to somehow prevent negative pointer years in the western trees.

Furthermore, it needs to be stated that the formation of pointer years may also depend on various other environmental conditions, and pointer years may then be more difficult to explain. Both climatic and non-climatic impacts are crucial and therefore, incidences of defoliating insects should not be neglected (Weidner et al. 2010). According to Gieger and Thomas (2005), severe attacks of defoliating insects or pathogenic fungi can affect the drought tolerance, influence the development of fine roots, lead to a reduction in carbohydrate reserves, and finally weaken the general frost hardiness of oaks (Hartmann & Blank, 1992; Thomas et al., 2002).

The comparison of the climatic responses of both oak stands has allowed us to better understand how tree growth is functioning in W and NE Germany. Overall, the comparison of the climate-growth relationships at the two sites suggests that tree growth at Lake Großer Fürstenseer See (TERENO Northeast) in NE Germany is more sensitive to climate variations, in particular to hydrological changes. However, extensive sampling of old living trees and archaeological material is needed to extent the local tree-ring chronology especially at Lake Großer Fürstenseer See. The combination of such a new multi-centennial chronology with varved lake sediment layers of Lake Großer Fürstenseer See will facilitate reconstructions of the regional landscape evolution and lake level dynamics. It will help to answer two important questions, that is, are the groundwater and lake level losses of up to 5 m happening within the last 30 years unique (Germer et al. 2011) and what are the absolute groundwater and lake level minima and maxima during the Holocene.

Acknowledgments

This study was conducted in the framework of the TERENO “Terrestrial Environmental Observatories” research project funded by the Federal Ministry of Education and Research (BMBF) and of the Virtual Institute of Integrated Climate and Landscape Evolution Analyses (ICLEA) funded by the Helmholtz Association of German Research Centres Initiative (Networking Fund for funding a Helmholtz Virtual Institute). The authors thank Karina Hennig for ideas on data analysis and statistical help. We also thank Dagmar Friedrichs, Mark Hennen, Diana Zoglauer, Sylvia Pinkerneil and Hagen Pieper for their help with the field work.

References

Baillie, M.G.L. (1994): Dendrochronology raises questions about the nature of the AD 536 dust-veil event. The Holocene 4: 212–217.

Bednarz, Z., Ptak, J. (1990): The influence of temperature and precipitation on ring widths of oak (*Quercus robur* L.) in the Niepolomice Forest near Cracow, southern Poland. Tree-ring Bulletin 50: 1–10.

Bréda, N., Cochard, H., Dreyer, E., Granier, A. (1993): Field comparison of transpiration, stomatal conductance and vulnerability to cavitation of Quercus petraea and Quercus robur under water stress. Annals of Forest Science 50: 571–582.

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

Briffa, K.R., Jones, P.D., Wigley, T.M.L., Pilcher, J.R., Baillie, M.G.L. (1986): Climate reconstruction from tree rings: Part 2, Spatial reconstruction of summer mean sea-level pressure patterns over Great Britain. International Journal of Climatology 6: 1–15.

Cook, E.R. (1985): A time series analysis approach to tree ring standardization. Ph.D. thesis, The University of Arizona. Tucson, Arizona. 171p.

Cook, E.R., Kairiukstis, L.A., (Eds.) (1990): Methods of dendrochronology: Applications in the environmental sciences. Dordrecht Kluwer Academic Publishers. 393p.

Cook, E.R., Briffa, K.R., Shiyatov, S., Mazepa, V. (1990): Tree-ring standardization and growth-trend estimation. In: Cook, E.R., Kairiukstis, L.A. (Eds.), Methods in Dendrochronology. International Institute for Applied System Analysis. Dordrecht, Netherlands. pp. 104–123.

Cook, E.R., Peters, K. (1997): Calculating unbiased tree-ring indices for the study of climatic and environmental change. The Holocene 7: 361–370.

Cropper, J.P. (1979): Tree-rings skeleton plotting by computer. Tree-ring Bulletin 39: 47–59.

Čufar, K., De Luis, M., Eckstein, D., Kajfez-Bogata, L. (2008): Reconstructing dry and wet summers in SE Slovenia from oak tree-ring series. International Journal of Biometeorology 52, 607-615.

Druckenbrod, D.L., Shugart, H.H. (2004): Forest history of James Madison’s Montpelier plantation. Journal of the Torrey Botanical Society 131: 204–219.

Friedrichs, D., Trouet, V., Büntgen, U., Frank, D.C., Esper, J., Neuwirth, B., Löffler, J. (2009): Species-specific climate sensitivity of tree growth in Central-West Germany. Trees 23: 729□739.

Fritts, H.C. (1976): Tree Rings and Climate. Academic Press Inc. London. 567p.

García-González, I., Eckstein, D. (2003): Climatic signal of earlywood vessels of oak on a maritime site. Tree Physiology 23: 497–504.

García-Suárez, M., Butler, C.J., Baillie, M.G.L. (2009): Climate signal in tree-ring chronologies in a temperate climate: A multi-species approach. Dendrochronologia 27: 183–198.

Germer, S., Kaiser, K., Bens, O., Hüttl, R.F. (2011): Water balance changes and responses of ecosystems and society in the Berlin-Brandenburg region (Germany) – a review. Die Erde 142: 65□95.

Gieger, T., Thomas, F.M. (2005): Differential response of two Central-European oak species to single and combined stress factors. Trees 19: 607–618.

Gray, B.M., Pilcher, J.R. (1983): Testing the significance of summary response functions. Tree-ring Bulletin 43: 31–38.

Hartmann, G., Blank, R. (1992). Winter frost, insect defoliation and Agrilus biguttatus Fabr. as causal factors of oak decline in northern Germany. Forst und Holz 15: 443–452.

Heinrich, I., Weidner, K., Helle, G., Vos, H., Banks, J. (2008): Hydroclimatic variation in Far North Queensland since 1860 inferred from tree rings. Palaeogeography, Palaeoclimatology, Palaeoecology 270: 116–127.

Holmes, R.L. (1983): Computer-assisted quality control in tree-ring dating and measurement. Tree-ring Bulletin 43: 69–78.

Kelly, P.M., Leuschner, H.H., Briffa, K.R., Harris, I.C. (2002): The climatic interpretation of pan-European signature years in oak ring-width series. The Holocene 12: 689-694.

Kelly, P.M., Munro, M.A.R., Hughes, M.K., Goodess, C.M. (1989): Climate and signature years in West European oaks. Nature 340: 57–60.

Lebourgeois, F., Cousseau, G., Ducos, Y. (2004): Climate-tree-growth relationships of Quercus petraea Mill. stand in the Forest of Bercé ("Futaie des Clos", Sarthe, France). Annals of Forest Science 61: 1–12.

Lévy, G., Becker, M., Duhamel, D. (1992): A comparison of the ecology of pedunculate and sessile oaks: Radial growth in the centre and northwest of France. Forest Ecology Management 55: 51–63.

Lövdahl, L., Odin, H. (1992): Diurnal changes in the stem diameter of Norway spruce in relation to relative humidity and air temperature. Trees 6: 245-251.

Menzel, A. (2000): Trends in phenological phases in Europe between 1951 and 1996. International Journal of Biometeorology 44: 76–81.

Mérian, P., Bontemps, J.D., Bergès, L., Lebourgeois, F. (2011): Spatial variation and temporat instability in climate-growth relationship of sessile oak (Qercus petraea [Matt.] Liebl.) under temperate conditions. Plant Ecology 212: 1855–1871.

Michelot, A., Bréda, N., Damesin, C., Dufrêne, E. (2012): Differing growth response to climatic variations and soil water deficits of Fagus sylvatica, Quercus petraea and Pinus sylvestris in a temperate forest. Forest Ecology and Management 265: 161–171.

Mitchell, T.D., Jones, P.D. (2005): An improved method of constructing a database of monthly climate observation and associated high-resolution grids. International Journal of Climatology 25: 693–712.

Neuwirth, B., Esper, J., Schweingruber, F.H., Winiger, M. (2004): Site ecological differences to the climatic forcing of spruce pointer years from the Lötschental, Switzerland. Dendrochronologia 21: 69–78.

Paltineanu, C., Mihailescu, I.F., Seceleanu, I., Dragota, C., Vasenciuc, F. (2007): Using aridity indices to describe some climate and soil features in Eastern Europe: a Romanian case study. Theoretical and Applied Climatology 90: 263–274.

Pederson, N., Cook, E.R., Jacoby, G.C., Peteet, D.M., Griffin, K.L. (2004): The influence of winter temperatures on the annual radial growth of six northern range margin tree species. Dendrochronologia 22: 7–29.

Pilcher, J.R. (1995): Biological considerations in the interpretation of stable isotope ratios in oak tree-rings. In: Frenzel, B. (Ed.): Problems of stable isotopes in tree-rings, lake sediments and peat-bogs as climatic evidence for the Holocene. Paläoklimaforschung 15. Special Issue. ESF Project. European Palaeoclimate and Man 10. Fischer, Stuttgart.

Rinn, F. (2007): TSAP Win Professional. Zeitreihenanalyse und Präsentation für Dendrochronologie und verwandte Anwendungen. Benutzerhandbuch, Bd. 0.55. Rinntech, Heidelberg. 91p.

Rötzer, T., Grote, R., Pretzsch, H. (2004): The timing of bud burst and its effect on tree growth. International Journal of Biometeorology 48: 109–118.

Ruseckas, J. (2006): Impact of climatic fluctuations on radial increment of English oak (Quercus robur L.). Ekologija 1: 16-24.

van der Schrier, G., Briffa, K.R., Jones, P.D., Osborn, T.J. (2006): Summer Moisture Variability across Europe. Journal of Climate 19: 2818–2834.

Soil Atlas of Europe, European Soil Bureau Network European Commission (2005): Office for Official Publications of the European Communities, L-2995 Luxembourg. 128p.

Speer, J.H. (2010): Fundamentals of tree-ring research. Academic Press Inc. Arizona. 333p.

Thomas, F.M., Blank, R., Hartmann, G. (2002): Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe. Forest Pathology 32: 277–307.

Tyree, M.T., Cochard, H. (1996): Summer and winter embolism in oak: Impact on water relations. Annals of Forest Science 53: 173-180.

Wazny, T. (1990): Aufbau und Anwendung der Dendrochronologie für Eichenholz in Polen. Dissertation, Universität of Hamburg.

Weidner, K., Heinrich, I., Helle, G., Löffler, J., Neuwirth, B., Schleser, G.H., Vos, H. (2010): Consequences of larch budmoth outbreaks on the climatic significance of ring width and stable isotopes of larch, Trees - Structure and Function 24: 399-409.

van der Werf, G., Sass-Klaassen, U., Mohren, G. (2007): The impact of the 2003 summer drought on the intra-annual growth pattern of beech (Fagus sylvatica L.) and oak (Quercus robur L.) on a dry site in the Netherlands. Dendrochronologia 25: 103–112.

Wigley, T.M.L., Briffa, K.R., Jones, P.D. (1984): On the average value of correlated time series, with application in dendroclimatology and hydrometeorology. Journal of Climate and Applied Meteorology 23: 201–213.

WinDENDRO (2003): WinDENDRO Manual, Régent Instruments Inc. Québec, Canada. 134 pp.

Zacharias, S., Bogena, H., Samaniego, L., Mauder, M., Fuß, R., Pütz, T., Frenzel, M., Schwank, M., Baessler, C., Butterbach-Bahl, K., Bens, O., Borg, E., Brauer, A., Dietrich, P., Hajnsek, I., Helle, G., Kiese, R., Kunstmann, H., Klotz, S., Munch, J.C., Papen, H., Priesack, E., Schmid, H.P., Steinbrecher, R., Rosenbaum, U., Teutsch, G., Vereecken, H., (2011): A network of terrestrial environmental observatories in Germany. Vadose Zone Journal 10: 955–973.

Zweifel, R., Zimmermann, L., Zeugin, F., Newbery, D.M. (2006): Intra-annual radial growth and water relations of trees: implications towards a growth mechanism. Journal of Experimental Botany 57: 1445–1459.

Growth course and climate sensitivity of Norway spruce (*Picea abies* [L.] Karst) in Brandenburg/Germany

N. Linke [1] & W. Beck [2]

[1] *Eberswalde University for Sustainable Development , Alfred-Möller-Str.01, 16225 Eberswalde, Germany*
[2] *Johann-Heinrich-von Thünen-Institut, Institut für Waldökologie und Waldinventuren, Alfred-Möller-Str.01,16225 Eberswalde, Germany*
E-mail: Nicole.Linke85@gmx.de

Introduction

One of the most vital tasks for current forest research is to assess the adaptive potential of economically important tree species to changing environmental conditions. Knowledge on climate sensitivity and its modification by local site conditions is, however still limited (Beck 2007). One of the most important tree species for the German forestry sector is Norway spruce (*Picea abies* [L.] Karst). At the same time this species is regarded to be one of the most vulnerable to projected climatic changes in the country (Kölling et al. 2009).

The aim of the study is to investigate the influence of weather conditions on the growth course of Norway spruce in Germany's federal state Brandenburg. In this region climate sensitivity of Norway spruce can be studied exemplary, as the growing conditions are assumed to be extremely adverse for this species. The results may be of value for regions in Germany where spruce now is the main tree species and climate projections suggest a warmer and drier climate in the future.

Brandenburg is one of the driest regions in Germany, with a mean precipitation of 600 mm/year (Lischeid 2010). Dry, sandy soils, characterized by poor water holding capacity, and mean temperatures between 7,8°C-9,5°C (Gerstengarbe et al. 2003) further contribute to unfavorable conditions. Consequently Norway spruce occupies only about 3% of the forested area in Brandenburg.

Material and Methods

Old growth stands of Norway spruce in Brandenburg with a minimum age of 80 years were selected for sampling. In each stand cores from 20 trees were extracted using a standard increment corer. Relative density measurements in intervals of 10µm were carried out via high-frequency densitometry as described in Schinker et al. (2003), using the measuring system "LignoStation" (RinnTech)[1]. Ring width measurements were verified using a "LINTAB" measuring table (RinnTech). Tree ring parameters used for analyzing were ring, early wood and late wood width as well as maximum density. After cross-dating and chronology building, the analysis includes the description of growth course, the assessment of sensitivity and first-order autocorrelation (AR (1)), single year and pointer year analysis and the description of the climate-growth system. Development of ring width chronologies were carried out using the method described in Beck (2008).

Results and discussion

In the following, preliminary results of 15 plots, analyzed with regards to growth course, mean sensitivity and AR (1), are presented.

In general the sampled trees show a similar pattern of comparatively high sensitivity values and

---

[1] This device was funded via the European Fund for Regional Development (EFRE)

DOI: 10.2312/GFZ.b103-13058

low AR (1) values (Figs. 1 and 2). Comparing the mean sensitivity values with those Beck (2010) found for spruce in different regions of Germany (Fig. 3) it can be assumed that Brandenburgs low altitude, and associated site conditions, is one of the main reasons for the comparatively high values. Noticeable are the increasing mean AR (1) values since the early 1990s for the overwhelming majority of the plots (Fig. 2). A simultaneous decrease of mean sensitivity values is observable in some of the stands (Fig. 1).

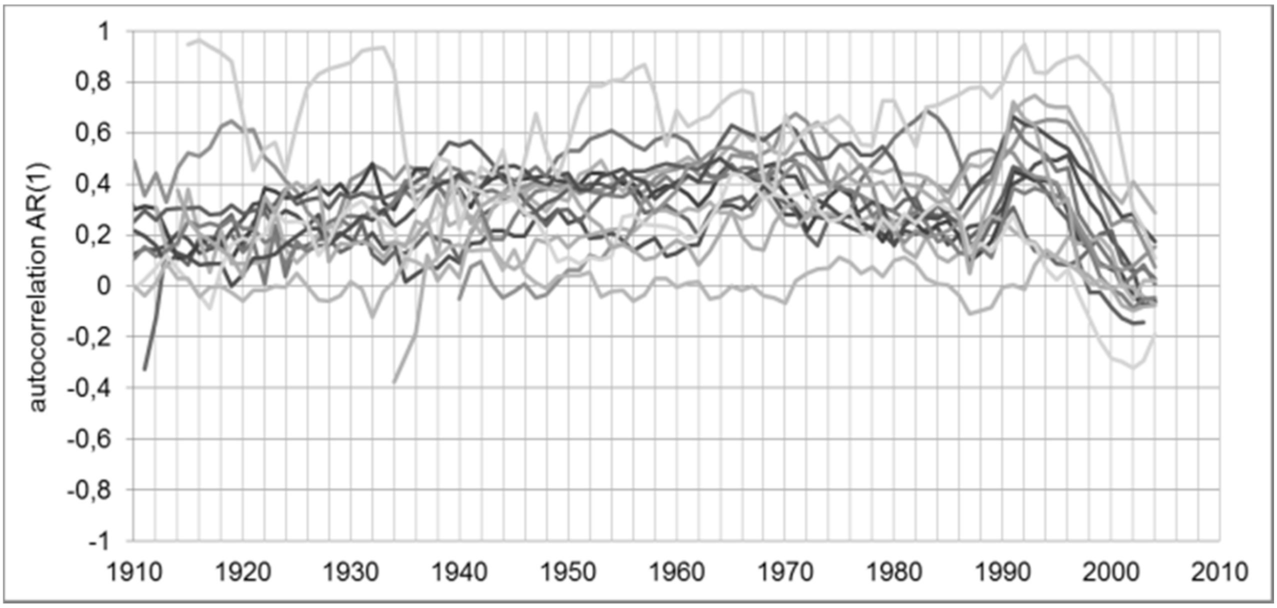


Figure 1: Autocorrelation of 15 Norway spruce plots in Brandenburg.

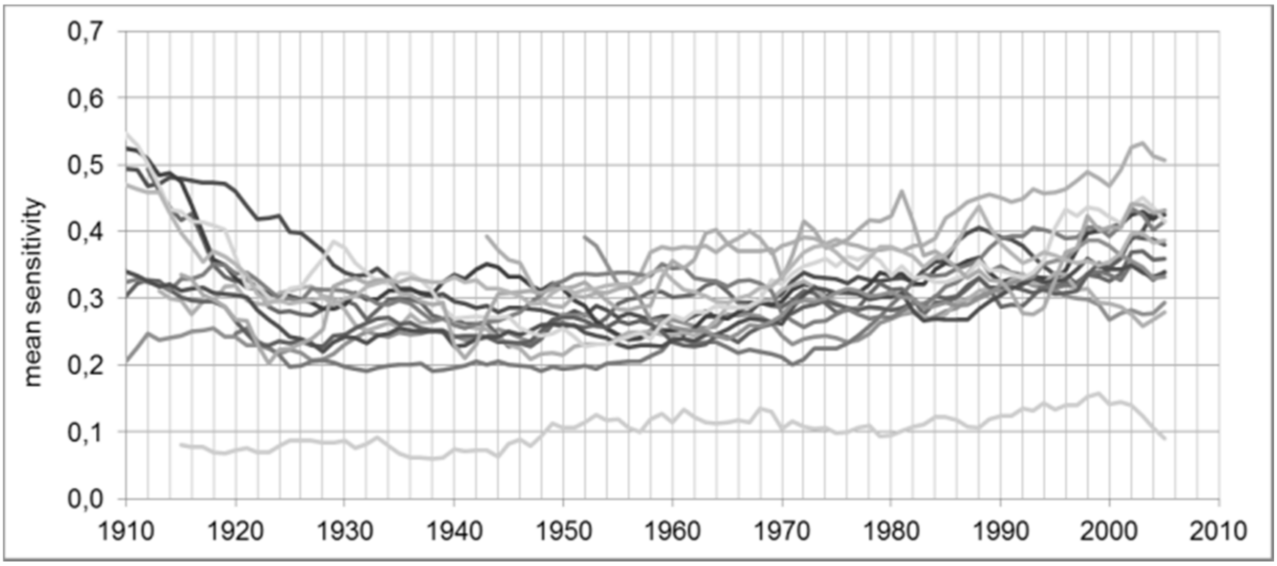


Figure 2: Mean sensitivity values of 15 Norway spruce plots in Brandenburg.

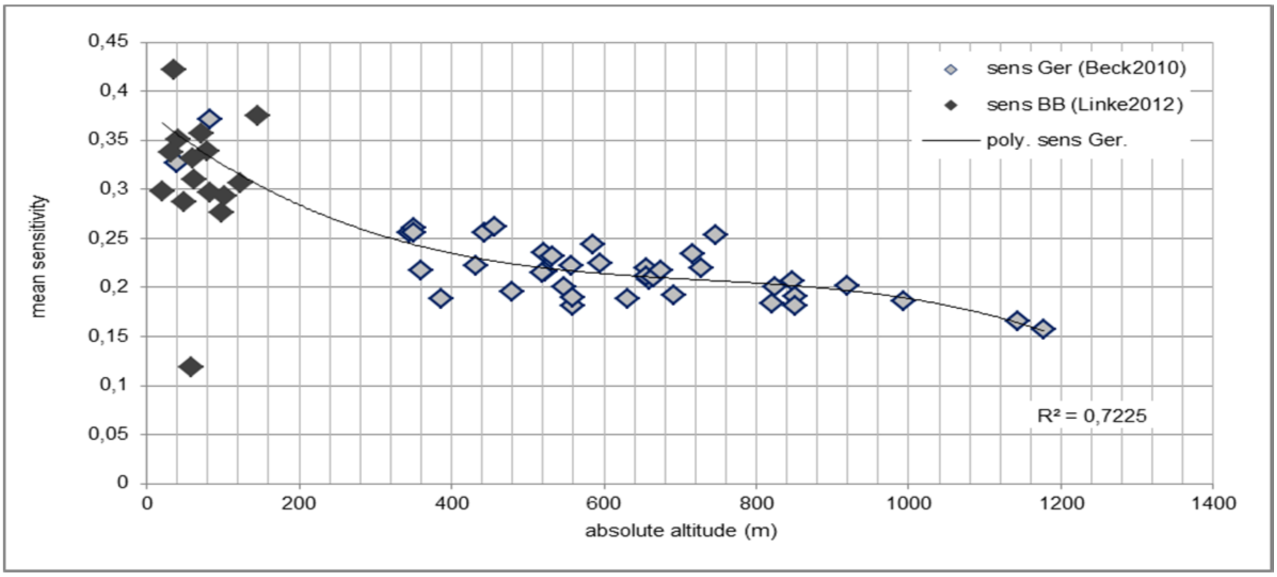


Figure 3: Comparison of mean sensitivity of Norway spruce in Brandenburg and Germany

This is accompanied by a change in growth dynamic patterns. Up to the 1990s the majority of sampled trees show declining ring widths, resulting in a degressive trend in diameter at breast height (DBH). Therefore basal area increment (BAI) rates stay relatively constant. As spruce is considered to be a semi-shade tolerant species these growth dynamics can be interpreted as a sign of low vitality. Under favorable conditions semi-shade and shade tolerant species are expected to show a relatively constant trend in ring-width development, resulting in a linear DBH development and increasing BAI rates. Interestingly, this growth course pattern was observed at almost all investigated plots (Fig. 4) at the beginning of the 1990s.

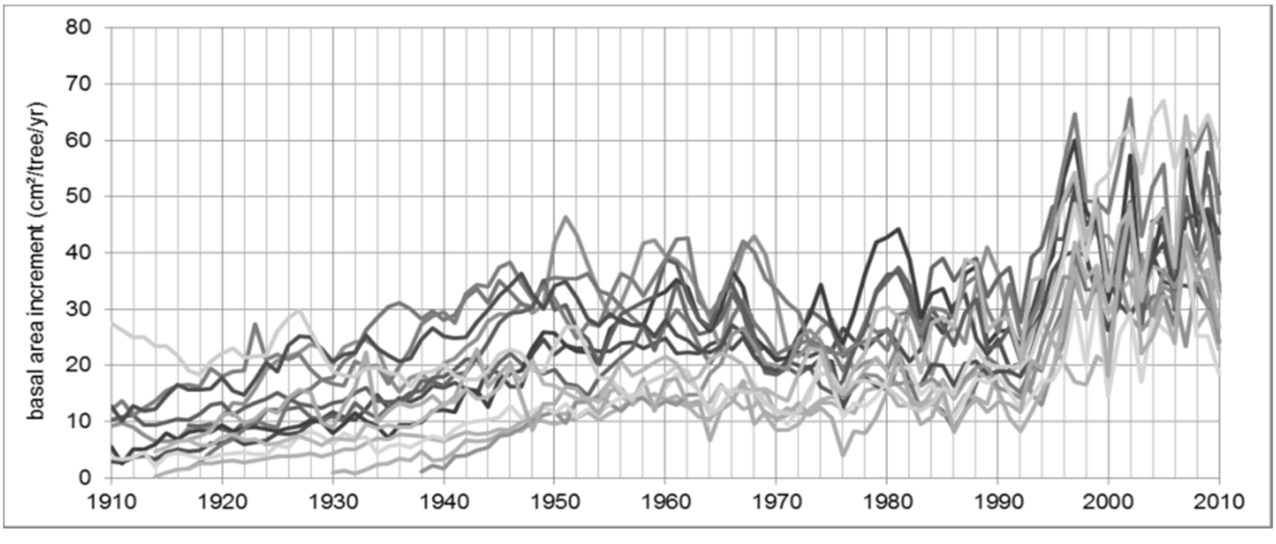


Figure 4: Basal area increment development of 15 spruce plots in Brandenburg

In conclusion it can be stated that the combined investigation of mean sensitivity, AR (1) and BAI development can give a more holistic understanding of the growth course of trees and possible relationships between these parameters. Interpreting mean sensitivity as a measure of environmental stress experienced by trees and AR (1) as the buffering ability of trees (Beck 2009), one could argue that the predisposition to be damaged was reduced between 1990 and 2005 and furthermore that the observed growth increases are a result of increased vitality.

Due to the fact that all of the plots show the growth trend changes in the 1990s, local release events, like thinning were ruled out as the main factor. Rather reduced emissions after the German

reunification are considered to have had a major impact. After this political event several major industries in eastern Germany were shut down or modernized respectively. As a result, emissions stemming from industrial production have been declining steadily since 1989 until the year of 2000. Besides, it could be speculated that climatic conditions in Brandenburg are not as unfavorable for Norway spruce as expected and also adaptation processes should be considered. However it also needs to be pointed out that despite an increase after 1990, AR (1) values are comparatively low and mean sensitivity values high (e.g. Neumann & Röhle 2001, Grundmann 2009).
The results of single and pointer year analysis, description of the climate-growth system (according to Fritts 1976), and of density measurements are expected to contribute to a more complete understanding of the growth responses of Norway spruce in Brandenburg.

References

Beck, W., 2007: Finding the best regression approach for description of climate-growth relationships by floating time spans of varying widths. In: Haneca, K., Verheyden, A., Beekmann, H., Gärtner, H., Helle,G., Schleser, G., (eds.) 2007. TRACE. Tree Rings in Archeaology, Climatology and Ecology Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th -22nd 2006, Tervuren, Belgium. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 74.44-53.

Beck, W., 2008: Mean growth behaviour of forest stands - Methodological aspects from dendrochronology and forest mensuration. In: Elferts, D. et al. (eds., 2008): TRACE Tree Rings in Archeology, Climatology and Ecology, Proccedings of the Dendrosymposium 2007, May 3rd - 6th 2007, Riga, Latvia, pp. 154-161

Beck, W., 2009: Growth patterns of forest stands-the response towards pollutants and climatic impact. iForest 2: 4-6 [online: 2009-01-21] URL: http://www.sisef.it/iforest/show.php?id=472

Beck, W., 2010: Sensitivity and elevation of Norway spruce chronologies in Germany. Unpublished personal communications

Fritts , H. C., 1976: Tree rings and climate. Academic Press, London, 567 S.

Gerstengarbe, F.-W., Badeck, F., Hattermann,F., Krysanova, V., Lahmer, W., Lasch, P., Stock, M., Suckow, F., Wechsung, F., Werner, P.C., (eds.) 2003. PIK – Report. Studie zur klimatischen Entwicklung im Land Brandenburg bis 2055 und deren Auswirkungen auf den Wasserhaushalt, die Forst- und Landwirtschaft sowie die Ableitung erster Perspektiven. Potsdam Institut für Klimafolgenforschung. Potsdam. 92 p.

Grundmann, B., 2009: Dendroklimatologische und dendroökologische Untersuchungen des Zuwachsverhaltens von Buche und Fichte in naturnahen Mischwäldern. Dissertation an der Technischen Universität Dresden. 199 S.

Kahle, H.-P., Spiecker, H., Park, Y.-I., 2008: Zusammenhänge zwischen der Variation von Klima und Witterung und inter- und intraanuellen Wachstumsreaktionen von Fichten, Tannen, Buchen und Eichen auf ausgewählten Standorten des Schwarzwalds. Projekt Europäisches Forschungszentrum für Maßnahmen zur Reinhaltung der Luft. Forschungsbericht KfK-PEF. 60 S. http://www.fachdokumente.lubw.baden-wuerttemberg.de/servlet/is/40021/PEF194002SBer.pdf?command=downloadContent&filename=PEF194002SBer.pdf&FIS=91063

Kätzel, R, 2009: Möglichkeiten und Grenzen der Anpassung an Klimaextreme –eine Betrachtung zu baumartenspezifischen Risiken aus Sicht der Ökophysiologie. In: Wald im Klimawandel –Risiken und Anpassungsstrategien. Eberswalder Forstliche Schriftenreihe. Band 42. Brandenburgische Universitätsdruckerei und Verlagsgesellschaft Potsdam mbH. S.22-34

Kölling, R., Knoke, T., Schall, P., Ammer, Ch., 2009: Überlegungen zum Risiko des Fichtenanbaus in Deutschland vor dem Hintergrund des Klimawandels. Forstarchiv 80, 42-54.

Lischeid, G., 2010. Landschaftswasserhaushalt in der Region Berlin-Brandenburg. Diskussionspapier 02.1/2010. Berlin-Brandenburgische Akademie der Wissenschaften. Interdisziplinäre Arbeitsgruppe Globaler Wandel-Regionale Entwicklung.

Neumann, U. & Röhle H., 2001: Der jährliche Radialzuwachs der Fichte (*Picea abies* (L.) Karst.) in den sächsischen Mittelgebirgen in Abhängigkeit von der Witterung. Forstw. Cbl., 120, S. 277-287.

Schinker, M.G., Hansen N., Spiecker, H., 2003. High-frequency densitometry – a new method for the rapid evaluation of wood density variations. IAWA Journal 24, 231-239.

Testing the application of Regional Curve Standardization to living tree datasets

S. Klesse & D. Frank

Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: stefan.klesse@wsl.ch

Introduction

How to detrend tree-ring series is a crucial point in dendrochronology. There are many different approaches to remove age-related trends and unfortunately none of them can objectively answer the question, which is the best. It is the opinion of the individual researcher whether to choose a stochastic, a deterministic, or an empirical method, not to mention the plethora of options within each of these broad categories (Cook & Kariukstis 1990).

The classical deterministic detrending method fits a modified negative exponential curve or straight line to the tree-ring series. Stochastic methods use low-pass filter such as the cubic smoothing spline with a fixed or relative 50% frequency cut-off of a certain wavelength (Cook & Peters 1981). The so-called regional curve standardization (RCS) is a commonly applied empirical based upon the presumption that for a given species and site a common age related biological growth signal exists, independent of when the trees were growing.

With the task to reconstruct long-term climate variation in mind, Cook et al. (1995) note that “the maximum length of recoverable climate information is ordinarily related to the lengths of the individual tree-ring series“ and usually ranges around a third of the mean segment length. To overcome this so-called “segment length curse“ Briffa et al. (1992) re-popularized the empirical RCS method (Mitchell 1967). RCS allows for the possibility of systematic over or underestimation of the actual tree growth level during any particular time period due to changing environmental conditions and thus permits climatic information to be preserved on time-scales longer than the individual segment lengths (Cook et al. 1995). As tree-ring data are one of the most important data sources to place recent climate trends in a long-term context, researchers have heavily favored using RCS for climate reconstruction purposes during the past decade or so (Frank et al. 2010).

In RCS, all core segments are aligned by their cambial age and averaged to obtain the regional growth curve (RC). The RC is further smoothed, either by deterministic or stochastic means, to reduce high frequency variance and then applied to remove the age trend of each single series. After the regional curve derivation the detrended single series are reset to their calendar age. With this detrending method the century-scale fluctuations may be successfully preserved, however the correlation between individual samples decreases leading to a greater uncertainty than using “traditional“ methods, thus a high sample replication is needed (Briffa et al. 1992).

Other more subtle challenges and limitations with RCS have only recently been recognized. With RCS, care has to be taken that one might even lose low-frequency when all samples span the full length of the chronology, because the overall climate signal is contained in the regional curve and therefore completely removed by standardization (Briffa & Melvin 2011). Thus ideally RCS is applied to composite datasets including trees with a uniform distribution of both germination and death (or sampling) dates. Yet, in practice such datasets are rare, and the desire to preserve long-term climate information from sites with only living trees is desired.

Briffa & Melvin (2011) recently described three major possible biases in applying RCS with living only data:

i) The “trend-in-signal“ bias, which occurs when the growth-forcing signal has variance on timescales close to or greater than the length of the chronology. During detrending the average slope of each sample is removed and therefore distortions of the chronology, especially towards

DOI: 10.2312/GFZ.b103-13058

the beginning and the end, may occur. In most cases this bias is of more minor concern since the existence of a trend overlying the chronology is unknown.

ii) The "different-contemporaneous-growth-rate" bias describes the problem if a single RC systematically differs from the age trend of fast or slow-growing trees, due to differences in non-climatic factors such as exposition, soil quality, or competition. If in one period fast-growing trees outnumber the slow ones (or vice versa), false medium-frequency trends might become apparent (Briffa & Melvin 2011).

iii) The combination of variations in the longevity of trees, sampling practice and different growth rates of contemporaneous trees can lead to the "modern-sample" bias. Assuming that large trees have a higher risk of mortality trees are more likely to be killed by an extreme event when they are close to their maximum size. A slow growing tree takes longer to reach this size and therefore can become older (Black et al. 2008, Bigler & Veblen 2009). This bias becomes most obvious in chronologies with only living samples from some old, yet primarily young trees. The regional curve may overestimate the old and slow-growing trees at the beginning of the chronology and underestimate the overall chronology in the later years and hence lead to an increased rise of chronology indices, where the new young and faster growing trees contribute to the RC (Briffa & Melvin 2011).

Other challenges related to RCS application include the use of a single RCS curve to detrend data from clearly differing sites (e.g. Esper et al. 2002). Measurements at a specific site may be systematically under- or overestimated, due to the different growth levels at these particular sites with the bias depending upon the differences in chronology length and age structure among the sites. It is therefore required to normalize those single site chronologies before averaging them together to mitigate trends evolving due to changing site replication. A final recognized systematic bias in RCS curves may arise from not having information (i.e. pith offset (PO) estimates) on the quantity of rings missing between the innermost sampling ring and the stem pith. This absence will "reduce the expected ring width maximum in early years of tree growth and consequently lower the expected trend of declining growth with increasing age" (Briffa & Melvin 2011). The use of pith-offset estimates (POE) is generally recommended, as it will increase the accuracy of the growth curve.

In this study we focus on applying regional curve standardization (RCS) to samples from only living *Pinus nigra* from Mt. Olympus, Greece. The dataset consists of seven potentially drought sensitive sites and 556 samples, collected with the aim to reconstruct past summer moisture variability. The sites span the lower to upper elevation range of black pine forest in this area (850m – 1700m) and are distributed around the Mt. Olympus massive to capture different slope exposures and luff-lee conditions. We only use latewood width (LWW) measurements, as a previous investigation (Klesse 2012) revealed that this parameter contains the strongest response to summer drought conditions (May-July). We aim to assess and ideally overcome challenges related to employing RCS on this dataset with the ultimate aim to reconstruct inter-annual to multi-centennial climate variability. Accordingly, all site chronologies are screened for the above mentioned possible biases, the steps to construct the best possible master chronology are explained, and a preliminary May-July Standardized Precipitation Index (SPI) reconstruction for the last 400 years is shown.

Testing for biases in the Mt. Olympus dataset

Fig. 1a shows the seven TRW chronologies, detrended with an individual RC (smoothed with a 50-year spline) fitted for each site. Great similarities in the lower-frequency behaviour of the three old sites (PPP, PIGA and XEP) including a decreasing trend from the second half of the 17th century until the end of the 19th century and a strong upward shift (1895-1912) at the turn of the century. During the period of overlap the younger LIA and VPA sites shares this common low-frequency variability, where as the two other sites (REB and CHR) agree less well in the low-frequency domain.

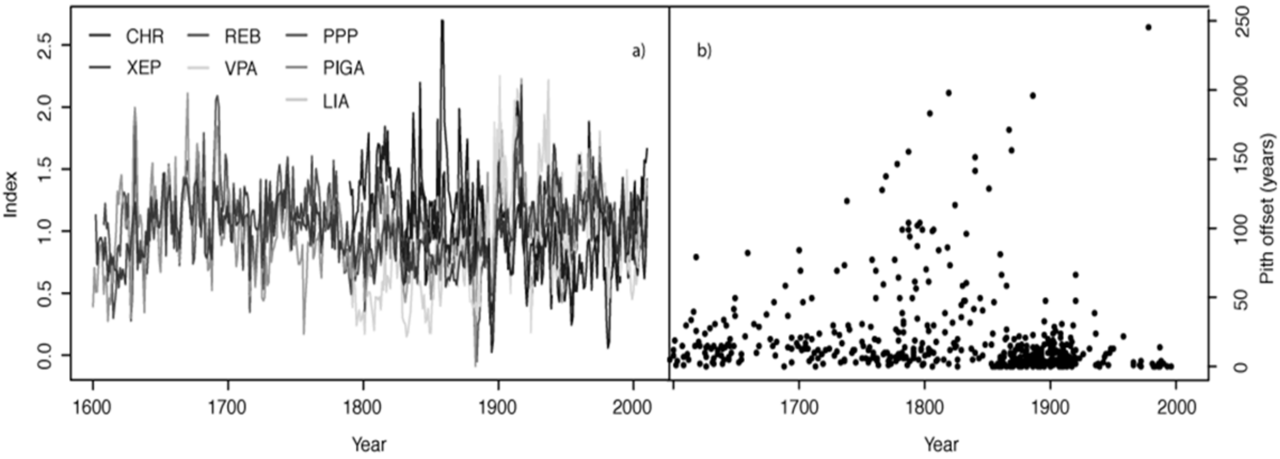


Figure 1: a) Seven individually detrended RCS_{TRW} chronologies from Mt. Olympus, Greece and b) showing pith offset estimates of 556 individual cores from all seven sites as a function of the calendar year of the innermost measured ring.

The PO distribution is generally homogeneous over time, with the exception that high PO values above 100 years accumulate in the 18th and 19th century (Fig. 1b). These high POs primarily arose while truncating some samples that could not be confidently crossdated due to their extremely low growth and many missing rings. The latewood RC from all sites combined without PO is shifted approximately 15 years towards the juvenile phase (Fig. 2a), but has the same slope. While the RCs are quite similar, in practice the innermost rings of a sample with a 150 year PO would be divided by ~0.2, whilst if the PO data were not considered the detrending starts with values over 0.4 – a huge difference. In this study only about 20 of 556 samples have large PO and their consideration tends to have a rather small influence. Differences are most extreme at the PPP site for TRW, where the slope without POE is much shallower than with POEs (Fig. 2b). Most of the segments start within the first 200 years of the chronology (Fig. 2c). If the POs are disregarded growth of those samples with a small PO (<50 years) is heavily underestimated, thus leading to inflated values at the beginning of the chronology. The opposite happens with the samples with many rings missing to the pith. They will be divided by a higher growth curve, the overall chronology lowered for the next 150 years (Fig. 2d). When PO data are ignored, most chronologies show higher values at the beginning due to a shallower growth curve and the fact that the first rings of the oldest samples are generally close to the pith. High PO values seldom occur and therefore their influence on the shape of the chronology is low. The more evenly distributed POE are in size and time, the lower are the differences in the resulting chronologies.

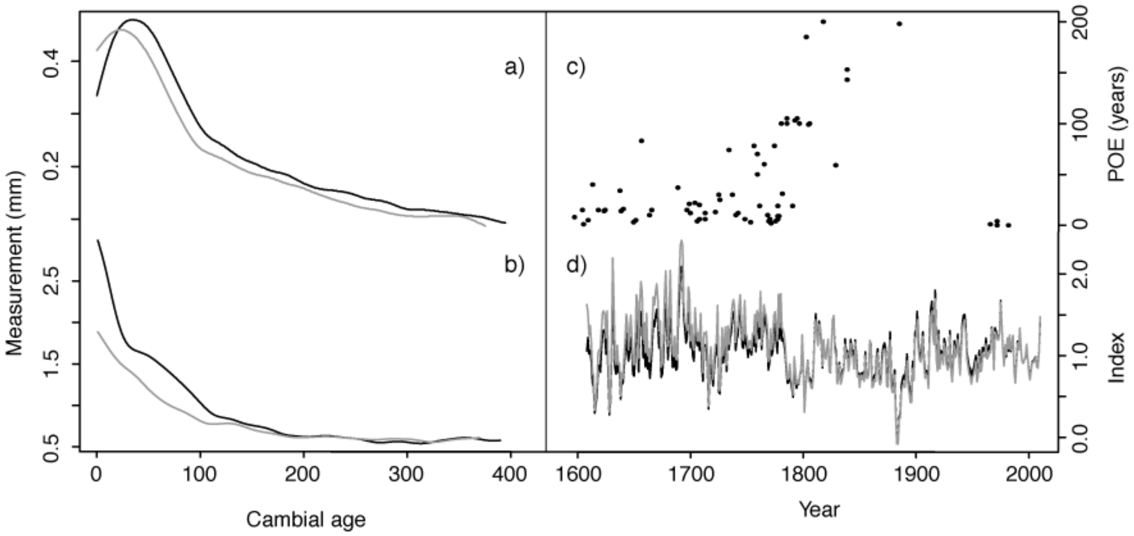


*Figure 2: Comparisons of regional curves with (black) and without pith offset estimates (POE) (grey) with a) showing the differences using all 556 LWW samples and **b)** the extreme case of TRW at the PPP site. **c)** temporal distribution of the pith offset estimates for the PPP site and **d)** the resulting RCS chronologies with and without the use of POEs (black and grey, respectively) for PPP.*

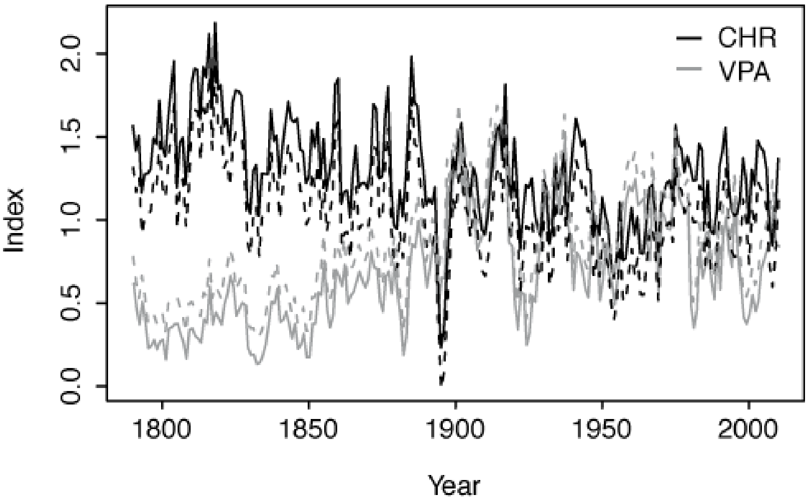


Fig. 3: CHR and VPA RCS_{TRW} chronologies detrended with the same RC untreated (solid lines) and normalized (dashed lines).

To illustrate the challenges in using a single RC to detrend different sites, we show in Fig. 3 the CHR and VPA TRW chronologies after detrending with the overall growth curve of all seven sites, Several problems are readily observed. The first problem is the different overall slope of both chronologies prior to 1900. CHR decreases constantly, while VPA has a steep upward trend. The second problem is the obviously different mean of both curves. This results from the overall RC, leading to high values in the fast growing, high elevation CHR site and the opposite at VPA. After normalization over the common period 1840-2010 this growth level difference is nearly eliminated (dashed lines in Fig. 4), but still the slope discrepancies remain. CHR is the only site where both the individual detrending and the overall regional curve display this unusual decreasing trend. A possible explanation can be found in the “different-contemporaneous-growth-rate” bias. In the first years of the possible ”site history” only a few trees were growing. We hypothesize that low competition led to high growth rates. With passing years more and more trees germinated and competed for resources, leading to declining growth rates in the individual trees. This anomalous behavior, patterns consistent with the different-contemporaneous-growth-rate bias, and the generally weaker response to summer drought (Klesse 2012) lead to the exclusion of CHR from the regional master chronology.

In contrast, the VPA site shows a pronounced upward trend in the second half of the 19^{th} century. Sample replication increases the most between 1870 and 1910 where about 20 single series start contributing to chronology. The resulting rise of the slope could potentially be attributed to these new samples as can be noticed in Fig. 4. However, the mean of the 20 oldest samples shows still an upward trend albeit not as strong as in the younger series. As the younger samples outnumber the old ones 2:1, the growth curve and hence the overall mean is likely biased in the direction of the younger and faster growing series in accordance with the “modern-sample” bias described earlier. In the present case, this bias appears to be of temporally limited impact. Considering the similar low frequency trends in the three old sites, where no (XEP, PPP) or only three (PIGA) young trees (germination after 1880) contribute to chronology, the site VPA is not excluded from the regional RCS chronology. Convential detrending with conservative negative exponential fits (not shown) yields quite similar patterns (e.g. greater growth in the 20th century in comparison to the 19th century) further suggesting the robustness of the RCS chronology.

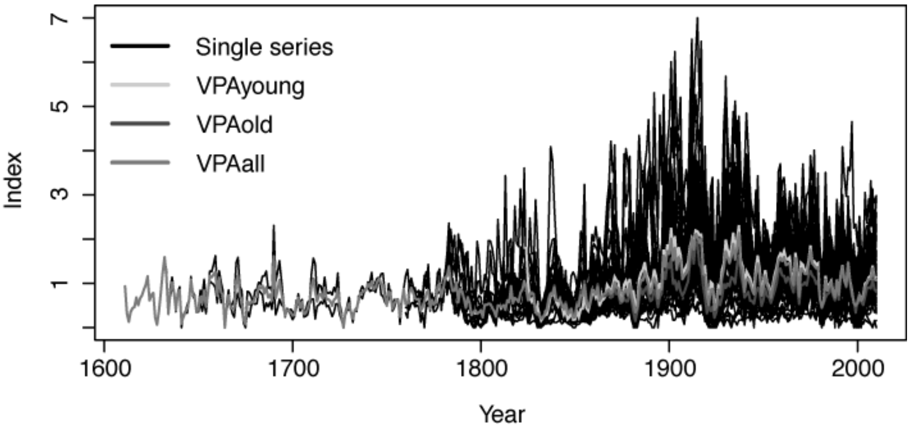


Figure 4: Single series of the RCS_{TRW} chronology of VPA (black) and the mean of the 20 oldest samples (dark grey), the 46 youngest samples (light grey) and the overall mean (grey).

We next sought to construct a Mt. Olympus final chronology from six of the sampled sites. The easiest way to build this Mt. Olympus chronology would be to use a single growth curve for all samples (hereafter referred to as RCS_single). The robust use of RCS_single requires a more or less equal distribution of all series and all sites over time. If individual growth curves display overall the same shape but on different levels as in this present study’s case, RCS_single could be employed if the age and replication structure of all sites over time is similar. Otherwise, this method is prone to distortions due to changing sample and site replication.

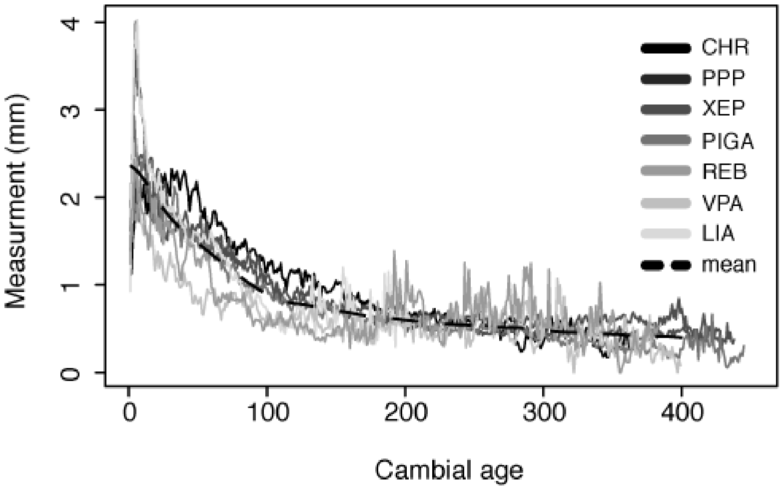


Figure 5: Raw RC_{TRW} curves of all seven sites (sorted according to their elevation) and their smoothed mean (dashed line, 50-year spline).

The RC curves for our individual sites have a similar shape, but if the smoothed mean growth curve is compared against the raw site growth curves major departures can be easily detected (Fig. 5). From the age of 200 onwards all series nicely fit the composite RC. Before that, the slow growing low elevation sites (VPA and REB) are heavily overestimated and the faster growing high elevation sites are underestimated (CHR, XEP, PPP). This underestimation of the (mainly) old sites in their first 200 years leads to increased index values. As a consequence the beginning of the RCS_single chronology displays inflated values, because only faster growing old trees of the high elevation sites build the chronology at this time. When a lot of the young slow growing trees start contributing to the chronology around 1850 the chronology trends downward because the overall growth curve is too high for all low elevation sites (which start at 1790, 1840 and 1900, Fig. 6b) and overestimates nearly all series in the last 110 years (Fig. 6a). Thus RCS_single does not seem to be an appropriate method for developing a regional Mt. Olympus chronology.

The splitting and recombination of the sites should circumvent the problems with RCS_single when the site chronologies are normalized before merging together. The distortions at both ends are decreased (Fig. 6a), but are nevertheless still clearly visible when compared to the individually detrended regional chronologies. These distortions are also due to the slightly different shapes of growth curves the single sites. For example at LIA the first 10-15 years will be underestimated and after the cambial age of 90 overestimated. Given the fact, that nearly all single series of LIA start from 1890 to 1920, this leads to increased values around 1900 and a slow decrease from 1980 onwards. LIA consequently has a steeper downward slope than it should have when detrended with its appropriate individual growth curve. These tests revealed significant difficulties in the collective detrending of data from six sites. We concluded that application of individual growth curves to each site and then merging them seems to be the most appropriate way to build the regional RCS chronology.

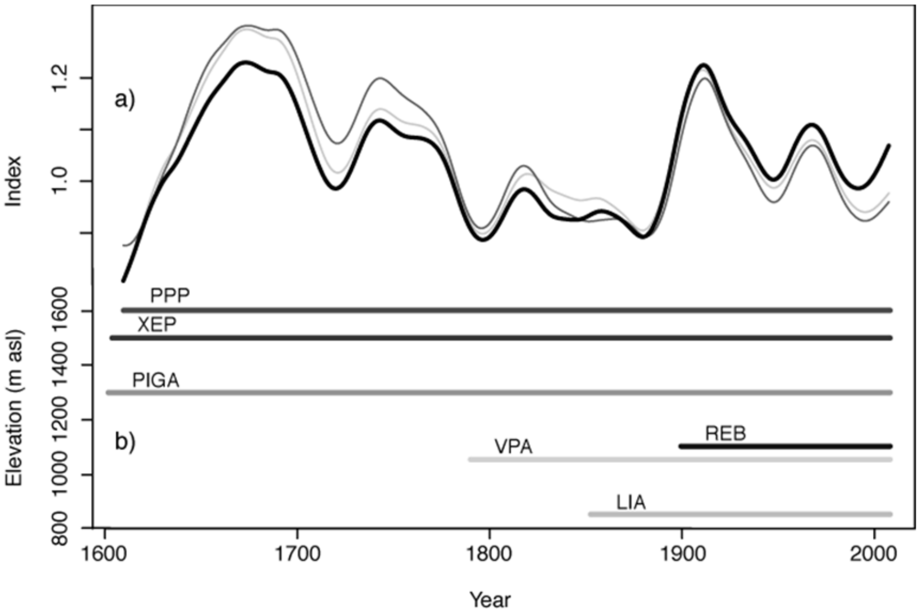


***Fig. 6: a)** 50-year smoothed RCS regional chronologies. RCS_single (dark grey), RCS_recombined (light grey) and RCS_individual (black). **b)** The time spans of the individual sites included in the master RCS chronology as a function of their elevation in m asl.*

A final consideration, which was not yet discussed, is the even-aged site REB. Like CHR it showed no low growth in the 19th century as the other five sites. Climate response analysis showed high sensitivity of REB to summer drought. As one of the study's objectives was to reconstruct past moisture variability, this site could be still of use. Therefore the standard deviations of the RCS_individual chronologies were examined, with and without REB. This analysis revealed great consistency in the 20th century however a large increase in standard deviation before 1900. Based upon these patterns REB was truncated so that only the last 110 years contribute to the regional RCS chronology.

Discussion and Conclusion

In this study we performed methodological trials to produce a chronology that robustly preserves inter-annual to low-frequency climate signals from a living tree dataset. After carefully merging the individually detrended site chronologies the final latewood width chronology explains 42% of the variance of the May-July standardized precipitation index (r=0.65). Our preliminary reconstruction shows very good agreement with other high frequency reconstructions of the Eastern Mediterranean (Fig. 8) (e.g. Xoplaki et al. 2003, Akkemik & Aras 2005, Touchan et al. 2007). The recent drying trend (1975-2000), known from instrumental data is also well captured by the tree-ring data. However, the reconstruction suggests that the current status quo (i.e., late 20th- early 21st century dry conditions that are a concern for agriculture and human societies) is well within the range of natural variability experienced during the past 400 years.

To achieve an unbiased RCS chronology, a multi-site strategy and the use of POE are of major importance. In addition to the common knowledge that a high sample replication is required for RCS, we found it is also helpful that these samples are distributed among several sites with different age structures. This sampling design allows for the systematic testing of biases. The use of POE greatly increases the accuracy of the RC. We also recommend to detrend the sites individually to achieve the best curve fit possible, especially when the sites do not span the same time period and growth levels are different.

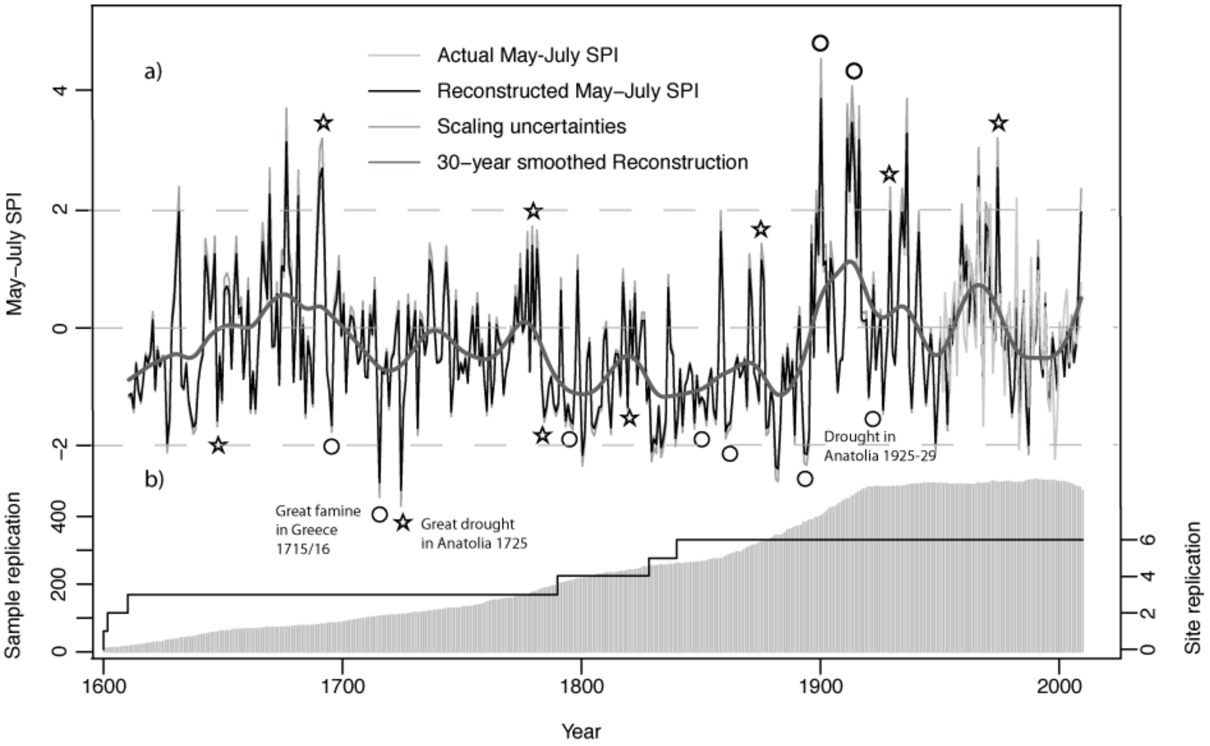


Figure 7: a) Actual and reconstructed May-July SPI with b) sample and site replication over time. Asterisks (circles) represent pointer years (periods) also mentioned in other climate reconstruction literature of the Eastern Mediterranean.

References

Akkemik, Ü. & A. Aras (2005): Reconstruction (1689-1994 AD) of April-August precipitation in the southern part of Central Turkey. International Journal of Climatology 25: 537-548.

Black, B., J. Colbert & N. Pederson (2008): Relationships between radial growth and lifespan within North American tree species. Ecoscience 15. 349-357.

Bigler C. & T. Veblen (2009): Increased early growth rates decrease longevities of conifers in subalpine forests. Oikos 118: 1130-1138.

Briffa, K.R., P. Jones, T. S. Bartholin, D. Eckstein, F. Schweingruber, W. Karlen, P. Zetterberg, M. Eronen (1992): Fennoscandian summers from AD 500: temperature changes on short and long timescales. Climate Dynamics 7: 111-119.

Briffa, K.R. & T. Melvin (2011): A Closer Look at Regional Curve Standardization of Tree-Ring Records: Justification of the Need, a Warning of Some Pitfalls, and Suggested Improvements in Its Application. In: M. Hughes, H. Diaz & T. Swetnam (eds.) (2011): Dendroclimatology: Progress and Prospects. Developments in Paleoenvironmental Research 11: 113-145

Cook, E.R. & K. Peters (1981): The smoothing spline: A new approach standardizing forest interior tree-ring series for dendroclimatic studies. Tree-Ring Bulletin 41: 45-53.

Cook, E.R. & L. Kariukstis (eds.) (1990): Methods of Dendrochronology: Applications in the Environmental Sciences. Dordrecht.

Cook, E.R., K. Briffa, D. Meko, D. Graybill, G. Funkhouser (1995): The „segment length curse“ in long tree-ring chronology development for paleoclimatic studies. The Holocene 5: 229-237.

Esper, J., E. Cook & F. Schweingruber (2002): Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability. Science 295: 2250-2253.

Frank, D., J. Esper, E. Zorita & R. Wilson (2010): A noodle, hockey stick, and spaghetti plate: a perspective on high-resolution paleoclimatology. Wiley Interdisciplinary Reviews Climate Change 1: 507-516.

Klesse, S. (2012): Response of Pinus nigra to long-term moisture variability on Mt. Olympus, Greece. Diploma thesis. Mainz.

Mitchell, V. (1967): An investigation of certain aspects of tree growth rates in relation to climate in the central Canadian boreal forest. Techn Rep 33. University of Winsconsin, Department of Meteorology, Wisconsin.

Touchan, R., Ü. Akkemik, M.K. Hughes, N. Erkan (2007): May-June precipitation reconstruction of south-western Anatolia, Turkey during the last 900 years from tree rings. Quaternary Research 68: 196-202.

Xoplaki, E., J. González-Rouco, D. Gyalistras, J. Luterbacher, R. Rickli & H. Wanner (2003): Interannual summer air temperature variability over Greece and its connection to the large-scale atmospheric circulation and Mediterranean SSTs 1950–1999. Climate Dynamics 20: 537-554.

Forward modelling of tree-ring width chronologies from the Spanish Pyrenees using VS-Lite model

W. Acevedo [1], U. Cubasch [1], S. Reich [2] & K. Matthes [3]

[1] Freie Universität Berlin, Institut für Meteorologie, Berlin, Germany
[2] Universität Potsdam, Institut für Mathematik, Potsdam, Germany
[3] Helmholtz Zentrum für Ozeanforschung Kiel – GEOMAR, Kiel, Germany
E-mail: walter.acevedo@met.fu-berlin.de

Introduction

Presently, the most widely used process-based forward model for tree-ring width is the so-called VS (Vaganov-Shashkin) model, which simulates climate-driven tree-ring growth by means of simple but non-linear representations of the principle of limiting factors and the cambium cellular processes involved in tree-ring formation. VS model requires latitude and daily time series of temperature and precipitation to calculate a daily growth rate function, which is subsequently used to drive a cellular automaton model that simulates the cambial processes of growth, mitosis, differentiation and dormancy. VS model has been shown to be skilful modelling the tree-ring growth response to climate of different conifer species coming from very distinct climate regimes (Vaganov et al 2006, Evans et al 2006, Shi et al 2008, Touchan et al 2012). In practice, however, its large number of parameters (>40) makes the tuning procedure time consuming and its demanding data requirements limit to a considerable extent VS model applicability.

Recently, a simplified version of VS model named VS-Lite - requiring only monthly data, with just 12 parameters and lacking cellular processes representation - was introduced (Tolwinski-Ward et al 2011). This new tree-ring width forward model, despite its much lower level of complexity as compared to full VS model, has been shown to skilfully represent climate-driven variability of an extensive North American tree-ring network. Furthermore, due to its computational affordability and parameter fewness, it has allowed for systematic calibration schemes. In this work we study the performance of VS-Lite at simulating a set of 3 chronologies from the Spanish Pyrenees using several gridded datasets as climate information source.

Data and methods

VS-Lite model

The calculation of the growth rate in VS-Lite model is based on the principle of limiting factors, represented in the form of the following non-linear equation:

$$Gr = gE * \min(gT,gM)$$

where Gr is the growth rate and gE, gT and gM stand for non-dimensional growth responses to insolation, temperature and soil moisture, respectively. gE is estimated as the normalized monthly mean solar irradiation (neglecting attenuations due to the atmosphere, topography or any other factor) while gT and gM are given by piecewise linear functions with 2 free parameters (Figure 1.a).

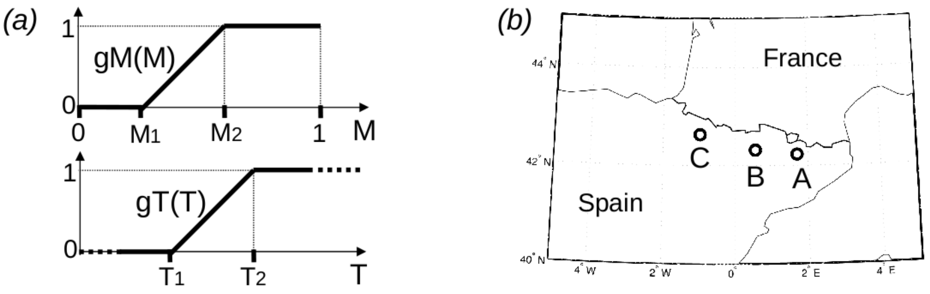


Figure 1: (a) Functional form of VS-Lite growth responses to temperature and soil moisture.(b) Geographical position of the chronology sites.

gT can be calculated directly as temperature is an input variable, whereas gM depends on the soil moisture, which is not given beforehand. In VS-Lite soil moisture is obtained via the “CPC Leaky bucket model” (Huang et al 1996), which simulates water balance cycle considering precipitation, evapo-transpiration, surface and subsurface runoff, and groundwater loss. Finally, the obtained monthly growth rate is integrated over a moving time window, not necessarily 12 months long, and the annual tree-ring width series this way produced is standardized so as to generate the final simulated chronology.

In our calculations, the leaky bucket model parameters were set to their default values, temperature and moisture response parameters were obtained via the Bayesian estimator provided with the model, and the integration time window used was 16 months long, starting in September of the previous year. This time window configuration was the one used in Tolwinski-Ward et al (2011) in their validation experiments, as it contributed to account for the autocorrelation observed in real tree-ring width series.

Climate and tree-ring data

Monthly temperature and precipitation time series for the studied sites were obtained via bi-lineal interpolation of several gridded datasets (Table 1). As for tree-ring data, we used 3 ring width chronologies of Mountain Pine (Pinus uncinata) coming from the Spanish Pyrenees (Figure 1.b), characterized for their high expressed population signals (Table 2). The similarity between observed and simulated chronologies was assessed through the calculation of their Pearson correlation, whose significance, measured by its p-value, was corrected for effective number of degrees of freedom, so as to take into account the chronologies' autocorrelation.

Table 1: Characteristics of the climate datasets used as input for VS-Lite model.

Database	Source	Grid	Time Span	Gridding Methodology
ERA40	ECMWF	Regular 1.5°x 1.5°	1957 - 2002	Reanalysis
NCEP-NCAR R1	NCEP-NCAR	Gaussian 1.88°	1948 - 2012	Reanalysis
GPCC V5	GPCC	Regular 0.5°x 0.5°	1901 - 2009	Interpolation
CRU TS 3.1	CRU	Regular 0.5°x 0.5°	1901 - 2009	Interpolation

Table 2: Characteristics of the tree-ring width chronologies.

Site	EPS	Cores	Latitude	Longitude	Altitude
A	> 0.95	68	42.23	1.7	2100
B	> 0.91	42	42.32	0.55	2400
C	> 0.97	67	42.63	-0.98	2135

Results and Discussion

VS-Lite operation strongly depends on the climate dataset used and the chronology site (Table 3). Results utilizing ERA40 reanalysis both for temperature and precipitation were satisfactory only at site A. This performance was greatly improved by using GPCC precipitation data, which is quite consistent with the well know deficiencies of reanalysis data in terms of precipitation. Simulated chronologies produced with NCEP/NCAR reanalysis behaved similarly; however, in this case the correlation increase was considerably smaller which suggests a higher quality of NCEP/NCAR R1 precipitation data. In general, correlation values achieved with the temperature-precipitation combination ERA40-GPCC V5 were higher than the ones obtained with NCEP/NCAR-GPCC V5, probably owing to the fact that the models used into ERA40 reanalysis were specially tuned for Europe. Finally, our outcome using CRU TS 3.1 presented again an improvement when using GPCC data. Nonetheless, in this case at sites A an B the performance was significantly poorer than the aforementioned ones.

A particularly robust feature of our results is the apparent poorer performance of VS-Lite at sites B and C regardless of the climate data set used, which might be attributed to an stronger influence at these places of non-climatic factors or climate-driven tree-ring growth aspects not properly captured by VS-Lite. On the other hand, for all 3 sites the highest correlations between modelled and actual chronologies were obtained using the input data combination ERA40-GPCC V5. For this combination we also tried to partially consider topographic effects by performing an adiabatic correction to the temperature values proportional to the elevation difference between the chronology site and the interpolated grid altitude (0.56°/100m). This attempt, however, was rather counter-effective probably as a consequence of the crudeness of the lapse rate correction.

Table 3: Pearson correlation between observed and modelled tree-ring width chronologies.

Climate Data		Site A		Site B		Site C	
Temperature	**Precipitation**	**Correlation**	**p-value**	**Correlation**	**p-value**	**Correlation**	**p-value**
ERA40	ERA40	0.54	0.054	0.14	-	0.04	-
ERA40	GPCC V5	0.65	0.029	0.44	0.018	0.34	0.06
NCEP R1	NCEP R1	0.46	0.049	0.40	0.056	0.16	0.36
NCEP R1	GPCC V5	0.49	0.038	0.40	0.056	0.23	0.13
CRU TS 3.1	CRU TS 3.1	0.18	0.23	0.11	0.26	0.26	0.11
CRU TS 3.1	GPCC V5	0.21	0.19	0.21	0.11	0.27	0.064
ERA40*	GPCC V5	0.39	0.055	0.38	0.066	0.29	0.17

** Temperature value corrected adiabatically for the elevation difference between site and dataset grid.*

Figure 2(a) shows actual and simulated chronologies during the time span 1958-1997 for the aforementioned highest skill combination of temperature-precipitation data. An interesting common feature of our modelled chronologies is a noticeable shared low-skill period around year 1970, presumably imputable to a regional phenomena not described by VS-Lite.

Mean growth response plots (Figure 2(b)) indicate that the climate-driven tree-ring growth at site A was mostly driven by temperature, as the mean response to moisture was always maximum and therefore never influenced the growth rate. Climate-driven growth at sites B and C, in turn, was intermittently driven by temperature and moisture, as around August the mean response to moisture was smaller than the mean response to temperature and accordingly moisture stress became the growth limiting factor.

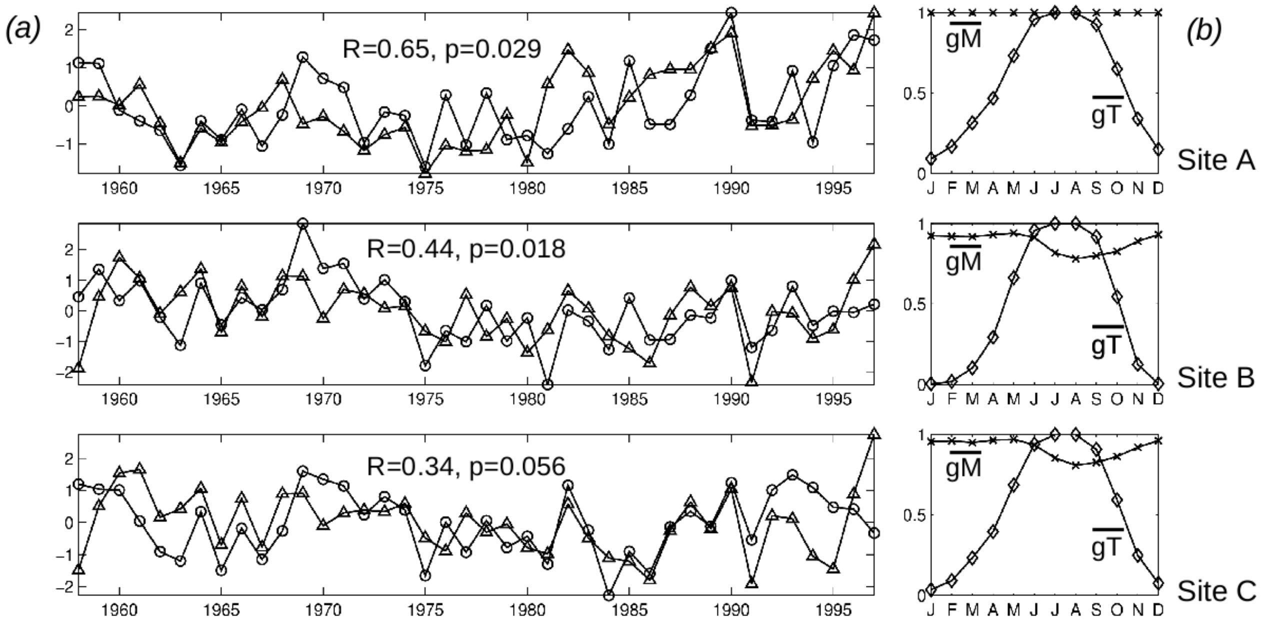


Figure 2: VS-Lite results using temperature data from ERA40 reanalysis and precipitation data from GPCC database V5. (a) Observed (circles) and simulated (triangles) standardized tree-ring width chronologies (b) Mean Response Functions to temperature (diamonds) and moisture (crosses).

Conclusion

Despite its very simplified approach to the modelling of climate-driven tree-ring growth, VS-lite was skilful at simulating tree-ring width chronologies of the Pyrenees area using gridded datasets as climate input. The best agreement between real and modelled chronologies was obtained using reanalysis temperature data and interpolated precipitation records.

Acknowledgements

We are very grateful to Isabel Dorado Liñán for her valuable comments and feedback. Thanks to the Dendrochronology Group of Barcelona University for sharing the chronologies used in this work. Support for this work was provided by Helmholtz Association and Freie Universität Berlin through its graduate research school GeoSim.

References

Tolwinski-Ward S., Evans M., Hughes M., Anchukaitis K. (2011): An efficient forward model of the climate controls on interannual variation in tree-ring width. *Clim. Dyn.* 36, 2419-2439.

Evans M., Reichert B., Kaplan A., Anchukaitis K., Vaganov E., Hughes M., Cane M. (2006): A forward modeling approach to paleoclimatic interpretation of tree-ring data, *J. Geophys. Res.*, 111, G03008, 13pp.

Huang J., van den Dool H., Georgankakos K. (1996): Analysis of model-calculated soil moisture over the United States (1931–1993) and applications to long-range temperature forecasts. *J. Clim.* 9, 1350–1362.

Shi J., Liu Y., Vaganov E., Li J., Cai Q. (2008): Statistical and process-based modeling analyses of tree growth response to climate in semi-arid area of north central China: A case study of Pinus tabulaeformis, *J. Geophys. Res.*, 113, G01026, 10 pp.

Touchan R., Shishov V. Meko D., Nouiri I., Grachev A. (2012) : Process based model sheds light on climate sensitivity of Mediterranean tree-ring width, *Biogeosciences*, 9, 965-972.

Vaganov E., Hughes M., Shashkin A. (2006): Growth dynamics of conifer tree rings: Images of Past and Future Environments. In *Ecological studies*, vol 183. Springer, New York. 354 pp.

SECTION 2

ISOTOPES

Stable oxygen isotopes in xylem water and soil water of alpine trees

B. Ullrich [1], E. Graf Pannatier [1], M. Saurer [2], S. Simard [1,3] & K. Treydte [1]

[1] Federal Research Institute WSL, Zuercher Str. 111, 8903 Birmensdorf, Switzerland
[2]Paul Scherrer Institute PSI, 5253 Villigen-PSI, Switzerland
[3] GFZ German Research Centre for Geosciences, Telegrafenberg, C127, 14473 Potsdam, Germany
E-mail: bastian.ullrich@wsl.ch

Introduction

Oxygen isotopes in tree rings have become an increasingly significant tool in obtaining retrospective insight into plant physiological response to climate and other environmental variables (e.g. Brienen et al. 2012; Danis et al. 2006; Edwards et al. 2008; Gessler et al. 2009; Kress et al. 2009; Kress et al. 2010; McCarroll & Loader 2004; Miller et al. 2006; Poussart et al. 2004; Robertson et al. 2001; Saurer et al. 1997a; Saurer et al. 1997b; Treydte et al. 2007; Treydte et al. 2006). δ^{18}O values are constrained by the isotopic ratio of the source water (Roden et al. 2000) and locally integrate the stomatal response to vapour pressure deficit (VPD) via leaf water enrichment, being coupled with transpiration (Barbour et al. 2004; Yakir & DeNiro 1990). The possible mixture of xylem water and needle water as well as the exchange of carbonyl positions of glucose during cellulose formation (Barbour & Farquhar 2000) makes it difficult to decipher whether isotopic patterns of regional atmospheric circulation patterns through precipitation or local short-term variations in air humidity dominate the tree-ring signal. Since no fractionation of oxygen isotopes takes place during water uptake by the root system (Barbour 2007; Dawson & Ehleringer 1991), the water in the xylem should reflect the ^{18}O-signature of the soil water and its vertical seasonal variation. A number of studies have been conducted using this circumstance to distinguish which water source is utilized by the tree (Darrouzet-Nardi et al. 2006; Dawson 1998; Dawson & Ehleringer 1991; Valentini et al. 1994).

Here we present a highly resolved dataset of oxygen isotopes in soil and xylem water from two alpine sites and tree species. This unique dataset is used to test how far the sampled soil water reflects xylem water on a highly resolved seasonal basis and if a single isotope, two-source mixing model (Brunel et al. 1995; Phillips & Gregg 2001) using two soil depths can be applied to estimate xylem water δ^{18}O. This should help to achieve a closer understanding of seasonal changes in the water uptake and hence, the trees' internal water cycle.

Material and Methods

Study design

The study region is the Loetschental (46° 24' 38.48" N, 7° 49' 43.67" E), an inner-alpine dry valley in the Swiss Alps. Two sites were selected, one on a small ridge at the valley bottom (1300 m asl) considered to be warm and dry, and the other, cool and moist, at the tree line (2100 m asl) of the south-facing slope. Soil types are similar at both sites with about 60 cm depth from the surface to the bedrock and are classified as podzolic cambisols.

At both sites four larch (*Larix decidua* MILL.) and at the lower site additional four spruce (*Picea abies* H. KARST.) were selected. Each of the trees sampled grew in an open forest stand ensuring a good exposition to sunlight. Sampling took place during the growing seasons 2008-2011, on a weekly basis from March/April to November. Three twigs per tree of about 10 cm, with sun exposition, at a height of approximately 5-8 m were cut with pruning scissors for xylem water δ^{18}O measurements. Needles, bark and phloem were peeled off the twigs to expose the xylem and then all tissues were pooled tree-wise into air-tight glass tubes. In 2009, the pooling included all trees, resulting in only one dataset for needle and xylem water respectively.

Additionally, rain collectors were set up at each site, with the funnels of the collectors connected to a 2 l storage bottle buried and covered by a PVC pipe to protect the sample from high temperatures and solar radiation (O'Driscoll et al. 2005; Thimonier et al. 2005). The installation was tested with water of known $^{18}O/^{16}O$-ratio to ensure no evaporative enrichment. Soil water was sampled with tension lysimeters at 10 and 60 cm depth. The lysimeters were custom-made. Glass suction plates with 50 mm diameter (Schmizo AG, Zofingen, Switzerland) were used at 10 cm depth whereas the soil water at 60 cm depth was sampled using high-flow porous ceramic cups (Soil moisture Equipment Cop., Santa Barbara, USA). Both soil and precipitation water samples were collected weekly. All samples (twigs, soil water and precipitation) were carried on ice during fieldwork and later on stored at -21 °C in the laboratory prior to analysis.

Soil moisture was measured with ECH_2O EC-5 Sensors (Decagon Devices, Inc., Pullman, USA) at 10 and 70 cm depth at the tree line and 10 and 60 cm depth at the valley bottom, respectively. The hourly measured soil moisture data were averaged over the respective sampling period of approximately seven days.

Xylem water for isotope measurements was extracted using a cryogenic vacuum line (Ehleringer et al. 2000) at the Laboratory of Atmospheric Chemistry (PSI), Switzerland, where also the isotope ratios were determined with a Delta Plus XP mass-spectrometer and a Thermo-Conversion Elemental Analyzer TC/EA (Thermo Fisher Scientifics Inc., Waltham, MA, USA). Measurements of the oxygen isotopic ratio of the soil water and the precipitation were carried out at the Central Laboratory of the Swiss Federal Institute WSL, Switzerland, with a Delta V Advantage mass spectrometer, Gas bench II (Thermo Fisher Scientifics Inc., Waltham, MA, USA).

Data analysis

A two-source mixing model was applied giving the fraction f of one of two possible source partitioning with the following mass balance equation after Phillips & Gregg (2001):

$$\delta_{xyl} = f^*\delta_{soil10} + (1-f)^*\delta_{soil60} \qquad \text{(Eqn. 1)}$$

where δ_{xyl}, δ_{soil10} and δ_{soil60} represent the oxygen isotope ratio of water sampled at the twig's xylem, and soil depth of 10 and 60 cm, respectively. Equation 2 was rearranged to obtain f (Phillips & Gregg 2001):

$$f = (\delta_{xyl} - \delta_{soil60})/(\delta_{soil10} - \delta_{soil60}) \qquad \text{(Eqn. 2)}$$

Values of *f* higher than one and lower than zero were set to one and zero, respectively. A *f* value of zero indicates that the xylem water originates exclusively from soil layers at 60 cm depth or, since negative values have been set to zero, deeper. On the other hand, *f* values of one indicate that xylem water originates exclusively from shallow soil or even surface water.

Additionally, $\delta^{18}O$ values of soil water at 10 cm and 60 cm depth were averaged for each sampling week, weighted by their corresponding soil moisture values and compared with xylem water $\delta^{18}O$ of the same week. For the weighting only plant available water was used. Plant available water is soil water content at field capacity minus soil water content at the permanent wilting point. Both were determined after Teepe et al. (2003) using bulk density and soil texture.

Since the timing of the last sampling dates of every year varied, the mean $\delta^{18}O$ value from October 15 to November 15 of the respective year was used for calculations relating to the end of these seasons.

Results

Seasonal patterns of xylem water $\delta^{18}O$

All trees at a site and within both species show strong common xylem water $\delta^{18}O$ variation with distinct seasonal trends (Fig. 1). Common patterns are indicated by high inter-series correlations (mean r) in 2008, 2010 and 2011 and low standard deviation (SD) within each of the three datasets per sampling date (mean SD: larch at the tree line = 0.9‰, larch at the valley bottom = 1.3‰, spruce at the valley bottom = 0.9‰). These strong coherencies among individuals point to homogenous site conditions and suggest that the selected trees represent the population signal at the site, therefore allowing averaging data on a site basis for subsequent calculations. Common trends between trees are particularly seen in the low frequency, with a striking decreasing trend to minimum values in early spring only seen in larch (mean difference from maximum to minimum: 12.9±0.7‰) and increasing trends of both species and both sites during the growing seasons. At the tree line, the lowest values are observed around the end of June with an average minimum (all years included) of -12.5‰. The xylem water $\delta^{18}O$ values then increase until the end of the sampling period (October 15 to November 15) to a maximum, all years included, ranging from -9.9‰ to -6.7‰. Mean xylem water $\delta^{18}O$ calculated for the growing seasons of all years is similar at both tree line and valley bottom (-9.7‰ and -9.0‰, respectively). At the latter location, minimum values for larch are observed in mid-May and range from -11.8‰ in 2010 to -13.9‰ in 2011. At the end of the growing season (Oct. 15 – Nov. 15) values are within the range observed at the tree line with a mean $\delta^{18}O$ of -9.5‰. Spruces in 2010 and 2011, in comparison with larch, present the most ^{18}O depleted xylem water at the beginning of the growing season (around the beginning of April) with mean values of -12.3‰ and an increasing trend up to values from -9.7‰ to -6.2‰ at the end of the sampling period. Winter xylem water $\delta^{18}O$ values between December 2010 and March 2011, measured four times for both species at the valley bottom and once for larch at the tree line, suggest a slightly increasing trend reaching the maximum values in early spring.

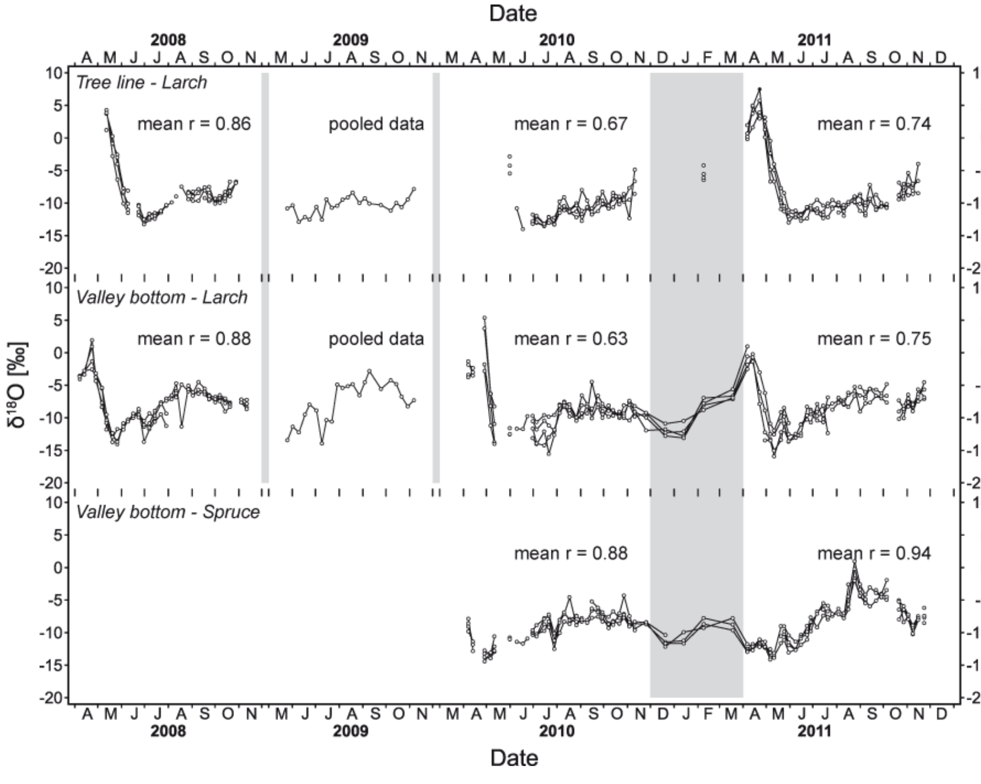


Figure 1: Seasonal trends of all three datasets of xylem water $\delta^{18}O$. Each point represents one tree at each sampling date. Mean r is the inter-series correlation for each species, site and year. Grey areas highlight the winter season.

Soil water δ^{18}O

In early spring of all four years, oxygen isotope values of soil water sampled at 10 and 60 cm depth show similar and strongly ^{18}O depleted values (-14.5‰ at the tree line and -14.2‰ at the valley bottom, respectively) (Fig. 2). Rapidly, the isotope values of both soil depths diverge and show different trends and offsets during the season. While water from the deeper soil layers shows damped variations compared to the surface water and enriches slowly towards summer, the surface water shows higher variations. A mean seasonal δ^{18}O value of -8.6±1.7‰ at the tree line, including all years, is close to the mean δ^{18}O precipitation values measured in the study region during the sampling season at both sites: -8.5±3.5‰; data not shown). At the valley bottom, the soil is often dry during the summer preventing any water to be sampled as seen in 2009 and 2011. However, 2008 and 2010 were sufficiently wet for soil water sampling. Mean δ^{18}O value of soil water during both growing seasons is -7.0±2.7‰, slightly enriched compared to δ^{18}O precipitation values as mentioned above. At the end of the sampling periods (Oct. 15 to Nov. 15 in 2009-2011) the upper soil layer contains water depleted in ^{18}O (-9.5±1.0‰) compared to the summer. The soil water sampled deeper shows similar values (-11.0±0.7‰). In 2008, the sampling ended already in September, (average for September: 10 cm: -7.5±0.8‰; 60 cm: -10.0±0.8‰), and therefore these values were excluded from the subsequent calculations.

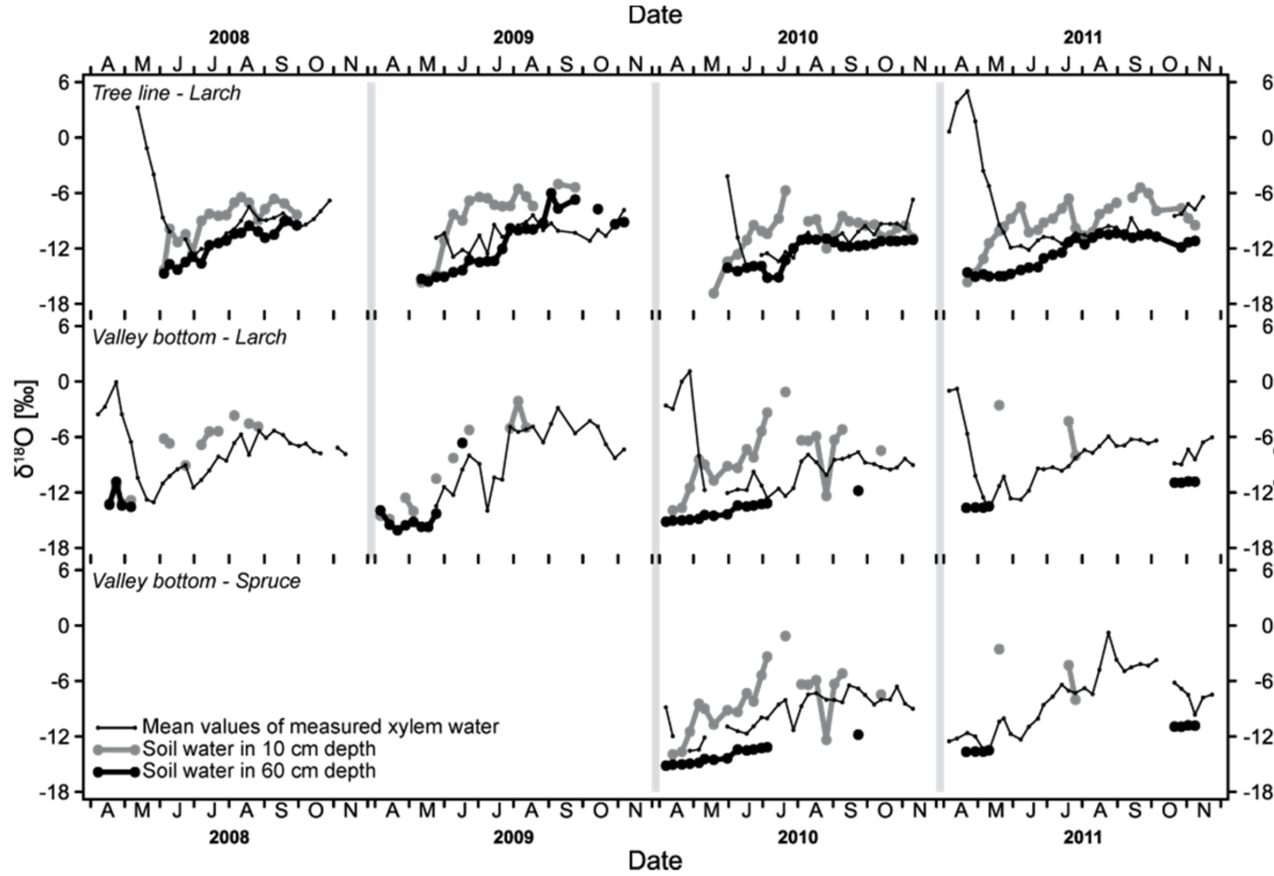


Figure 2: Seasonal trends of averaged weekly xylem water δ^{18}O compared to weekly soil water δ^{18}O of both depths from April to November. Winter season 2010/11 is excluded since soil water was not collected. Grey areas highlight the winter season.

The high δ^{18}O$_{xyl}$ values of larch at the beginning of all sampling periods strongly differ from the highly depleted soil water values at the same time. After δ^{18}O$_{xyl}$ values have reached a minimum, they generally follow the seasonal trends of δ^{18}O$_{soil}$ at the tree line with a closer dependency on the deeper soil water. The relation between δ^{18}O of the xylem and the deeper soil water cannot be fully confirmed at the valley site due to large gaps in the soil water records.

Source partitioning and influence of soil moisture

The fraction of soil water from 10 cm depth shows a high variability at both sites (Fig 3). Values for *f* cover the full range from zero to one. However, the lowest value for spruce reached only 0.22. Due to the low number of *f*-values at the valley bottom due to a low amount of soil water samples, this site was excluded from any further calculations and interpretations.

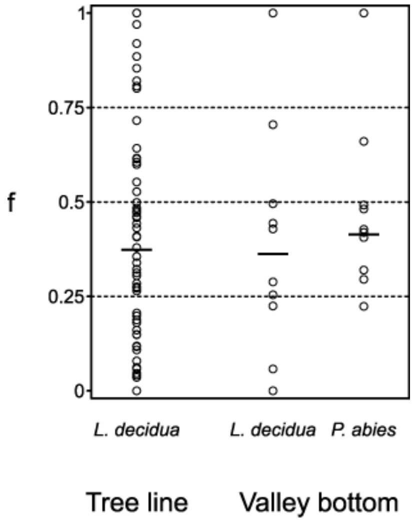


Figure 3: Fraction of water (f) obtained from 10 cm soil depth with 0 and 1 values respectively meaning 0% use of surface water (100% use of deep soil water (60cm depth)), and vice-versa. Each point represents one sampling date whereas the median f is indicated by a bold line.

The difference between the weighted average of soil water and the average of xylem water shows less variability than *f* during the growing seasons and stays most of the time within the range of minimum and maximum values of the measured xylem water δ^{18}O of each sampling date (Fig. 4A).

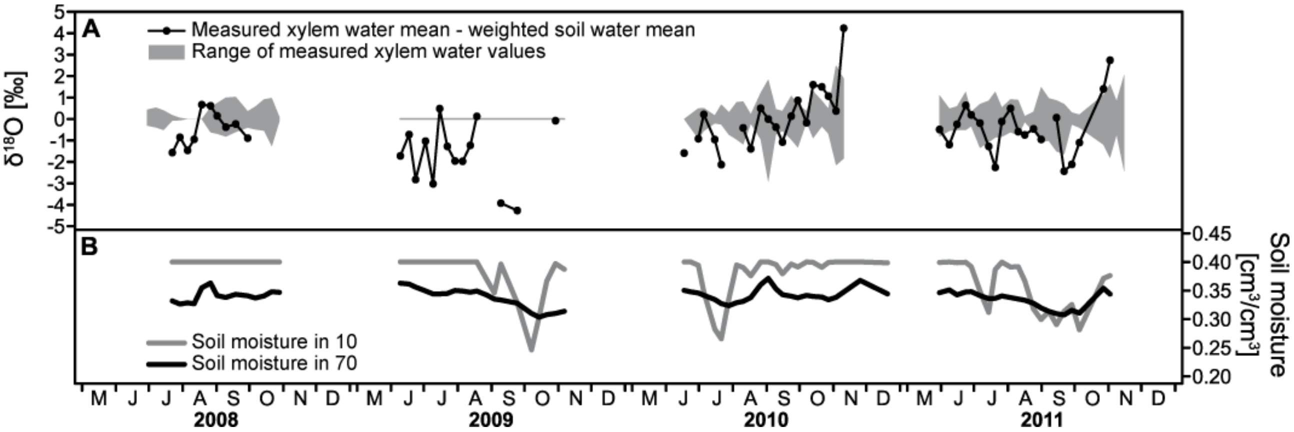


Figure 4: A) Difference between the weighted average of soil water δ^{18}O and average xylem water δ^{18}O compared to the total range of measured xylem water δ^{18}O during the four sampling periods at the tree line. Negative values indicate xylem water values depleted in ^{18}O compared to average soil water, positive values indicate ^{18}O enriched xylem water. B) Soil moisture of both sampling depths during the sampling seasons. Values represent the average soil moisture during the sampling week.

Samples in August 2008 and the whole season 2009 were pooled and thus, do not allow much interpretation. Strong negative and positive differences are obvious.

A strongly negative difference would be the minimum in September/October 2009 where xylem water δ^{18}O is -4.3‰ lower than average soil water. Another minimum is reached at the end of July with a difference of -2.1‰ compared to average soil water. In 2011, the xylem water δ^{18}O is two times below the average of soil water: -2.3‰ in July and -2.4‰ in September. Here, the values of the average soil water are outside the range of xylem water δ^{18}O. In November 2010 and 2011, the xylem water is much more enriched compared to the average soil water (4.2‰ for 2010 and 2.7‰ for 2011, respectively).

During the sampling seasons at the tree line, the soil in both depths is usually moist, close to field capacity, (Fig. 4B). During dry periods, the soil moisture decreases in the upper soil (10 cm depth), such as in October 2009, July 2010, and July and October 2011.

Discussion and Conclusions

Regarding the seasonal variation of xylem water δ^{18}O of larches, two phases can be distinguished: (i) a pre-seasonal phase, where xylem water is highly ^{18}O enriched compared to isotopically depleted soil water at the same dates, suggesting a decoupling between δ^{18}O$_{soil}$ and δ^{18}O$_{xyl}$ during that period, and (ii) the growing season, where xylem water δ^{18}O values are comparable to those of the soil water, which undergoes a positive trend from early spring to late autumn towards more important enrichment. This phase starts every year at the absolute minimum of xylem water δ^{18}O, being also the date of bud break. At the end of the sampling season, the δ^{18}O values of xylem water start being above the soil water again. Therefore, xylem water δ^{18}O values at that time might already be a part of the pre-seasonal phase. The processes behind the appearance of this winter enrichment are not fully clear yet, but freeze-thaw events, which occur during wintertime (Mayr et al. 2006) might be the main driver. While twigs above the snow surface experience strong radiation during day time in winter and can heat up accordingly (Mayr et al. 2012; Tranquillini 1976), the transpiration stream within the tree has stopped. This might lead to a slow enrichment, especially during late winter, when daily radiation becomes stronger every day.

The soil water δ^{18}O sampled in spring is generally depleted at both soil depths. These values show the strong influence of water from snowmelt, which soaks the ground. From this time on, the soil water from the upper soil layers becomes quickly enriched, partly due to the mixing with precipitation during the growing season, but also the influence of evaporative processes at the soil surface. The soil layer in 60 cm depth plays a key role in melt water storage and suggests a gradient from enriched to depleted water from surface to deep soil layers. The δ^{18}O values in 60 cm depth represent therefore an older and more integrated signal dominated by winter snowfall.

The fraction *f* of soil water represented in xylem water varies strongly over all seasons, from 0-1, suggesting that source partitioning from the upper soil layers, reflecting precipitation, to the deep soil layers, is possible. The existence of groundwater with a differing δ^{18}O signal can be excluded at both sites. Since the difference in δ^{18}O values of both soil layers becomes smaller during the season, we might not be able to assess the source partitioning after August or September.

Looking at the comparison between moisture weighted soil water and xylem water, it becomes clear that a direct uptake of precipitation is unlikely. For this, xylem water should be markedly higher than averaged soil water. An exception is the late season in 2010 and 2011, where xylem water is already strongly enriched. In this time larches already lost their needles at the tree line and this enrichment would be a first indicator for uncoupling from soil water signal and could be already accounted for during the pre-seasonal enrichment phase.

During the growing seasons, soil and xylem water stay within the same range almost all the time. During summer and autumn only, xylem water δ^{18}O decreases below soil water. This is always accompanied by dry soil conditions. Plants take up water where it is most available (Dawson (1998), especially larches with their expansive root system, which can reach water from shallow soil down to deeper layers, resulting in a mixture controlled by soil water potential. Surface water or precipitation seems not to have a direct influence on xylem water, since it is never markedly enriched compared to average soil water. Rain is integrated in the upper soil layer and therefore has surely an indirect influence. Fog as a potential source is seldom at our study site at the tree line and is therefore not taken into account. The acquisition of water from soil layers deeper than 60 cm, which are unfortunately out of reach for measurements, during drier periods suggests a stronger influence of depleted water from the winter season. This was the case in autumn 2009. In combination with the occurring exchange of sugars with xylem water during cell formation (Barbour & Farquhar 2000), the depleted xylem water could have an increasing dampening effect during periods with a high VPD and therefore on the originally strong $\delta^{18}O$ enrichment during photosynthesis. So the weighted average of soil water is a possibility to calculate the corresponding xylem water. To get better results, a more precise soil water model that incorporates deeper soil layers is in the test phase. In addition, another site where the lower soil is continuously saturated with water characterized by a relatively constant $\delta^{18}O$ value was installed at the valley bottom. Data compilation for this new wet site has just started and will be presented in a later manuscript.

Acknowledgements

We thank Roger Köchli, Michael Dal Molin, Loïc Schneider and the whole WSL Dendro Team for field work, lab assistance and discussion, and the Swiss National Science Foundation (200021_130112 'ISOPATH') for financial support.

References

Barbour, M., Roden, J., Farquhar, G. & Ehleringer, J. (2004): Expressing leaf water and cellulose oxygen isotope ratios as enrichment above source water reveals evidence of a Péclet effect. *Oecologia* 138: 426-435.

Barbour, M.M. (2007): Stable oxygen isotope composition of plant tissue: a review. *Functional Plant Biology* 34: 83-94.

Barbour, M.M. & Farquhar, G.D. (2000): Relative humidity- and ABA-induced variation in carbon and oxygen isotope ratios of cotton leaves. *Plant Cell and Environment* 23: 473-485.

Brienen, R.J.W., Helle, G., Pons, T.L., Guyot, J.L. & Gloor, M. (2012): Oxygen isotopes in tree rings are a good proxy for Amazon precipitation and El Nino-Southern Oscillation variability. *Proceedings of the National Academy of Sciences of the United States of America* 109: 16957-16962.

Brunel, J.-P., Walker, G.R. & Kennett-Smith, A.K. (1995): Field validation of isotopic procedures for determining sources of water used by plants in a semi-arid environment. *Journal of Hydrology* 167: 351-368.

Danis, P.A., Masson-Delmotte, V., Stievenard, M., Guillemin, M.T., Daux, V., Naveau, P. & von Grafenstein, U. (2006): Reconstruction of past precipitation $\delta^{18}O$ using tree-ring cellulose $\delta^{18}O$ and $\delta^{13}C$: A calibration study near Lac d'Annecy, France. *Earth and Planetary Science Letters* 243: 439-448.

Darrouzet-Nardi, A., D'Antonio, C. & Dawson, T. (2006): Depth of water acquisition by invading shrubs and resident herbs in a Sierra Nevada meadow. *Plant and Soil* 285: 31-43.

Dawson, T.E. (1998): Fog in the California redwood forest: ecosystem inputs and use by plants. *Oecologia* 117: 476-485.

Dawson, T.E. & Ehleringer, J.R. (1991): Streamside trees that do not use stream water. *Nature* 350: 335-337.

Edwards, T.W.D., Birks, S.J., Luckman, B.H. & MacDonald, G.M. (2008): Climatic and hydrologic variability during the past millennium in the eastern Rocky Mountains and northern Great Plains of western Canada. *Quaternary Research* 70: 188-197.

Ehleringer, J.R., Roden, J.S. & Dawson, T.E. (2000): Assessing ecosystem-level water relations through stable isotope ratio analysis. *In* Methods in Ecosystem Science. Eds.

Sala, O.E., Jackson, R.B., Mooney, H.A. & Howarth, R.W. Springer Verlag, New York, USA, pp 181-195.

Gessler, A., Brandes, E., Buchmann, N., Helle, G., Rennenberg, H. & Barnard, R.L. (2009): Tracing carbon and oxygen isotope signals from newly assimilated sugars in the leaves to the tree-ring archive. *Plant Cell and Environment* 32: 780-795.

Kress, A., Saurer, M., Büntgen, U., Treydte, K., Bugmann, H. & Siegwolf, R. (2009): Summer temperature dependency of larch budmoth outbreaks revealed by Alpine tree-ring isotope chronologies. *Oecologia* 160: 353-365.

Kress, A., Saurer, M., Siegwolf, R.T.W., Frank, D.C., Esper, J. & Bugmann, H. (2010): A 350 year drought reconstruction from Alpine tree ring stable isotopes. *Global Biogeochem. Cycles* 24: GB2011.

Mayr, S., Schmid, P. & Beikircher, B. (2012): Plant Water Relations in Alpine Winter. *In* Plants in Alpine Regions. Ed. Lütz, C. Springer Vienna, pp 153-162.

Mayr, S., Wieser, G. & Bauer, H. (2006): Xylem temperatures during winter in conifers at the alpine timberline. *Agricultural and Forest Meteorology* 137: 81-88.

McCarroll, D. & Loader, N.J. (2004): Stable isotopes in tree rings. *Quaternary Science Reviews* 23: 771-801.

Miller, D.L., Mora, C.I., Grissino-Mayer, H.D., Mock, C.J., Uhle, M.E. & Sharp, Z. (2006): Tree-ring isotope records of tropical cyclone activity. *Proceedings of the National Academy of Sciences of the United States of America* 103: 14294-14297.

O'Driscoll, M.A., DeWalle, D.R., McGuire, K.J. & Gburek, W.J. (2005): Seasonal ^{18}O variations and groundwater recharge for three landscape types in central Pennsylvania, USA. *Journal of Hydrology* 303: 108-124.

Phillips, D.L. & Gregg, J.W. (2001): Uncertainty in source partitioning using stable isotopes. *Oecologia* 127: 171-179.

Poussart, P.F., Evans, M.N. & Schrag, D.P. (2004): Resolving seasonality in tropical trees: multi-decade, high-resolution oxygen and carbon isotope records from Indonesia and Thailand. *Earth and Planetary Science Letters* 218: 301-316.

Robertson, I., Waterhouse, J.S., Barker, A.C., Carter, A.H.C. & Switsur, V.R. (2001): Oxygen isotope ratios of oak in east England: implications for reconstructing the isotopic composition of precipitation. *Earth and Planetary Science Letters* 191: 21-31.

Roden, J.S., Lin, G. & Ehleringer, J.R. (2000): A mechanistic model for interpretation of hydrogen and oxygen isotope ratios in tree-ring cellulose. *Geochimica et Cosmochimica Acta* 64: 21-35.

Saurer, M., Aellen, K. & Siegwolf, R. (1997a): Correlating δ^{13}C and δ^{18}O in cellulose of trees. *Plant Cell and Environment* 20: 1543-1550.

Saurer, M., Borella, S. & Leuenberger, M. (1997b): δ^{18}O of tree rings of beech (*Fagus sylvatica*) as a record of δ^{18}O of the growing season precipitation. *Tellus B* 49: 80-92.

Teepe, R., Dilling, H. & Beese, F. (2003): Estimating water retention curves of forest soils from soil texture and bulk density. *Journal of Plant Nutrition and Soil Science* 166: 111-119.

Thimonier, A., Schmitt, M., Waldner, P. & Rihm, B. (2005): Atmospheric Deposition on Swiss Long-Term Forest Ecosystem Research (LWF) Plots. *Environmental Monitoring and Assessment* 104: 81-118.

Tranquillini, W. (1976): Water Relations and Alpine Timberline. *In* Water and Plant Life. Eds. Lange, O.L., Kappen, L. & Schulze, E.D. Springer Berlin Heidelberg, pp 473-491.

Treydte, K., Frank, D., Esper, J., Andreu, L., et al. (2007): Signal strength and climate calibration of a European tree-ring isotope network. *Geophys. Res. Lett.* 34: L24302.

Treydte, K.S., Schleser, G.H., Helle, G., Frank, D.C., Winiger, M., Haug, G.H. & Esper, J. (2006): The twentieth century was the wettest period in northern Pakistan over the past millennium. *Nature* 440: 1179-1182.

Valentini, R., Anfodillo, T. & Ehleringer, J.R. (1994): Water sources and carbon isotope composition (δ13C) of selected tree species of the Italian Alps. *Canadian Journal of Forest Research* 24: 1575-1578.

Yakir, D. & DeNiro, M.J. (1990): Oxygen and Hydrogen Isotope Fractionation during Cellulose Metabolism in *Lemna gibba* L. *Plant Physiology* 93: 325-332.

A novel approach for the preparation of high-resolution stable isotope records from tropical tree-rings

K. Schollaen, I. Heinrich & G. Helle

GFZ - German Research Centre for Geosciences, Section 5.2 Climate Dynamics and Landscape Evolution,
Telegrafenberg, 14473 Potsdam, Germany
E-mail: karina.schollaen@gfz-potsdam.de

Introduction

Stable isotopes (carbon, oxygen and hydrogen) from tree-rings are widely used in climate and environmental studies (e.g. Schleser et al. 1999, McCarroll & Loader 2004, Leavitt et al. 2007, Saurer et al. 2008, Hennig et al. 2011, Dorado Liñán et al. 2011, Schollaen et al. 2013). Physiological processes affecting isotope fractionation such as stomatal conductance and photosynthetic rate react sensitively to climatic and environmental factors during the year. To extract valuable seasonal climatic and environmental information high-resolution stable isotope analyses of tree rings are needed. To date, the common method to prepare intra-annual isotope samples is to divide tree rings in tangential sections using a fixed-blade sledge microtome (e.g. Loader et al. 1995, Helle & Schleser 2004, Verheyden et al. 2005), a scalpel (e.g. Roden et al. 2009) or a twist drill (Fichtler et al. 2010). Thereby, the rings were subdivided into segments of equal widths along a radial direction and thickness of tangential sections varies from 20 µm to 180 µm. Accurate sample adjustment, as well as correct identification of tree-ring borders was provided by visual inspection using a binocular or microscope. Wood samples were ground to a fine powder and either cellulose was extracted or bulk wood samples were used, as recent studies on isotopic differences of bulk wood and cellulose extraction report little or no differences in the variability of the isotope signal (Borella et al. 1998, Van de Water 2002, Loader et al. 2003, Verheyden et al. 2005, Taylor et al. 2008). Important for this method is the selection of parallel rings with almost straight tree-ring borders. As the curvature of growth rings varies under natural conditions, often only a limited number of consecutive rings per sample is suitable for high-resolution intra-annual isotope measurements. Another method for high-resolution stable isotope sampling is the use of a UV-laser ablation. Wood sample material from a tree core is extracted with an UV-laser leaving 40µm-wide holes (Schulze et al. 2004). Ablated wood dust is then combusted to CO_2, at 700°C, separated from other gases and injected into an isotope ratio mass spectrometer.

Here, we tested a new UV-laser microdissection system from LEICA (www.leica-microsystems.com). Laser microdissection (LMD) is a specific form of laser-assisted microdissection that uses an UV cutting laser to isolate tissues of interest from thin sections of biological samples, which are collected by gravity below the sample. LMD is being applied widely in biomedical research and also in animal and plant research (e.g. Nelson et al. 2006, Abbott et al. 2010). We present the use of an UV-Laser Microdissection Microscope (LMD) to prepare reliable high-precisely intra-annual wood samples. The design and the handling of this UV-Laser Microdissection Microscope for dendrochronological research is described. Advantages and constraints are discussed on the basis of high resolution stable isotope analyses on woody plant material of teak (*Tectona grandis*) samples from Indonesia.

Samples and Methods

Sample preparation

The wood material selected is from living tropical teak trees (*Tectona grandis*) at Java (Indonesia) collected with increment cores of 5 mm diameter. Firstly, the cores were cut in pieces of 5 cm length corresponding with the size of the object holders of the UV-Laser Microdissection

Microscope. Secondly, transverse or cross sections of approximately 500 µm thickness from sampled cores were cut with a core microtome (Gärtner & Nievergelt 2010). To prepare the wood surface for an effective cutting process the sample lies some hours in a glycerin solution to make the surface soft. At last, the cross-sections were fixed on special object holders (Fig.1), designed at the GFZ (German Research Centre for Geosciences) and treated under the LMD.

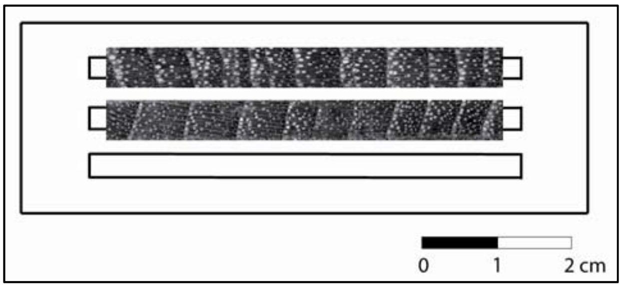


Figure 1: Object holder with wood samples. Tree-ring cross-sections are fixed between 2 metal frame slides, wherein up to three cross sections of 59 mm length can be mounted.

UV-Laser Microdissection Microscope

The UV-Laser Microdissection Microscope from LEICA (LMD 7000) enables the analyses of cells or tissues and is frequently used in biomedical research. Biological samples are viewed under an upright microscope, dissected via an UV-laser coming from above and collected into tubes by gravity (Fig. 2).

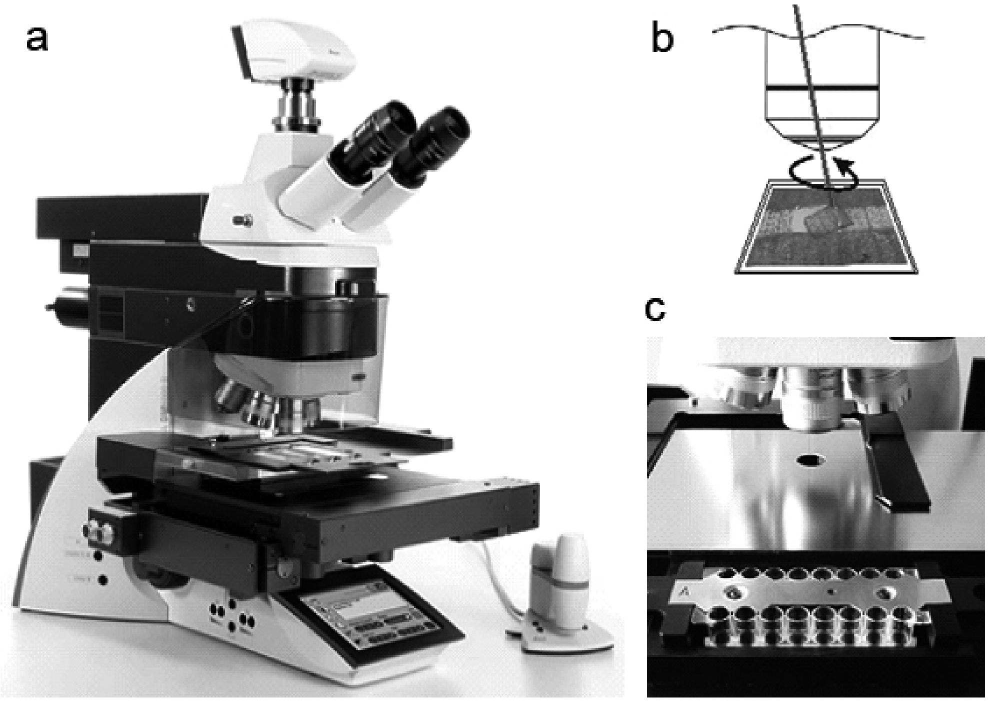


Figure 2: Leica LMD 7000, Research microscope with an UV-Microdissection Laser (a). Marked wood areas are cut by a moving UV-laser (b) and fell down by gravity into tin or silver capsules standing in a collection device (c).

This UV-laser is able to cut fast and easy dissections of tree-rings or/and parts thereof with contact- and contamination-free specimen collection. Cutting lines can be drawn accurate by mouse or with a pen-screen and dissectioning of areas of any size or shape is possible. This allows to exclude irrelevant areas as resin ducts or rays. Furthermore, it is possible to cut serial section or even to pool sample material, e.g. if the mass of the cut area is not sufficient for stable isotope measurements. The laser moves via optics and the cross section sample stays fixed. The dissected wood samples can be collected directly in thin or silver capsules for carbon and oxygen isotope analyses with conventional IRMS systems. The whole drawing and cutting process can be automatically documented (e.g. images, videos, database) for quality control.

Sample collection

The cross sections of approximately 500 µm thickness from teak cores are fixed in object holders and visualized under the microscope (magnification 5x, 10x). Several annual tree rings were graphically subdivided into segments, with the number of segments per year varying depending on the tree-ring width and sample mass for following stable isotope measurements (range from 10 to 40 segments per year). The scheme of the intra-annual sampling process is illustrated in Figure 3. Every drawn segment is dissected with the UV-laser and collected by gravity in single silver capsules standing in the collection holder. The laser dissection process from wood segment selection to the cutting process was documented with an image-database (IM500).

Finally, the dissected and collected wood segments were given in the Isotope Ratio Mass Spectrometer (IRMS) for δ^{18}O measurements. The mass of dissected samples varies from 80 µg to 220 µg.

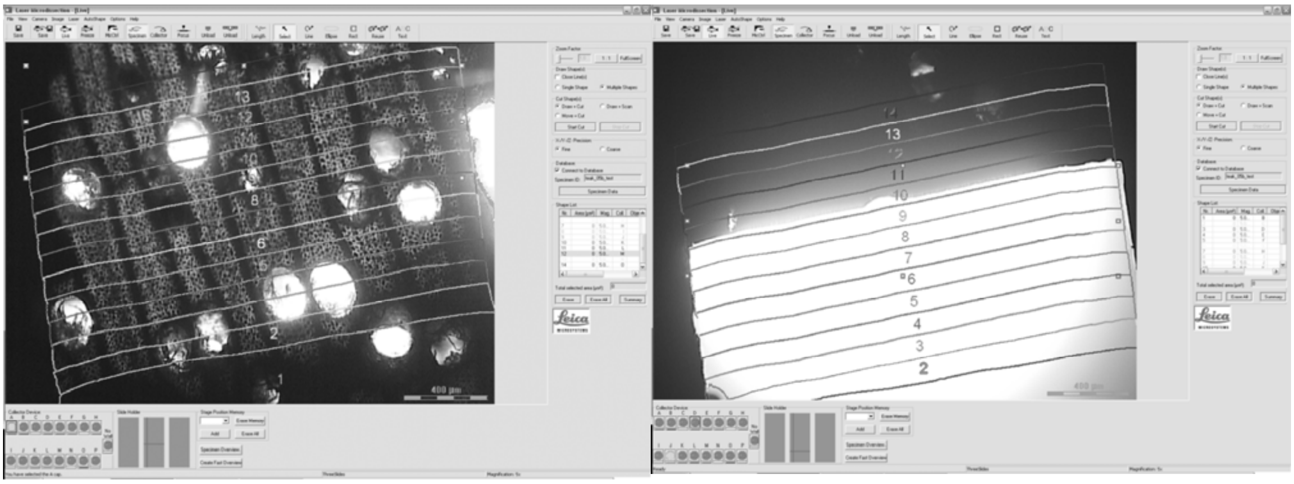


Figure 3: Left part: Selected segments (numbered 1,2,3, etc.) within one teak tree-ring for cutting process with an UV-Laser Microdissection Microscope (LMD 7000, Leica). Right part: Cutting process with the first 10 parts already cut and fallen down in separate collector devices.

Results and Discussion

High-resolution intra-annual δ^{18}O variations

The δ^{18}O profile shows a clear annual cycle. Wood formation starts with a parenchyma band showing δ^{18}O values that are similar to the δ^{18}O values at the end of the previous ring. Then the δ^{18}O values are rising up to a seasonal maximum appearing early in the growing season. This δ^{18}O maximum is followed by a decline to a seasonal minimum typically in the 2nd third of each tree ring before δ^{18}O is marginally rising again in the last third of the growing season. The annual δ^{18}O pattern follows the annual cycle in rainfall amount and its corresponding isotope signature at this site (Schollaen et al. 2013). High tree-ring δ^{18}O values during the start of the growing season represent the δ^{18}O signature in precipitation of the prior dry season. Low tree-ring δ^{18}O values reveal the δ^{18}O signature in precipitation of the main rainy season. To our knowledge, this is the first time that intra-annual $\delta^{18}O$ values in tropical trees can reflect the rainfall pattern over an entire year with distinct rainy and dry season signals.

As AD 1987 shows, less than 10 data points per tree ring are mostly not sufficient to produce reliable intra-annual variations. Minimum 10 data points per tree ring are recommended to illustrate high-resolution intra-annual stable isotope records.

This result shows the crucial value of the new dissection method as it allows for new approaches towards high-resolution isotope chronologies.

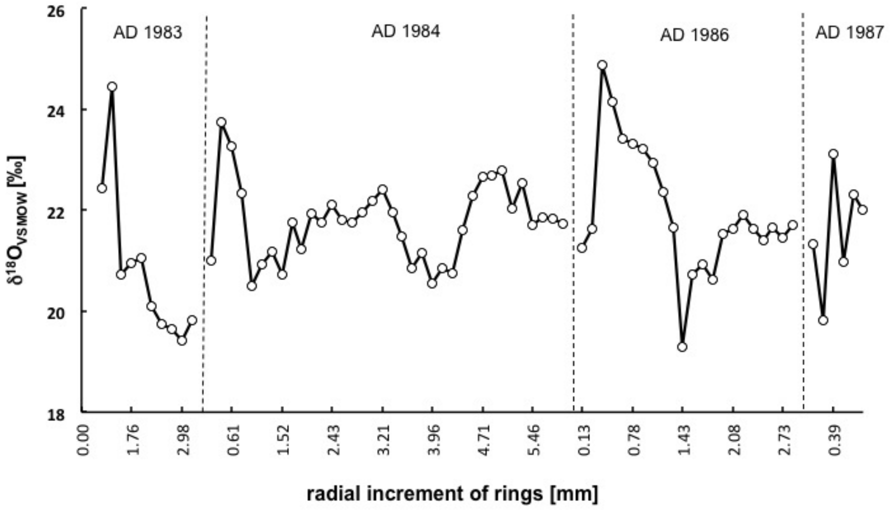


Figure 4: Intra-annual $\delta^{18}O$ variations from tree core 15b collected at Java, Indonesia, plotted vs. radial increment of the particular tree ring. The data points represent the number of segments dissected per tree ring. This isotopic cycle is hypothesized to reflect the annual cycle in rainfall amount and humidity at this location (Schollaen et al. 2013).

Evaluation of the laser microdissection from Leica (LMD 7000)

The automatic high-precision laser dissection tool is a fast and reliable method for preparing high-resolution wood samples. The LMD can be used for inter-and intra-annual carbon and oxygen stable isotopes investigations on tree rings. Our current measurement scheme contains 3 steps:

1. Preparation of thin cross sections (max. 1000 µm thickness),
2. UV-laser microdissection of inter-or intra-annual wood sections and
3. Stable carbon and oxygen isotope analysis via Isotope Ratio Mass Spectrometry (IRMS).

There are several advantages using the LMD: Relevant cells/tissues can be selected on screen by pen, where else non-relevant tissues (e.g. resin ducts) can be removed. Any size and area can be dissected by the UV-laser and the complete selected sample is recovered. In addition, samples can be pooled and if desired cellulose extraction is possible after the cutting process. The use of thin cross sections leaves the core intact and provides the opportunity for other dendrochronological investigations. Furthermore, there is a detailed documentation of the dissecting and cutting process. The laser dissection method avoids several disadvantages of the laser ablation method where spot size is limited, the loss of particles is >60µm (dust filter) and no online monitoring of the laser ablation process is possible (Schulze et al. 2004).

Limitation of the LMD system is a non-automatic z-focus. When the selected shape does not fall down after the cutting process, a new cutting process must be started manually. The LEICA system uses high-precision optics to steer the laser beam using prisms along the desired cut lines on the tissue. This involves the limitation that the laser can only cut drawn lines/areas marked on the visible screen. If larger areas should be dissected a new shape must be drawn and a new cutting process must be started. However, pooling of selected specimen solve this limitation.

Conclusion and Applications

The automatic UV-laser dissection system (LMD7000, LEICA Microsystems) allows the user to cut samples of wood at unprecedented precision. Here, we tested the LMD tool as a fast and reliable method for preparing high-resolution intra-annual wood samples from tropical trees for standard stable isotope measurements. The new technique facilitates inter-and intra-annual tree-ring analysis and opens various possibilities for wood anatomical and plant physiological studies. For instance, detailed assessment of carbon and oxygen isotope variability in wooden parts such as resin ducts, rays, fibres vessels or parenchyma cells are possible. Plant structure in relation to plant functioning by combining wood anatomy and stable isotope analysis can be evaluated. Furthermore, the UV-laser microdissection system facilitates the establishment of long and continuous high-resolution isotope chronologies for high quality climate reconstructions. Multidisciplinary analyses (e.g. wood density, wood chemistry analyses) on the same wood sample are now possible with a complete recovery of the sample due to the use of thin cross sections.

References

Abbott, E., Hall, D., Hamberger, B., Bohlmann, J. (2010): Laser microdissection of conifer stem tissues: isolation and analysis of high quality RNA, terpene synthase enzyme activity and terpenoid metabolites from resin ducts and cambial zone tissue of white spruce (*Picea glauca*). BMC Plant Biol 10: 106.

Borella, S., Leuenberger, M., Saurer, M., Siegwolf, R. (1998): Reducing uncertainties in δ^{13}C analysis of tree rings: Pooling, milling, and cellulose extraction. *Journal of Geophysical Research* 103:19519-19526

Dorado Liñán, I., Gutiérrez, E., Helle, G., Heinrich, I., Andreu-Hayles, L., Planells, O., Leuenberger, M., Bürger, C., Schleser, G. (2011): Pooled versus separate measurements of tree-ring stable isotopes. *Science of the Total Environment* 409(11): 2244-2251.

Fichtler, E., Helle, G., Worbes, M. (2010): Stable-Carbon Isotope Time Series from Tropical Tree Rings Indicate a Precipitation Signal. *Tree-Ring Research* 66(1): 35-49.

Gärtner. H., Nievergelt, D. (2010): The core-microtome: A new tool for surface preparation on cores and time series analysis of varying cell parameters. *Dendrochronologia* 28: 85-92.

Helle, G., Schleser, G. (2004): Beyond CO2-fixation by Rubisco – an interpretation of ^{13}C/^{12}C variations in tree rings from novel intra-seasonal studies on broad-leaf trees. *Plant, Cell & Environment* 27(3): 367-380.

Hennig, K., Helle, G., Heinrich, I., Neuwirth, B., Karyanto, O., Winiger, M. (2011): Toward multi-parameter records (ring width, δ^{13}C, δ^{18}O) from tropical tree-rings - A case study on *Tectona grandis* from Java, Indonesia. *TRACE - Tree Rings in Archaeology, Climatology and Ecology*, Vol. 9, 158-165.

Loader, N. J., Switsur, V.R., Field, E.M. (1995): High-resolution stable isotope analysis of tree rings: implications of "microdendroclimatology" for palaeoenvironmental research. *The Holocene* 5(4): 457-460.

Loader, N. J., Robertson, I., McCarroll, D. (2003): Comparison of stable carbon isotope ratios in the whole wood, cellulose and lignin of oak tree-rings. *Palaeogeoraphy Palaeoclimatology Palaeoecology* 196:395–407.

Leavitt, S. W., T. N. Chase, et al. (2007): Southwestern U.S. Drought Maps from pinyon tree-ring carbon isotopes. *EOS* 88 (4): 39-40.

McCarroll, D. and N. J. Loader (2004): Stable isotopes in tree rings. *Quaternary Science Reviews* 23(7-8): 771-801.

Nelson, T., Tausta, SL., Gandotra, N., Liu, T. (2006): Laser microdissection of plant tissue: what you see is what you get. *Annu Rev Plant Biol* 57**:**181-201.

Saurer, M., Cherubini, P., Reynolds-Henne, C. E., Treydte, K. S., Anderson, W. T., Siegwolf, R. T. W. (2008): An investigation of the common signal in tree ring stable isotope chronologies at temperate sites. *Journal of Geophysical Research-Biogeosciences* 113(G4).

Schleser, G. H., Helle, G., Lücke, A., Vos, H. (1999): Isotope signals as climate proxies: the role of transfer functions in the study of terrestrial archives. *Quaternary Science Reviews* 18(7): 927-943.

Schollaen, K., Heinrich, I., Neuwirth, B., Krusic, P.J., D'Arrigo, R.D., Karyanto, O., Helle, G. (2013): Multiple tree-ring chronologies (ring width, $\delta^{13}C$ and $\delta^{18}O$) reveal dry and rainy season signals of rainfall in Indonesia. *Quaternary Science Reviews* 73(0): 170-181.

Schulze, B., Wirth, C., Linke, P., Brand, W. A., Kuhlmann, I., Horna, V., Schulze, E. D. (2004): Laser ablation-combustion-GC-IRMS - a new method for online analysis of intra-annual variation of delta C-13 in tree rings. *Tree Physiology* 24(11): 1193-1201.

Taylor, AM., Renée Brooks, J., Lachenbruch, B., Morrell, JJ., Voelker, S. (2008): Correlation of carbon isotope ratios in the cellulose and wood extractives of Douglas-fir. *Dendrochronologia* 26:125-131.

Van de Water, P. K. (2002): The effect of chemical processing on the $\delta^{13}C$ value of plant tissue. *Geochimica et Cosmochimica Acta* 66:1211–1219.

Verheyden, A., Roggeman, M., Bouillon, S., Elskens, M., Beeckman, H., Koedam, N. (2005): Comparison between $\delta^{13}C$ of α-cellulose and bulk wood in the mangrove tree Rhizophora mucronata: Implications for dendrochemistry. *Chemical Geology* 219:275-282.

Trends and signals in decadally resolved carbon isotopes from the Spanish Pyrenees

O. Konter [1], S. Holzkämper [1+2], G. Helle [3], U. Büntgen [4] & J. Esper [1]

[1] *Department of Geography, Johannes Gutenberg University, Becherweg 21, 55099 Mainz, Germany*
[2] *Department of Physical Geography and Quaternary Geology, Stockholm University, 10691 Stockholm, Sweden*
[3] *German Centre for Geosciences, Climate Dynamics and Landscape Evolution, Dendro Laboratory, Potsdam, Germany*
[4] *Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland*
E-mail: o.konter@geo.uni-mainz.de

Introduction

The Mediterranean Basin is considered to be a hotspot of global warming, associated with severe impacts on both bio-ecological and socio-economical systems (IPCC 2007). Several dendroclimatological studies have been carried out in the Pyrenees, where robust temperature signals are predominantly retained from nearby altitudinal treeline ecotones (Büntgen et al. 2010). Büntgen et al. (2008) analyzed maximum latewood densities (MXD) from a high-elevation sampling site in the Spanish Pyrenees and reconstructed May-September temperatures back to medieval times. Despite the commonly used tree ring width (TRW) and MXD parameters (Büntgen et al. 2010, Dorado Liñán et al. 2012), carbon isotopic ratios also showed promising results in different locations and became an important proxy of past climate variability (overview in Treydte et al. 2007). In the Pyrenees, climatic signals retained in stable carbon isotopes include both summer precipitation and temperature (Andreu et al. 2008, Dorado Liñán et al. 2011). Carbon fractionation procedures within trees and their impact on low-frequency trends are not well understood, as variations in the amount and isotopic composition of atmospheric CO_2 as well as climate variations are simultaneously incorporated in tree rings (Farquhar et al. 1982, Feng & Epstein 1995, Kürschner 1996, Treydte et al. 2004, McCarroll & Loader 2004, Helle & Schleser 2004). Analyses of low-frequency changes in tree ring stable isotopes are constrained by the work load required to produce annually resolved $\delta^{13}C$ and $\delta^{18}O$ time series from single trees. Esper et al. (2010) established decadally resolved, millennial-length $\delta^{13}C$ and $\delta^{18}O$ records to analyze long-term trends in tree ring isotope data. These data have, however, not being calibrated against instrumental time series, a procedure explored here.

We present six decadally resolved carbon isotope records spanning the 1901-2009 period, derived from *Pinus uncinata* trees originating from the same sampling site as used in Esper et al. (2010). These single-tree $\delta^{13}C_{raw}$ time series are transformed considering various correction methods (Feng & Epstein 1995, Kürschner 1996, McCarroll & Loader 2004) and calibrated against climate data to assess the reconstruction potential of the millennial-length carbon isotope data from the region.

Material and Methods

Study site and sampling strategy

The altitude of the selected treeline site, located near Gerber Lake at the northern border of the "D'Aigüestortes Estany de Sant Maurici" Spanish National Park in the Central Pyrenees, west of Andorra, ranges from 2314 to 2380 m asl. The prevailing tree species is *Pinus uncinata*, a shade-intolerant conifer tree in the open forest ecotone. Tree height varies between 3-6 m, and diameter at breast height ranges from 0.25-1.08 m.

In June 2010 twenty-three *Pinus uncinata* trees were selected at the aforementioned treeline site. The selection of the pine individuals was based on the estimated tree ages, to establish a dataset including only trees of similar or comparable age throughout the calibration period. Since dry-dead

DOI: 10.2312/GFZ.b103-13058

material was rare, the selection focused on material from living trees. The sampled trees have no access to ground water.

Four cores (0.5 cm diameter) were sampled from each tree in a radial configuration at breast height, two diametrically parallel and two diametrically perpendicular to the slope, whenever possible.

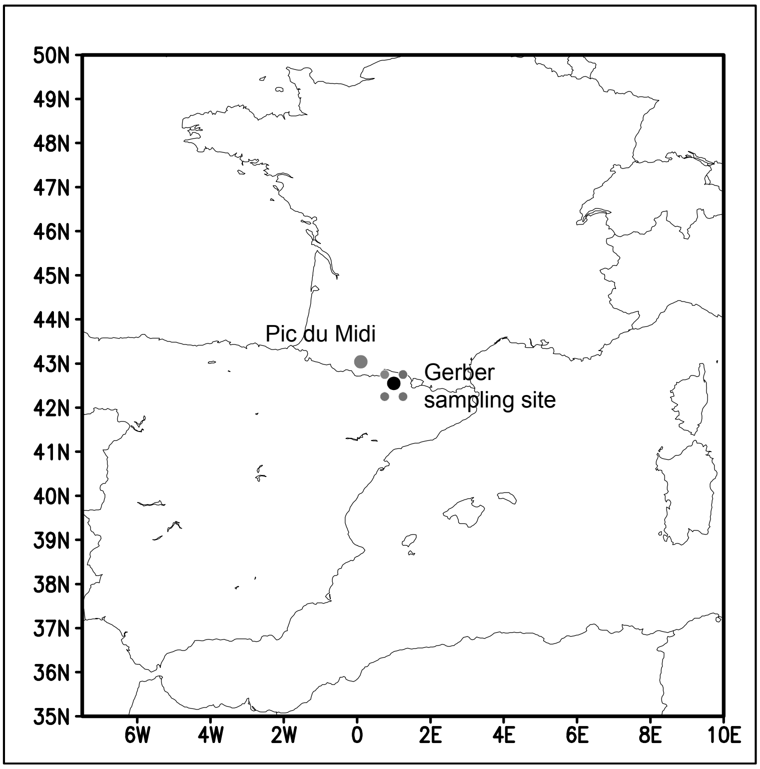


Figure 1: Study area; Gerber sampling site shown in black, gridded climate data in grey, and Pic du Midi station in grey (large dot).

Tree ring width and stable isotope measurements

Core samples were cut lengthwise and vertically to the wood fiber to maintain plain surfaces. Tree ring widths were measured using TSAP-WinTM Professional (Rinn et al. 2007), cross-dated using CoFecha (Holmes 1983), and detrended using the Regional Curve Standardization technique (RCS, Esper et al. 2003) within ARSTAN (Cook 1985).

A subset of six trees was selected and each tree ring, from 1901-2009, sectioned with a scalpel. For isotopic measurements, two core samples were merged to represent a single tree, i.e. two cut samples (from the same year) were joined. From this basic wood material α-cellulose was extracted following procedures established by Green (1963) and advanced by Loader (1996). Homogenization of the α-cellulose samples was achieved by using an ultrasonic technique (Laumer et al. 2009). Samples were freeze-dried prior to analyzing carbon isotope ratios using an IsoPrime (GV Instruments, Manchester, UK) Isotope Ratio Mass Spectrometer (IRMS) with an interfaced elemental analyzer (Fisons NA 1500 NC) on a continuous carrier gas flow, operated at the *GeoForschungsZentrum (GFZ) Potsdam*.

The resulting annual values, expressed relative to the international VPDB standard in per mill (‰), were transformed to decadal, no mass weighted values by calculating 10-year-means (1901-1910,..., 1991-2000; except 2001-2009 representing only 9 values) to transform the explored climate signal to the millennial long, decadally resolved time series displayed in Esper et al. (2010). Six δ^{13}C time series representing individual trees (two radii per tree) and consisting of eleven decadal values from 1901 to 2009 are used in this assessment.

Physiological fractionation and correction

Anthropogenic fossil fuel burning since the beginning of industrialization has lead to a declining trend of $\delta^{13}C$ in atmospheric CO_2 and is also reflected in tree ring $\delta^{13}C_{raw}$ values (Farquhar et al. 1982, McCarroll & Loader 2004, Treydte et al. 2007). This non-climatic decreasing trend inherent in the tree ring data is corrected by applying a procedure detailed in McCarroll and Loader (2004); the dataset is referred to as $\delta^{13}C_{atm}$ hereinafter. As the increased atmospheric CO_2 concentration also influences plant metabolism – through stronger discrimination against the heavier ^{13}C isotope – we additionally corrected the $\delta^{13}C_{raw}$ values following suggestions by Kürschner (1996, hereinafter $\delta^{13}C_K$) and Feng & Epstein et al. (1995, hereinafter $\delta^{13}C_{FE}$).

Climate data and calibration

Climate signals of the TRW, $\delta^{13}C_{atm}$, $\delta^{13}C_K$, and, $\delta^{13}C_{FE}$ were assessed using Pearson product-moment correlation coefficients calculated over the 1901-2009 period, including 11 decadal values. Temperature data from the Pic du Midi station (2,862m asl, 43°04'N, 0°09'E), and gridded precipitation (CRU TS 3.1, Mitchell & Jones 2005) and PDSI data (Dai et al. 2004) are considered. To calibrate climate data against the decadally resolved isotope data, decadal arithmetic means were calculated for all climate variables. Since the availability of climate data of the most recent decade varies (temperature 1901-2005, precipitation 1901-2009, PDSI 1901-2005), the period from 2001-2009 represents varying number of values (temperature: 5 values, precipitation: 9 values, PDSI: 5 values).

Results and Discussion

Stable isotope data

The individual stable isotope time series show a remarkable offset among single trees (Fig. 2). Mean values of single trees range from -21.75 ‰ to -23.90 ‰ ($\delta^{13}C_{raw}$) and offsets increase up to >3 ‰ during several periods. Whereas these differences do not alter substantially in the different corrections, interseries correlations increase from 0.23 for $\delta^{13}C_{atm}$ to 0.69 for $\delta^{13}C_K$ and 0.93 for $\delta^{13}C_{FE}$. These changes are associated with the common and most important increasing trends added throughout the corrections. The common declining trend inherent in $\delta^{13}C_{raw}$ is removed in the $\delta^{13}C_{atm}$ data. The additional correction for physiological fractionations caused an overall positive low-frequency trend in $\delta^{13}C_K$ – and even more so in $\delta^{13}C_{FE}$, altering the correlations to eventually > 0.9.

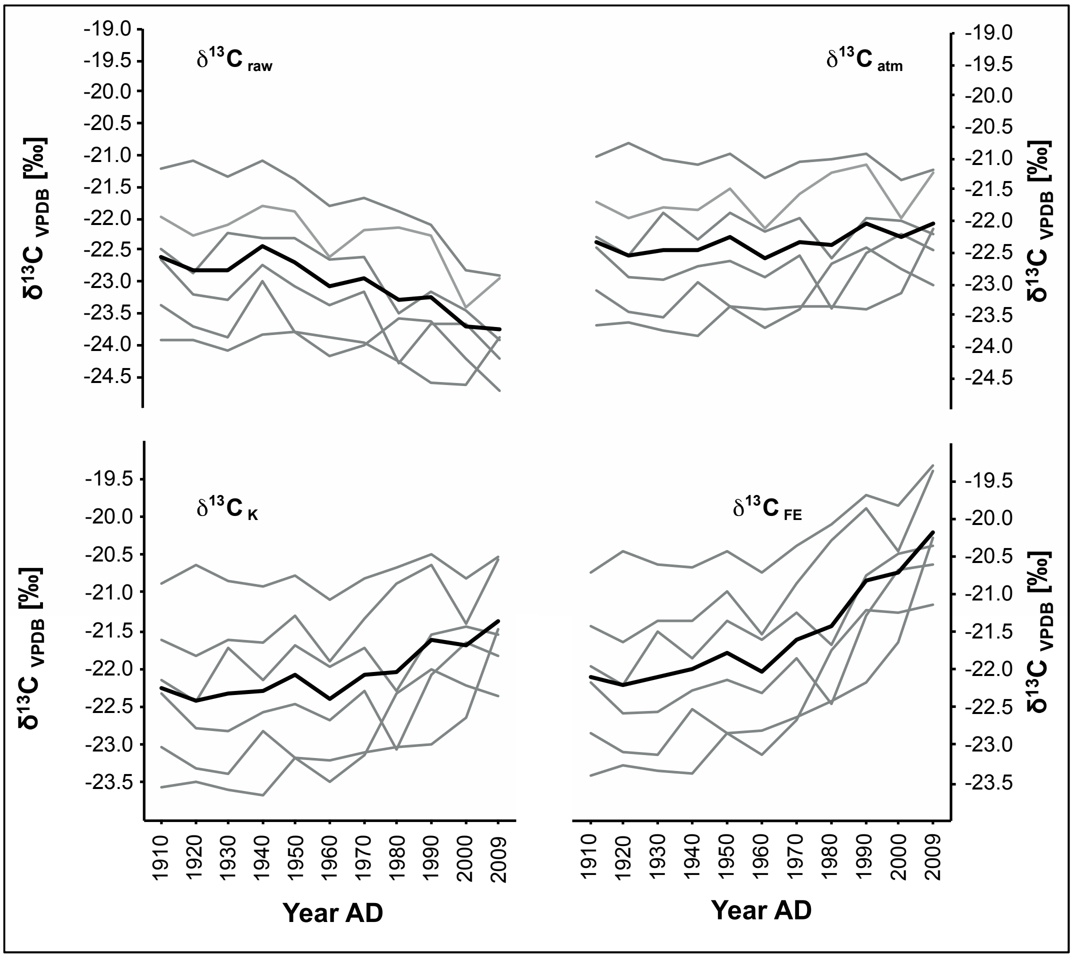


Figure 2: Decadally resolved carbon isotope data. Grey lines indicate individual trees, black lines their arithmetic means, for the $\delta^{13}C_{raw}$, $\delta^{13}C_{atm}$, $\delta^{13}C_{K}$, and $\delta^{13}C_{FE}$ data.

Climate signals

Since the $\delta^{13}C_{raw}$ data contain a well-known non-climatic trend, climate/growth relationships are estimated between $\delta^{13}C_{atm}$, $\delta^{13}C_{K}$, $\delta^{13}C_{FE}$ and monthly temperature anomalies, precipitation sums, and mean PDSI values (Fig. 3). Most significant results are revealed among the carbon isotope data and summer temperatures, particularly during July ($p < 0.001$). The strongest association is detected between $\delta^{13}C_{K}$ and July-September mean temperatures (r=0.94, 1901-2009 period). Whereas the influence of precipitation seems overall negligible (except for a 95% significant signal in April), PDSI shows coherent negative correlations up to r=-0.88 ($p < 0.001$) likely driven by the longer-term temperature variations.

The strong coherence between $\delta^{13}C_{FE}$ and (summer) temperatures points to the low-frequency trends, inherent in temperature and largely absent from precipitation, as the key variable influencing the correlation results. The relationships between carbon isotope and climate data vary according to their low-frequency loadings: $\delta^{13}C_{FE}$ (in contrast to $\delta^{13}C_{atm}$) correlates significantly with PDSI due to the common low-frequency trends inherent in both datasets. Consequently, $\delta^{13}C_{atm}$ correlates better with precipitation, compared to $\delta^{13}C_{K}$ and $\delta^{13}C_{FE}$. All significance levels mentioned in the text are not corrected for lag-1 autocorrelation, which are 0.23 for $\delta^{13}C_{atm}$, 0.76 for $\delta^{13}C_{K}$, 0.93 for $\delta^{13}C_{FE}$, and 0.47 for July-September mean temperature, for example. After reduction of the degrees of freedom due to lag-1 autocorrelation, $\delta^{13}C_{atm}$ values still exceed the 99.9 % confidence level when correlated with July-September temperatures (r=0.90), in contrast to $\delta^{13}C_{K}$ and $\delta^{13}C_{FE}$ data.

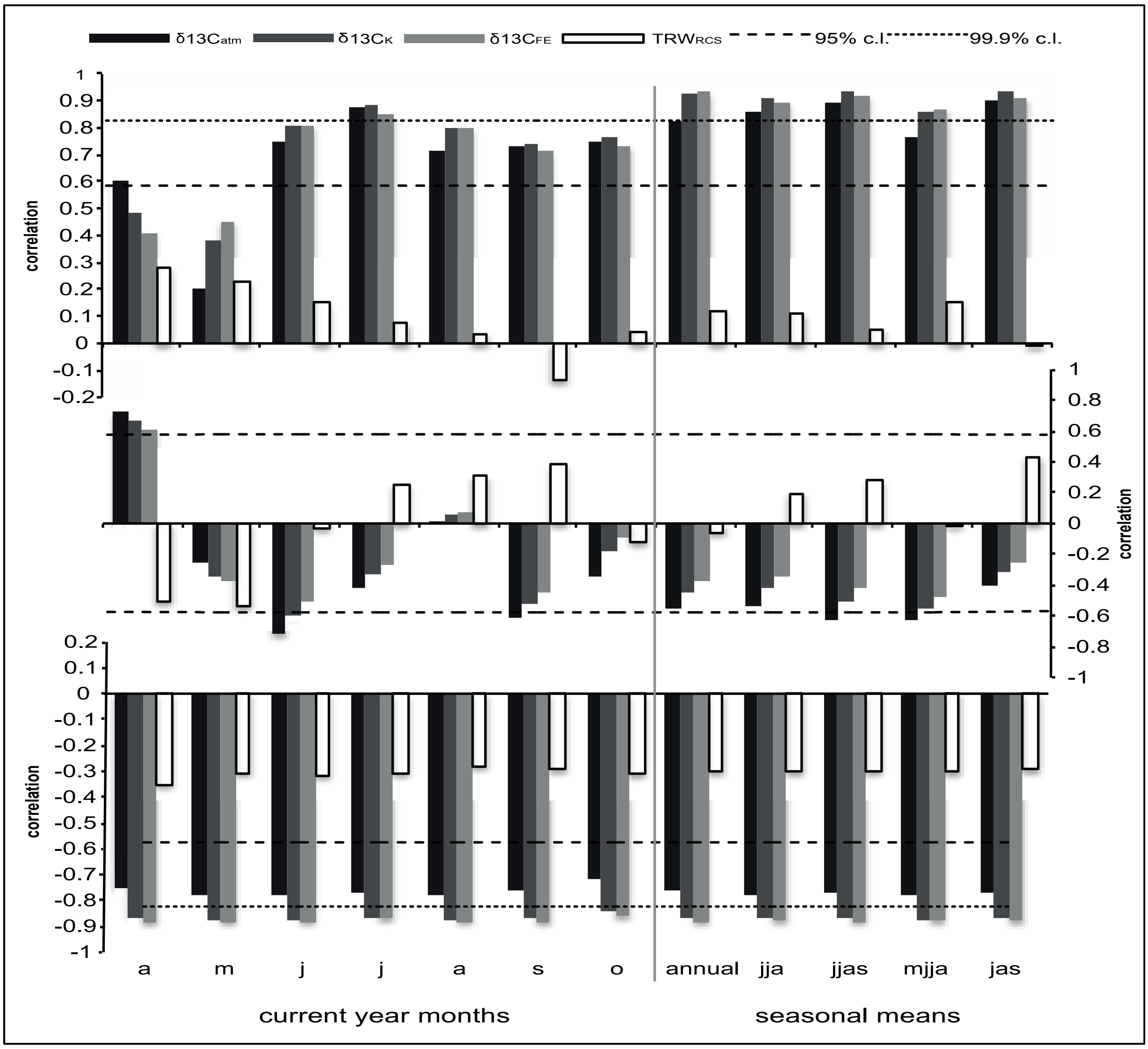


Figure 3: Growth-climate relationships. Monthly and seasonal correlation coefficients between δ $^{13}C_{atm}$ (black), $\delta^{13}C_K$ (grey), and $\delta^{13}C_{FE}$ (light grey) versus temperature (top panel), precipitation (middle), and PDSI (bottom) over the 1901-2009 period. Dashed curves indicate the 95% (bold) and 99% significance levels. These are not corrected for lag-1 autocorrelation effects; for corrected values, see text.

Spurious trends

The inter-tree offsets shown in this study do not alter the mean values functions (the chronologies), since replication (n=6) does not change throughout the calibration period (1901-2009). However, an inter-tree range of 2-3 ‰ can cause spurious trends within carbon isotope datasets, if replication changes over time – which is a typical feature of longer term tree ring records (Esper et al. 2002). To illustrate this effect, we omitted the first three decadal sets of two individual time series and additionally the last three decadal sets of two different time series, as if the dataset would contain two individuals covering the 1901-1980 period and two individuals covering the 1940-2009 period (as well as two trees covering the full 1901-2009 period) (Fig. 4). The replication of this new data is consequently reduced from six to four trees at the beginning (1901-1930) and the end (1980-2009) of the calibration period, which still is considered to be an adequate and representative amount of individuals for isotope based climate evaluations (Leavitt and Long 1984). During the period represented by all individuals (1940-1980) the original data and mean remain unaltered. This setup mirrors tree core composition and age structure changes typical to long-term chronologies (Treydte et al. 2009, Seftigen et al. 2011, Gagen et al. 2011). The resulting mean chronologies (see the black curves in Fig. 4), however, indicate entirely different low-frequency trends as a result of our data treatment. These spurious trends are the consequence of the substantial level differences of individual stable carbon isotope time series that do not cover the exact same period. The cause for these differing trends would remain unknown – and the trends perhaps interpreted as environmental signals – if the wood samples would have been pooled before isotope measurement. Removing the substantial level differences of individual time series by calculating anomalies to the individual mean values prior to producing a chronology could contribute to verify trends inherent in the data and, thus, could help to avoid discarding data of low-replicated periods.

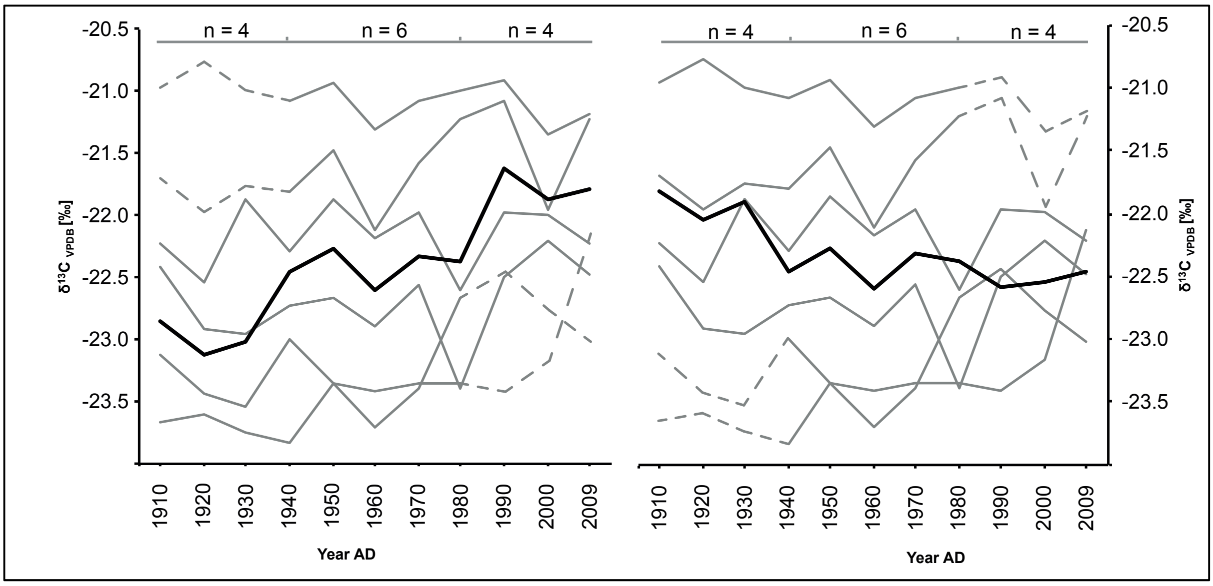


Figure 4: Changing $\delta^{13}C_{atm}$ mean curves (black) as a consequence of removing decadal sets of individual trees (grey, see main text). Dashed lines indicate omitted data; left panel: early high and late low decadal values of two individual time series omitted; right panel: early low and late high decadal values of two individual time series omitted.

Conclusions

Decadally resolved carbon isotope measurements capture climate signals in the 20th century, enabling a calibration setup for reconstruction purposes. Especially summer temperature variations are reflected in tree ring stable carbon isotopes, displayed in correlation values of $r=0.90$ ($p<0.001$) between July-September temperature anomalies and $\delta^{13}C_{atm}$ values. Stomata aperture and subsequent isotopic fractionation in the leaves are driven by temperature, while precipitation is of a minor importance to the pine trees from the high-elevation Gerber site.

Commonly applied corrections of the carbon isotope data increase the low-frequency trends of $\delta^{13}C$ time series. The increased trends alter the relationship to climate indices: $\delta^{13}C_K$ and $\delta^{13}C_{FE}$ show higher correlations to climate indices that also incorporate low-frequency trends. The increasing autocorrelation affect the degrees of freedom, however, a feature that is particularly significant with decadally resolved data.

More analyses of the physiological processes are needed to clarify which correction is indeed recommended. In the Spanish Pyrenees, the Kürschner approach ($\delta^{13}C_K$) results in the closest association with temperature data, while the Feng & Epstein approach ($\delta^{13}C_{FE}$) seems to overestimate the low-frequency trend compared to temperature.

Low-frequency trends within carbon isotope data can also be caused by changes in replication and need careful analyses. In this study, tree replication is stable (n = 6) over the entire 1901-2009 calibration period. It is concluded that the displayed low-frequency stable carbon isotope trends reflect the increasing temperatures since the beginning of the 20th century.

References

Andreu, L., Planells, O., Gutierrez, E., Helle, G., Schleser, G.H. (2008): Climatic significance of tree ring width and $\delta^{13}C$ in a Spanish pine forest network. Tellus B 60, 771-781.

Büntgen, U., Frank, D., Grudd, H., Esper, J. (2008): Long-term summer temperature variations in the Pyrenees. Climate Dynamics 31: 615-631.

Büntgen, U., Frank, D.C., Trouet, V., Esper, J. (2010): Diverse climate sensitivity of Mediterranean tree ring width and density. Trees 24: 261-273.

Briffa, K.R., Jones, P.D., Bartholin, T.S., Eckstein, D., Schweingruber, F.H., Karlén, W., Zetterberg, P., Eronen, M. (1992): Fennoscandiansummers from AD 500: temperature changes on short and long timescales. Climate Dynamics 7: 111–119.

Cook, E. R. (1985), A time series analysis approach to tree ring standardization, Ph.D. dissertation, 171 pp., Univ. of Ariz., Tucson.

Dai, A., Trenberth, K. E, Qian, T. (2004): A global dataset of Palmer Drought Severity Index for 1870–2002: Relationship with soil moistureand effects of surface warming. Journal of Hydrometeorolgy 5: 1117-1130.

Dorado Liñán, I., Gutiérrez, E., Heinrich, I., Andreu-Hayles, A., Muntán, E., Campelo, F., Helle, G. (2011): Age effects and climate response in trees: a multi-proxy tree ring test in old-growth life stages. European Journal of Forest Research 131: 933-944.

Dorado Liñán, I., Büntgen, U., Gonzalez-Rouco, F., Zorita, E., Montavez, J.P., Gomez-Navarro, J.J., Brunet, M., Heinrich, I., Helle, G., Gutiérrez, E. (2012): Estimating 750 years of temperature variations and uncertainties in the Pyrenees by tree ring reconstructions and climate simulations. *Climate of the Past* 8: 919-933.

Esper, J., Cook, E.R., Schweingruber, F.H. (2002): Low-frequency signals in long tree ring chronologies and the reconstruction of past temperature variability. Science 295: 2250-2253.

Esper, J., Cook, E.R., Krusic, P.J., Peters, K., Schweingruber, F.H. (2003): Tests of the RCS method for preserving low-frequency variability in long tree ring chronologies. Tree ring Research 59: 81-98.

Esper, J., Frank, D.C., Battipaglia, G., Büntgen, U., Holert, C., Treydte, K., Siegwolf, R., Saurer, M. (2010): Low-frequency noise in $ð^{13}C$ and $ð^{18}O$ tree ring data: A case study of Pinus uncinata in the Spanish Pyrenees. Global Biochemical Cycles 24: doi: 10.1029/2010GB0037772.

Farquhar, G.D., O'Leary, M.H., Berry, J.A. (1982): On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Australian Journal of Plant Physiology 9: 121-137.

Feng, X., Epstein, S. (1995): Carbon isotopes of trees from aridenvironments and implications for reconstructing atmospheric CO2 concentration. Geochimica et Cosmochimica Acta 59, 12: 2599–2608.

Fritts, H.C. (1976): Tree Rings and Climate. Blackburn Press. 567 p.

Gagen, M., Zorita, E., McCarroll, D., Young, G.H.F., Grudd, H., Jalkanen, R., Loader, N., Robertson, I., Kirchhefer (2011): Cloud response to summer temperatures in Fennoscandia over the last thousand years. Geophysical Research Letters 38: doi: 10.1029/2010GL046216, 2011.

Green, J.W. (1963): Wood Cellulose. In Whistler, R.L. (Ed.), Methods of Carbohydrate Chemistry III. Academic Press. pp. 9-21.

Helle, G., Schleser, G.H. (2004): Interpreting climate proxies from tree rings. In: Fischer, H., Floeser, G., Kumke, T., Lohmann, G., Miller, H., Negendank, J.F.W., von Storch, H. (Eds.), The climate in Historical Times, Towards a synthesis of Holocene proxy data and climate models. Springer Verlag. pp. 129-148.

Holmes, R.L. (1983): Computer-assisted quality control in tree ring dating and measurement.Tree ring Bulletin 43, 69-78.

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

Kürschner, K. (1996): Leaf stomata as biosensors of paleoatmosphericCO2 levels. Utrecht, 160 p.

Laumer, W.; Andreu, L.; Helle, G.; Schleser, G. H.; Wieloch, T.; Wissel, H. (2009): A novel approach for the homogenization of cellulose to use micro-amounts for stable isotope analyses. Rapid Communications in Mass Spectrometry 23, 13: 1934-1940.

Leavitt, S.W., Long, A (1984): Sampling strategy for stable isotope analysis of tree rings in pine. Nature 311: 145-147.

Loader, N.J., Robertson, I., Barker, A.C., Switsur, V.R., Waterhouse, J.S. (1997): An improved technique for the batch processing of small wholewood samples to α-cellulose. Chemical Geology 136, 313-317.

McCarroll, D., Loader, N.J. (2004): Stable isotopes in tree rings. Quaternary Science Reviews 23: 771-801.

Mitchell, T.D., Jones, P.D. (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int. J. Climatology 25: 693-712, Doi: 10.1002/joc.1181.

Rinn, F., 2007. TSAP - WinTM Professional. Zeitreihenanalyse und Präsentation für Dendrochronologie und verwandte Anwendungen. Benutzerhandbuch, Heidelberg: 56 pp.

Seftigen, K., Linderholm, H.W., Loader, N., Liu, Y., Young, G.H.F. (2011): The influence of climate on $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios in tree ring cellulose of Pinus sylvestris L. growing in the central Scandinavian Mountains. Chemical Geology 286: 84-93.

Treydte, K., et al. (2007): Signal strength and climate calibration of a European tree ring isotope network, Geophysical Research Letter, 34: doi: 10.1029/2007GL031106.

Treydte, K., Frank, D.C., Saurer, M., Helle, G., Schleser, G.H., Esper, J. (2009): Impact of climate and CO_2 on a millennium-long tree ring carbon isotope record. Geochimica et Cosmochimica Acta 71: 4635-4647.

Testing the influence of graphite and gypsum markings on stable isotope values ($\delta^{13}C$, $\delta^{18}O$) of tropical tree rings

K. Schollaen & G. Helle

GFZ - German Research Centre for Geosciences, Section 5.2 Climate Dynamics and Landscape Evolution,Telegrafenberg, 14473 Potsdam, Germany
E-mail: karina.schollaen@gfz-potsdam.de

Introduction

Tree-ring parameters (e.g. ring-width, stable isotopes) are one of the most important outputs from climate archives because of their precisely dated and annually resolved information. Tree-ring stable isotope records usually show higher signal strengths than tree-ring widths (e.g. Gagen et al. 2011, Schollaen et al. 2013). A careful wood surface preparation is an essential precondition for dendrochronological studies, since dating errors can not be corrected afterwards. Normally, when tree-ring samples are used for stable isotope analysis carbonaceous or oxygenic tools which could contaminate the stable isotope values, e.g. chalk or pencil, are avoided. However, the use of pencils and chalk aids the dating and dissection of samples, particularly when working with difficult tropical species. It is often necessary to highlight the contrast between different wood cell structures for a better detection of narrow or indistinct annual growth boundaries. Here, we tested a possible contamination with graphite and gypsum on stable isotope values ($\delta^{13}C$, $\delta^{18}O$) from wholewood Indonesian teak samples.

Material and Methods

The wood material used for the contamination test is part of a dendro-climatic isotope study of Teak trees, collected in the eastern part of Central Java, Indonesia (Schollaen et al. 2013). All pre-treatment of the collected samples was carried out in the laboratory following standard procedures outlined in Stokes and Smiley (1968) and Schweingruber (1983). To improve the visibility of the tree-ring structure the surface of the core samples was cut with a core microtome (Gärtner and Nievergelt 2010) or special knifes (NT Cutter BA-170). Fine chalk, which consists today only of gypsum (calcium sulfate: $CaSO_4 \times 2H_2O$), was rubbed into the pores to increase the visual contrast. Pencil strokes, which consist essentially of graphite, have been used for dating procedure (Figure 1).

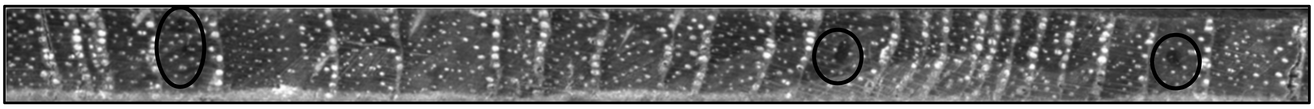


Figure 1: Wood surface from a teak core contaminated with pencil strokes (graphite, black circle) to mark dating and chalk (calcium sulfate $CaSO_4$) to highlight wood anatomical features.

For stable isotope measurements seven different tree cores were chosen and the wholewood was analyzed for ~100 years (1900-2007). The tree rings from all cores were cut seperately using a scalpel and grounded to assure homogeneity. Extractives, such as wood resins and oils, but also glue, pencil and chalk remains were removed from the wood with boiling de-ionized water and ethanol in a multiple sample isolation system for solids (Wieloch et al. 2011). Carbon isotope ratios were measured by combustion (at 1080°C) using an elemental analyser (Model NA 1500; Carlo Erba, Milan, Italy) coupled online to an Isotope Ratio Mass Spectrometer (IRMS, Isoprime Ltd. Cheadle Hulme, United Kingdom). Oxygen isotope ratios were measured using a high temperature TC/EA pyrolysis furnace (at 1340°C) coupled online to an IRMS (Delta V Advantage, Thermo

Scientific, Bremen, Germany). Sample replication resulted in a reproducibility of better than ±0.1‰ for $\delta^{13}C_{TR}$ values and ±0.25‰ for $\delta^{18}O_{TR}$ values. The isotope ratios are given in the δ–notation, relative to the standards V-PDB for $\delta^{13}C$ and V-SMOW for $\delta^{18}O$ (Craig, 1957).

Possible shifts of the original isotope values from pencil or chalk contaminants can be determined by:

$$\delta E_{TRC}\ [‰] = \frac{(MrTR \times \delta E_{TR}) + (MrC \times \delta E_C)}{MrTR + MrC} \tag{1}$$

where: δE_{TRC} is the $\delta^{13}C$ or $\delta^{18}O$ value of the contaminated wood sample,
$MrTR$, MrC are the respective relative mass fractions of wood or contaminant,
δE_{TR} is the original $\delta^{13}C$ or $\delta^{18}O$ value of the wood sample,
δE_C is the $\delta^{13}C$ (graphite) or $\delta^{18}O$ (gypsum) of the contaminants.

To calculate the mass fraction of chalk in the wood samples the used chalk was weighted several times after highlighting 15cm of the wood core surfaces. The repeated laboratory experiments gave a maximum contribution of chalk of 0.6% per tree ring. To simplify calculations, the mass fraction of graphite and chalk in the wood samples is estimated to be 1% (*MrC*), although the contribution is probably much lower. Thus, the relative mass fraction of wood is assumed to be 99% (*MrTR*).

Results and Discussion

Table 1 shows the results of the contamination tests. Calculations reveal that the graphite from pencil strokes ($\delta^{13}C_{Graphite}$=-26.25‰) has no significant influence (0.01‰) on the original carbon isotope ratio of the Teak wood ($\delta^{13}C_{TR}$=-25.22‰). The impact value is well below the measurement accuracy of the IRMS, which is ±0.1‰. The mean $\delta^{18}O$ value of chalk ($\delta^{18}O_{Gypsum}$=7.0‰) is far lower than typical $\delta^{18}O$ values of wood and thereby suggests a greater impact. However, the influence of chalk on the original oxygen isotope ratio of Teak ($\delta^{18}O_{TR}$ = 21.41‰) is -0.14‰ which is also within the analytical error of the oxygen isotope measurements (±0.25‰). In the worst case a possible analytical error of +0.25‰ to -0.39‰ could occur.

Table 1: Results from the contamination test of graphite and gypsum on tree-ring stable isotope values ($\delta^{13}C_{TR}/\delta^{18}O_{TR}$).

	$\delta^{13}C_{TR}$	$\delta^{18}O_{TR}$	$\delta^{13}C_{Graphite}$	$\delta^{18}O_{Gypsum}$
mean (δE_{TR}/ δE_C) [‰]	-25.22	21.17	-26.25	7.0
δE_{TRC}[‰]	-25.23	21.27		
Impact value (δE_{TRC}- δE_{TR}) [‰]	-0.01	-0.14		

It should be noted that this error value represents the maximum effect of a contamination without any pre-treatment, i.e. extraction of impurities, which has been done here. It can be assumed that graphite and chalk residues have no significant influence on the original isotope ratios of the wood samples used in this study. Therefore, the use of carbonaceous or oxygenic tools (e.g. pencil and chalk) can be recommended for dendro-isotopic studies. In particular, when working with new or difficult tree species, the tools help to improve the dating and dissection of samples.

Acknowledgements

This project was funded by the CADY (BMBF, 03G0813H) and the HIMPAC (DFG, HE 3089/4-1) project. Furthermore, we thank Carmen Bürger for support in the laboratory.

References

Craig, H. (1957): Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide. Geochimica et Cosmochimica Acta 12, 133-149.

Gagen, M., McCarroll, D., Loader, N., Robertson, I. (2011): Stable Isotopes in Dendroclimatology: Moving Beyond 'Potential', in: Hughes, M.K., Swetnam, T.W., Diaz, H.F. (Eds.), Dendroclimatology. Springer Netherlands, pp. 147-172.

Gärtner, H., Nievergelt, D. (2010): The core-microtome. A new tool for surface preparation on cores and time series analysis of varying cell parameters. Dendrochronologia 28: 85-92.

Schollaen, K., Heinrich, I., Neuwirth, B., Krusic, P., D´Arrigo, R., Karyanto, O., Helle, G. (2013): Multiple tree-ring chronologies (ring width, δ13C and δ18O) reveal dry and rainy season signals of rainfall in Indonesia. Quaternary Science Reviews 73, 170-181.

Schweingruber, F.H. (1983): Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie. Paul Haupt, Bern.

Stokes, M.A., Smiley, T.L. (1968): An Introduction to Tree-ring Dating. University of Arizona Press, Tuscon.

Wieloch, T., Helle, G., Heinrich, I., Voigt, M., Schyma, P. (2011): A novel device for batch-wise isolation of a-cellulose from small-amount wholewood samples. Dendrochronologia 29, 115-117.

Do stable oxygen isotopes from *Pinus sylvestris* reveal different water sources in Central Germany?

M. Stantscheva [1], J. Esper [1] & W. Werner [2]

[1] Department of Geography, Johannes Gutenberg-University, Becherweg 21, 55099 Mainz, Germany
[2] Department of Geobotany, University of Trier, Behringstraße 21, 54296 Trier, Germany
E-mail: M. Stantscheva (stantsma@uni-mainz.de)

Introduction

A growing number of studies utilize tree-ring stable oxygen isotopes to address palaeoclimatic and ecological research questions. Several papers demonstrate close associations of tree-ring $\delta^{18}O$ time series with observational temperature (e.g. Anderson et al. 1998, Rebetez et al. 2003) and precipitation data (e.g. Saurer et al. 1995). $\delta^{18}O$ in tree-rings reflects the isotopic composition of the source water utilized by trees. Since this composition is similar between precipitation and soil water of the topsoil (Anderson et al. 1998, Roden et al. 2000), tree-ring $\delta^{18}O$, particularly from shallow rooted trees, offers the possibility to study past isotopic variations of precipitation and climate conditions. However, this approach is likely controlled by the trees' access to soil water, which may vary within a sampling site — due to differing microsite conditions and root depths — resulting in varying correlations between tree-ring oxygen isotope and regional climate data.

The authors address this variability by analysing oxygen isotope variations of individual trees growing within a humid sampling site in Central Germany without drought stress and limiting climate factors. $\delta^{18}O$ time series of four trees are *(a)* related to GNIP precipitation data to investigate whether the trees have utilized water from precipitation, and *(c)* calibrated against regional temperature data to evaluate potentially differing soil water access (among trees) within an otherwise homogeneous sampling site.

Isotope Theory

Water collected by the roots of a tree is the source of oxygen stable isotopes in stem xylem. Tree-ring $\delta^{18}O$ depends mainly on the isotopic composition of the meteoric source water taken up by the roots, evaporative enrichment of water in the leaf, and biochemical fractionation (Roden et al. 2000, Anderson et al. 2002). Possible water sources for a tree are precipitation, soil water and ground or retained water, which have a different isotopic composition. Shallow soil water has a similar isotopic composition as precipitation, depending on the frequency and intensity of precipitation events and hydrological soil characteristics (Tang and Feng 2001). $\delta^{18}O$ time series from deeper soil- and groundwater resources are usually more negative and contain no short-term and inter-annual variations. This is also revealed in plants rooting in different soil depths indicating access to different water stocks in their tree-ring isotopic composition (Saurer et al.1997).

Study Site

The study site is located near Altenkirchen, Germany (50°39`N, 7°38`E), near a GNIP station in Koblenz and climate station in Hilgenroth. The site receives approximately 1000 mm precipitation per year. Mean annual temperature is 9.4°C. The soil type at the sampling site is determined as a cambisol with stagnic properties. The soil texture in the horizon from 75 cm to 105 cm depth was silty clayey loam (utL). The infiltration rate of this soil texture is lower than for a well-drained soil texture like sand, therefore water needs longer time to pass the unsaturated zone (Robertson 2001). Tree composition is dominated by Scots pine (*Pinus sylvestris*), mixed with beech (*Fagus sylvatica*) and oak trees (*Quercus robur*) (FAWF 2012).

DOI: 10.2312/GFZ.b103-13058

Material and Methods

Four *Pinus sylvestris* stem disks were sampled for isotopic analysis from a permanent monitoring plot. Four to eight radii were cut out from these disks and the ring width measured using WinDendro density software (Regent Instruments). Whole tree-rings (including early- and latewood) were separated with a scalpel, ground using a mixer mill (MM200 Retsch), and treated according to the Brendel method (Evans and Schrag 2004) to gain α-cellulose. Analysis of oxygen and carbon isotopes was performed at the Department of Geobotany in the University of Trier (Germany). To investigate our hypotheses, climate data from the station Hilgenroth in approximately 15 km distance, GNIP data (oxygen isotopes in precipitation) from Koblenz in approx. 35 km distance to the sampling site were used. Additionally maximum temperature on rainy days was calculated, which is defined as maximum temperature on days with > 0mm precipitation. The forest density was 57 trees on a 0.25 ha permanent sampling site in 2009, after the forestry thinning only 37 trees remained on the plot.

Results

The individual $\delta^{18}O$ time series indicate particular high values for the year 2003 and particular low values for the years 1998 and 2002. The range of $\delta^{18}O$ values is between 32.5‰ and 35.2‰ (Fig. 1).

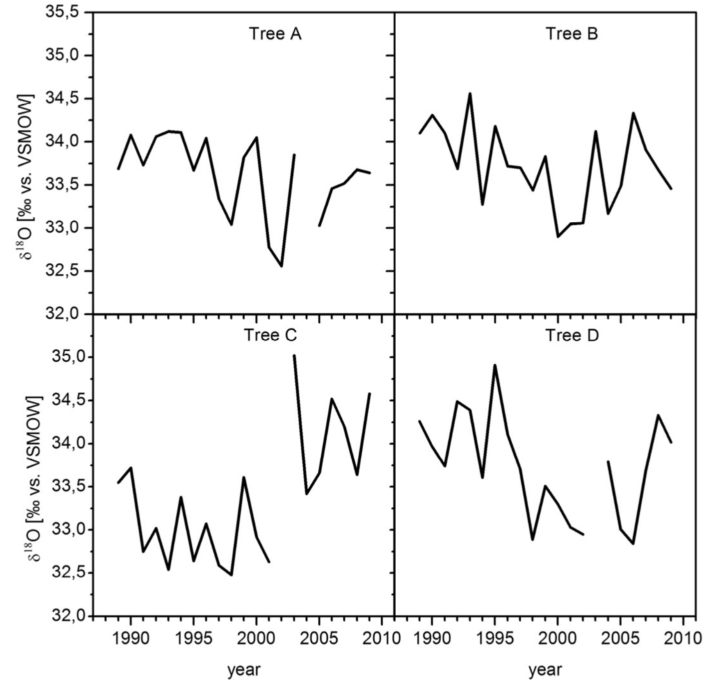


Figure 1: Oxygen stable isotope time series (1989 to 2009) of individual trees.

Inter-tree correlation at the sampling site shows low to medium correlations (Table 1). Tree C presents independent correlations compared to the other trees at sampling site. Tree A, B and D demonstrate medium correlations to each other.

Table 1: Inter-tree correlation between individual oxygen stable isotopes from tree rings.

	Tree A	Tree B	Tree C
Tree B	.44		
Tree C	.10	.19	
Tree D	.64**	.47*	-.13

We used precipitation δ^{18}O time series from the GNIP station in Koblenz, covering the 1989 to 2007 period, for calibration of the tree-ring stable isotope measurements from Altenkirchen. Comparison of the single-tree δ^{18}O time series with the nearby GNIP station in Koblenz reveals significant positive correlations between Tree C and July and September precipitation oxygen isotopes (Fig. 2). All other trees and all other months respectively showed insignificant correlations between tree-ring and precipitation oxygen isotopes, indicating a distinct differentiation within the Altenkirchen sampling site, likely related to differing microsite conditions. Most of the insignificant correlations of Tree A, B, and D are also of differing sign, compared to Tree C.

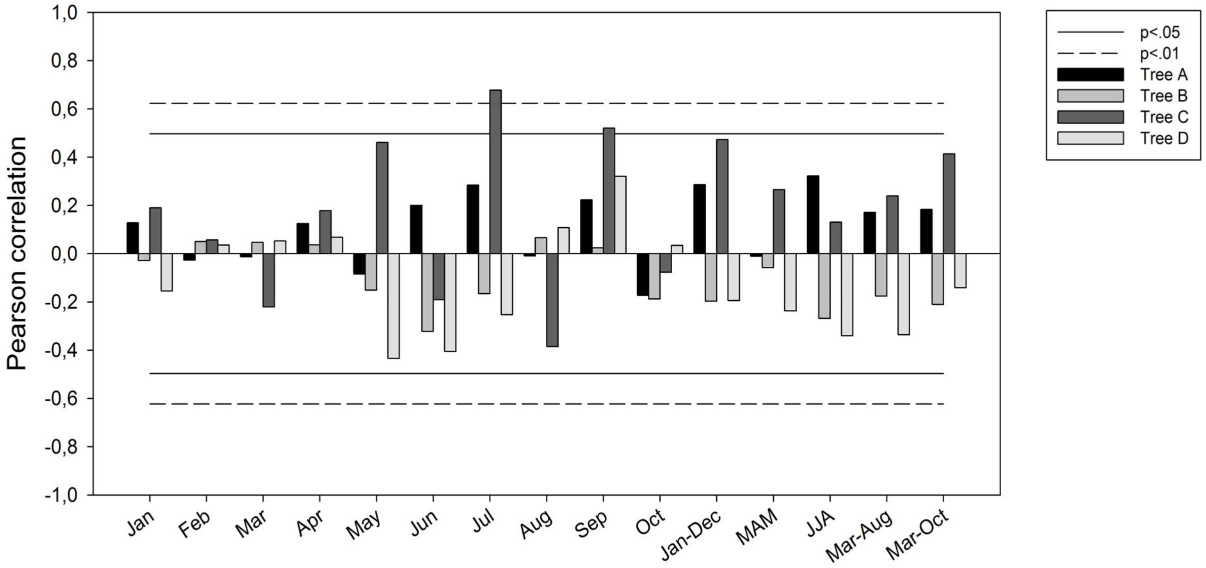


Figure 2: Pearson correlations between oxygen stable isotopes of individual trees and oxygen stable isotopes in precipitation recorded at the Koblenz GNIP station.

Correlations between tree-ring δ^{18}O and maximum temperature (Fig. 3) and maximum temperature on rainy days (Fig. 4), indicate a strong correlation of Tree C and no correlation of the other trees. Tree A, B and D presented insignificant positive correlations with Tmax and no improvement of correlations with Tmax on rainy days. Again, only Tree C showed significant correlations with Tmax and improved associations with maximum temperature on rainy days.

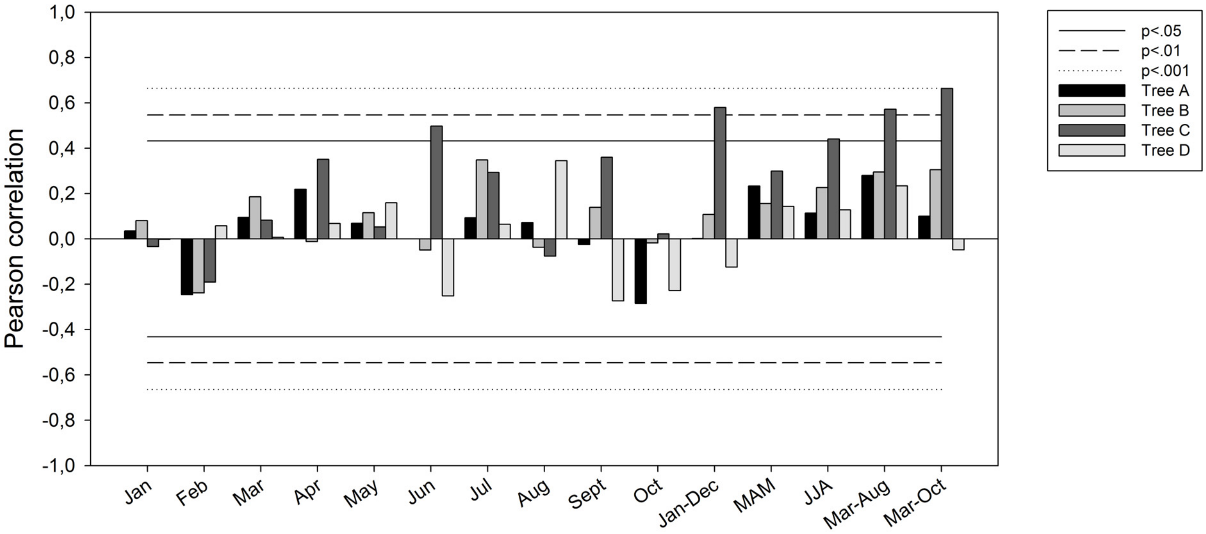


Figure 3: Pearson correlations between oxygen stable isotopes of individual trees and maximum temperature.

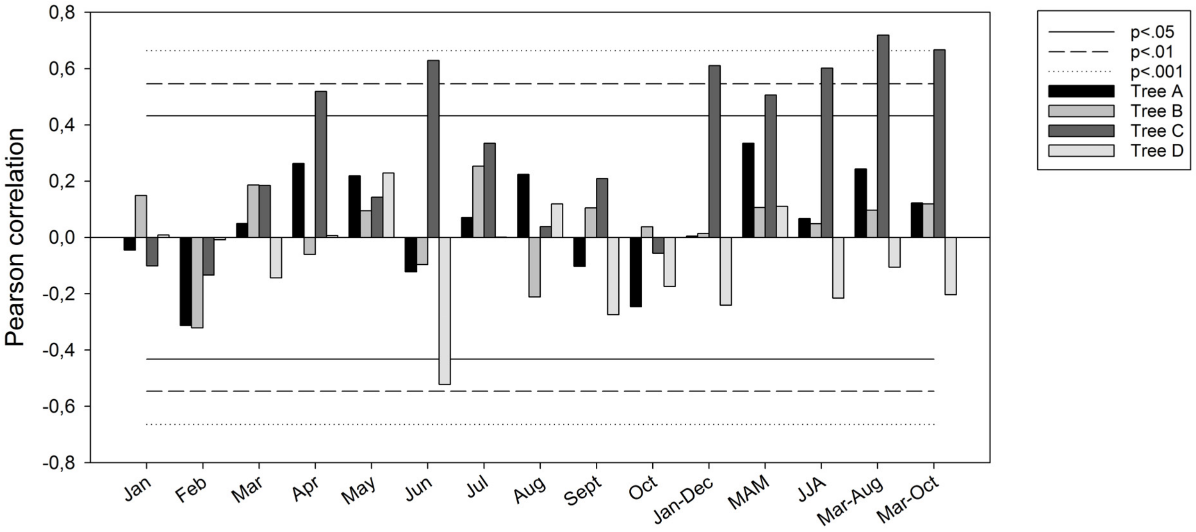


Figure 4: Pearson correlations between oxygen stable isotopes of individual trees and maximum temperature on rainy days.

Conclusions

The analysis of δ^{18}O time series from individual trees in a typical permanent monitoring plot showed varying trends over the past two decades, and associated differing correlations with the isotopic composition of precipitation and regional maximum temperature time series. The changing climate signals retained in individual tree-ring δ^{18}O time series is likely related to varying water supply of individual trees, caused by different rooting depths of single trees within the sampling site or different soil properties mentioned by differing stagnant qualities. These effects are triggered by the distinct isotope composition of precipitation, shallow soil water and stagnant or ground water. Tree C showed a good climate signal with maximum temperature and isotopic composition of precipitation. This indicates that Tree C has no access to a permanent water source like groundwater in contrast to the other trees.

These findings are in line with Saurer et al. (1995) indicating that trees growing in moist sites contain lower correlations with climatic data than trees growing on dry sites. Our analysis suggests that these between-site differences might also account for single trees within a site. Trees growing in dry microsites correlate higher with climate than trees growing in moist microsites (on this site especially stagnant soil water). Tree-ring δ^{18}O is related to the isotopic composition of the water source accessed through the root system (Roden et al. 2000). As Tree A, B and D showed no significant correlations with δ^{18}O in precipitation, this basic finding suggests that these trees use a different water source than the remaining Tree C. It is suggested that the roots of Tree A, B and D reach deeper into the stagnant or groundwater, and Tree C developed a shallower root system utilizing soil water from the unsaturated, precipitation influenced zone. As a consequence of the soil type and the infiltration rate, Tree A, B and D do not depend on precipitation water and hence the isotopic signal of δ^{18}O in precipitation is not reflected in δ^{18}O cellulose. It is likely that the climatic signal of δ^{18}O in precipitation is dampened by means of mixing with δ^{18}O in the upper soil layer. The findings suggest that the variability in correlations between δ^{18}O in trees and δ^{18}O in precipitation at the sampling site can be the result of heterogeneous isotopic composition of soil water. For our future work we recommend a detailed soil study on the permanent monitoring plot, investigating the soil texture and hydrological conditions near the trees to evaluate our findings. It is also of interest to measure δ^{18}O of water extracted from the stem (xylem) and compare it with δ^{18}O of soil water from different soil depths to estimate the level where roots mainly take up their water. Furthermore, a better replicated site with more individual trees on different environmental conditions are needed

Acknowledgements

We would like to thank Dorothea Krieger and Bernhard Backes from the University of Trier for the analytical measurements with the TC/EA-IRMS.

References

Anderson, W.T., Bernasconi, T.S.M., McKenzie, J.A., Saurer, M. (1998). Oxygen and carbon isotopic records of climatic variability in tree ring cellulose (Picea abies): An example from central Switzerland (1913-1995). *Journal of Geophysical research letters* 103 (D24): 31625-31636.

Evans, M.N., Schrag, D.P. (2004). A stable isotope-based approach to tropical dendroclimatology. *Geochimica et Cosmochimica Acta*, *68*(16): 3295-3305.

Farquhar, G.D., Leary, M.H., Berry, J.A. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Australian Journal of Plant Physiology* 9: 121-137.

FAWF (2012): Permanent monitoring plot 308: Altenkirchen. <http://www.fawf.wald-rlp.de/fileadmin/website/fawfseiten/fawf/FUM/index.htm?umweltmonitoring/DBFL/forschung.html> (Date of revision: 2012) (Date of access: 02.09.2012).

Rebetez, M., Saurer, M., Cherubini, P. (2003). To what extent can oxygen isotopes in tree rings and precipitation be used to reconstruct past atmospheric temperature? A case study. *Climate change* 61: 237-248.

Robertson, I., Waterhouse, J., Barker, A., Carter, A., Switsur, V. (2001). Oxygen isotope ratios of oak in east Ennglang: implications for reconstructing the isotopic composition of precipitation. *Earth and Planetary Science Letters* 191: 21-31.

Roden, J.S., Lin, G., Ehleringer, J.R. (2000): A mechanistic model for the interpretation of hydrogen and oxygen isotope ratios in tree ring cellulose. *Geochimica et Cosmochimica Acta* 64 (1): 21-35.

Saurer, M., Siegenthaler, U., Schweingruber, F. (1995): The climate-carbon isotope relationship in tree rings and the significance of site conditions. *Tellus B* 47: 320–330.

Saurer, M., Borella, S., Leuenberger, M. (1997). δ^{18}O of tree rings of beech (Fagus sylvatica) as a record of δ^{18}O of the growing season precipitation. *Tellus* 49B: 80-92.

Tang, K., Feng, X. (2001). The effect of soil hydrology on the oxygen and hydrogen isotopic composition of plant`s source water. *Earth and Planetary Science Letters* 185: 355-367.

SECTION 3

ECOLOGY

Intra-annual weather conditions, ecosystem water fluxes and tree growth reactions – hydroecological and dendroecological findings from intensive sampling plots with different forest tree species

W. Beck, J. Müller & T. Sanders

Institute of Forest Ecosystems, Alfred-Möller-Straße 1, 16225 Eberswalde, Germany
E-mail: wolfgang.beck@ti.bund.de

Introduction

The formation of tree-rings is the result of intra-annually fluctuating processes. These can be recorded by high-resolution dendrometers enabling the connection of the processes of daily diameter changes in the trunk to specific climatic patterns resulting in cause-effect-relationships. These however are especially important in the North-eastern German lowlands with its low precipitation (approx. 550-600 mm/a), freely draining sandy soils (water storage capacity approx. 100 mm), and frequent phases of temporal water shortage. Knowledge about the water consumption of different tree species as well as the impact of limited water resources on growth rates of trees in pure and mixed stands is needed by silviculture urgently. Another important question is the size of groundwater production of forested catchment areas. Here we give an insight to on-going research on the reaction of different tree species to climate and its extremes and the differences between the temporal growth patterns of different species.

Material and Methods

To analyse these cause-effect-relationships nine large-scale lysimeter are in operation at the Thünen-Institute for Forest Ecosystems. The individual lysimeters have an area of 10 x 10m and a depth of five meters. The location is representative of the north-eastern German lowlands (Müller, 2005). The lysimeters are stocked with stands of about 40 years of age comprising Scots pine, Common beech, European larch, Douglas fir and Black alder (Müller & Bolte 2009). A combination of measuring devices allows the complete quantification of water fluxes within the respective ecosystems (Müller 2007; Beck & Müller 2007). Dendrometer data is read manually three times a week. Since 1999 the data quality is sufficient to allow for scientific analysis. Focal points of this contribution are:

- The species specific onset, duration and end of diameter increase (tree species Scots pine, Common beech, European larch, Douglas fir and Black alder),
- The shrinking and swelling of the trunk of coniferous species during stress periods of water shortage and heat (Scots pine only),
- The effect pathways from weather events via soil water availability towards growth response (Scots pine and Common beech), and
- Similarities and differences between tree species.

Results

Species specific onset, duration and end of diameter increase

The intra-annual diameter change is not a monotonous increase. The trunk of trees may shrink and swell considerably, especially in conifers, depending on the weather conditions. At the beginning as well as the end of the growing season the diameter may oscillate to a certain degree. This makes it difficult to decide whether growth has already started or ended. Due to this uncertainty artificial limits were set with a cut off above 5% and below 95% of the maximum diameter increase; resulting in the further analysis of 90% of the full diameter formed (Figs. 1a, 1b).

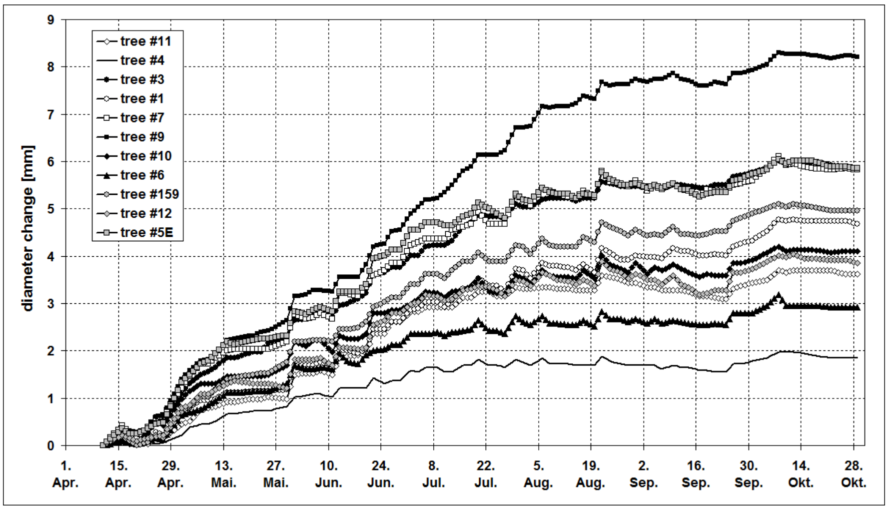


Figure 1a: Example of the Scots pine stand on lysimeter #9; data is recorded manually trice a week and interpolated for the intermediate days.

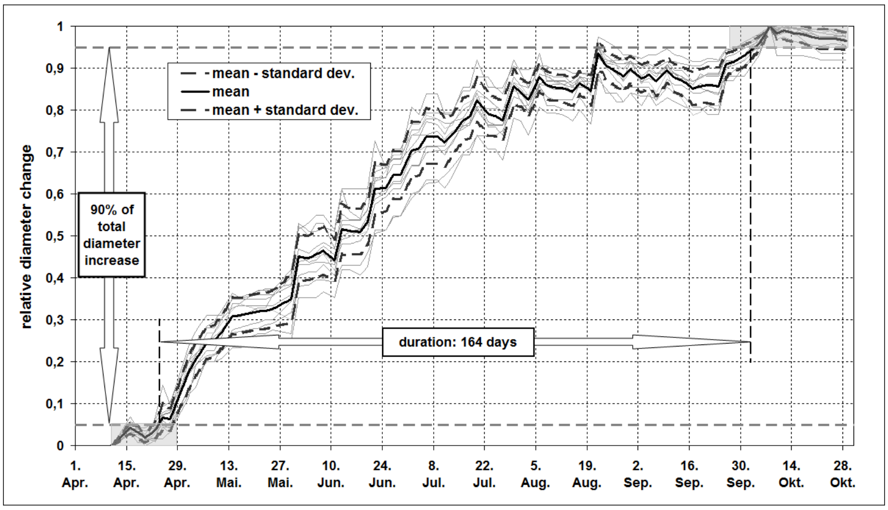


Figure 1b: The absolute values of diameter changes are transformed to relative values within the interval between 0 and 1.0 in order to improve the comparability between the monitored trees. The grey shaded boxes at the beginning and the end of the growing season indicate the times where it is difficult to decide to which extent the changes of the single curves show a true growth or only swelling and shrinking.

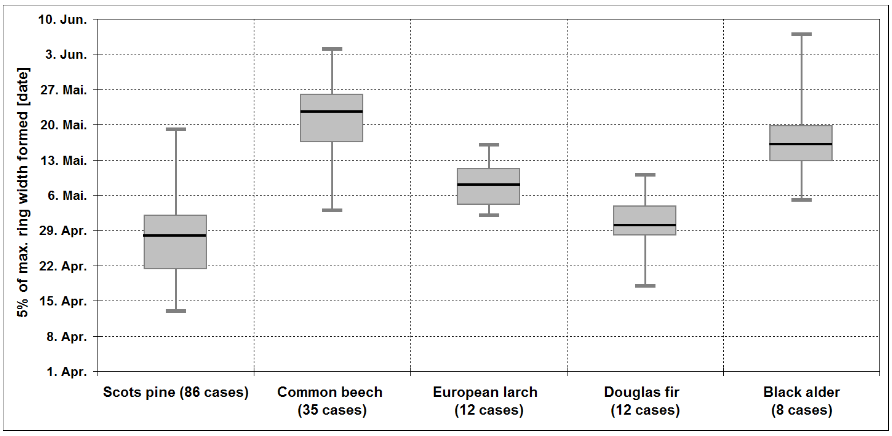


Figure 2: Dates of species specific growth onset of the observed tree species (5% of maximum diameter increase).

The results of this analysis comprising all above mentioned tree species led to considerable species specific differences regarding onset, duration and end of the diameter increase over the growing season (fig. 2 to 4). The Scots pines start growing first and stop last. Therefore the growing season of the pines is longest among the observed tree species (140 days). The seasonal growth patterns of Common beech is different to that of Scots pine, because beech as well as Black alder have unfold their foliage prior to growth resulting in a similar seasonal start of those two broadleaves. Growth season ends first for common beech resulting in the shortest of 87 days. The temporal course of the growth activities of the individual tree species is important regarding water consumption.

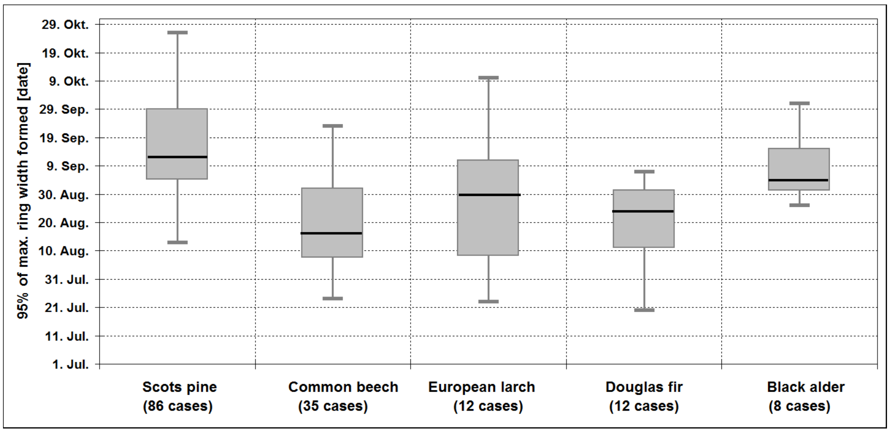


Figure 3: Dates of species specific growth end of the observed tree species (95% of maximum diameter increase)

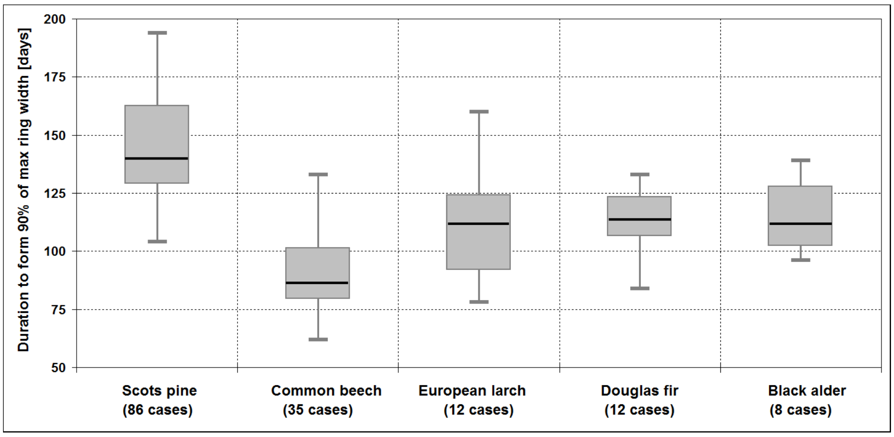


Figure 4: Resulting duration of species specific diameter growth of the observed tree species (90% of maximum diameter increase)

Mixed stands, composed of Scots pine in the over storey and Common beech in the under storey are a frequently occurring forest structure in the north-eastern German lowlands. Here both species have to coexist and compete for the limited water resources. Beech starts growth more than three weeks after pine. At this time water resources are already partially depleted due to the early growth onset of the pines.

Shrinking and swelling of the trunk of coniferous species

The course of diameter increase from spring to autumn is superposed by shrinking and swelling of the trunk. This phenomenon is much stronger in the case of conifers than in that of broadleaved hardwoods. The under most layer of the bark of conifers is spongy and fluctuations of its water content by temporal water shortage cause shrinking and swelling when water is available again.

This phenomenon may be seen as a disturbing influence in relation to the real diameter increase, but otherwise it seems to be worth to analyse its consequences on growth rates. The proportion of shrinking and swelling may be quantified by adding all increase and neglecting all diameter shrinkages (decrease). For this purpose, first the amount of swelling after previous shrinkage has to be separated from the true diameter increases. In a first step, all daily diameter increases are added up. In the following step only the daily diameter increases are taken into account not compensating for previous shrinkage. The difference between the two amounts represents the proportion of swelling after previous shrinkage of the total change in diameter for the season (Fig. 5). The data of shrinking and swelling and the corresponding diameter growth rates of all Scots pine stands, for all years with existing dendrometer measurements were compiled for further analysis. The percentage of swelling and shrinking at the cause-side and the radial growth rate at the effect- side, were standardised (Z-Scores) to obtain comparable data for all included Scots pine stands and all observational years. The resulting 2-phases spline shows that up to the break-point there is no influence on the growth rates (Fig. 6). By transforming the standardised data representing the break-point back to normal scale the values of 41% of swelling and shrinking and 4.2 mm mean radial growth rate were determined. Values up to 41% of swelling and shrinking seem to be a natural range wherein water shortage does not cause an enduring physiological damage. Increment losses increase where this threshold is exceeded. Seemingly, there is certain range, where temporal water stress affects high growth rates. Within this range shrinking and swelling are caused by transpiration stress under conditions of high temperatures and sufficient soil water availability. Shrinking and swelling more than 41% of the total growth rate of the season are probably caused by a combination of high temperature and dwindling soil water resources. These are the conditions of enduring drought periods frequently occurring in the north eastern lowlands. Such heavy drought periods result in both, extended shrinking phases and increment losses.

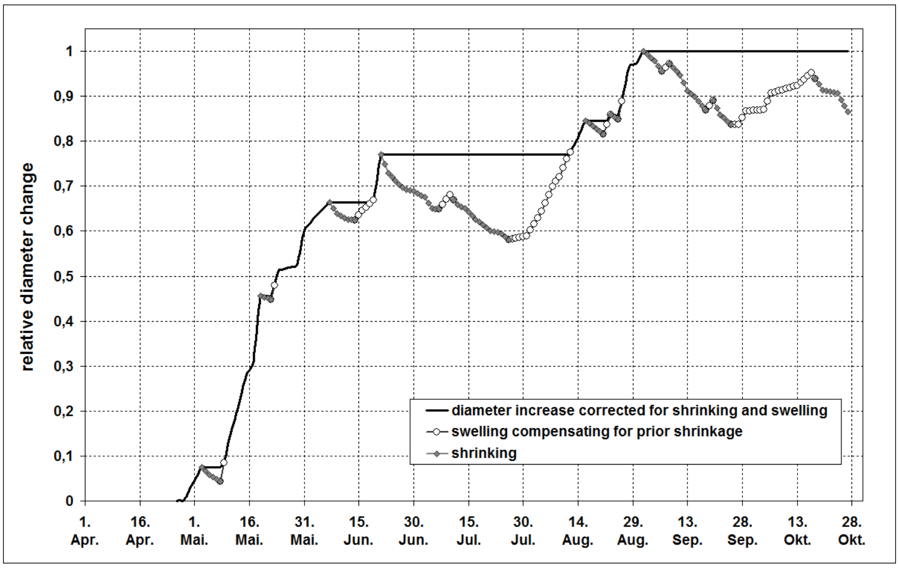


Figure 5: Example of the pure Scots pine stand on lysimeter #9; course of mean relative diameter change during the hot and dry growing season of the year 2006; the amount of swelling compensating for prior shrinkage (hollow circles) related to pure diameter increase (boldd line) is 49%.

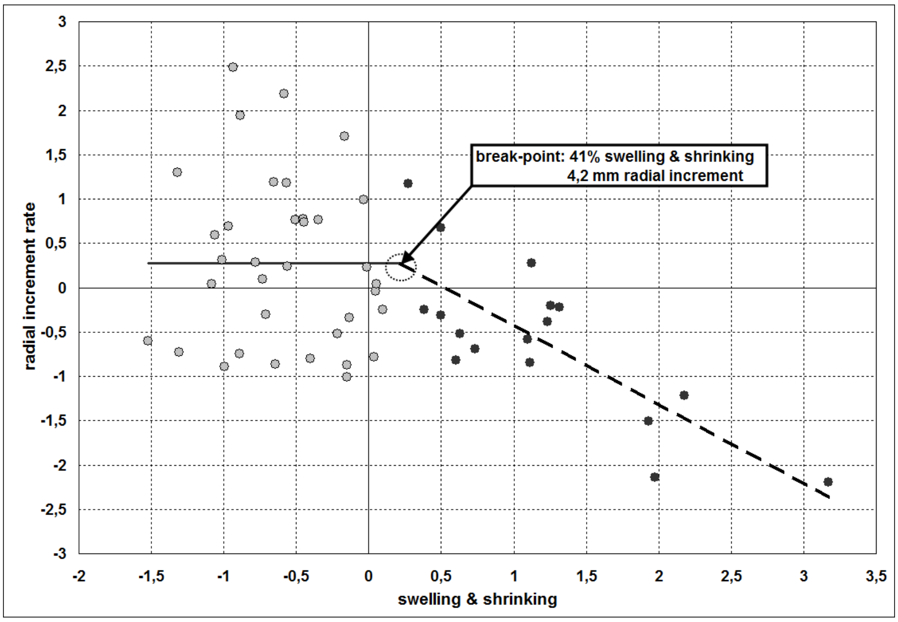


Figure 6: Tree species Scots pine; relationship between the size of intra-annual shrinking and swelling and the annual growth rate. The standardized data was described by using a linear 2-phases spline, r²=0,503; the data of the breakpoint is re-transformed absolute values.

Effect's pathway from weather events via soil water availability towards growth response

At the hydro-ecological research station "Britz" all important fluxes and processes are continuously recorded. This provides the opportunity to combine rainfall events, the course of soil water availability and temperature to explain growth courses and lead to a more qualified understanding of tree growth patterns. The summer 2000 was exceptionally cool and rainy. Contrary to that, the summers of 2003 and 2006 were extremely hot and enduringly dry. For these three years, the courses of daily rainfall, the relative soil water availability, the daily deviations of temperatures from long-time mean and the intra-seasonal diameter change of an intensively investigated Scots pine stand of the Britz station were compiled for analysis (Fig. 7). During the 2000 growing season a drought period lasted from the end of April up to the middle of May. Accordingly, the soil water availability decreased rapidly. Nevertheless, there is no limitation to tree growth, because the trees could use the soil water content left from the winter. Only at the end of May a small shrinkage is recorded.

The short shrinkages in June are not caused by water shortage but by the high temperatures. The temperatures during July and partly in August are on the other hand very low. The period at the end of August without showing any nameable precipitation led to a sharp decrease of soil water availability and also to a short shrinkage. This prompt reaction is an expression of the low water storage capacity of the sandy soil and also of the rapid water consumption of the tree stand. As soon as soil water availability falls below 40% for a longer time, serious shrinkage is observable. Such situations do not really appear over the summer of 2000. In the summer of 2003, an enduring drought period from the end of July up to the end of August reduced soil water availability to an average of 35% for 27 consecutive days. Small rainfall events of 4 and 2 mm in between did not improve the strained situation. The drought events during 2006 are even stronger than in 2003. The first drought period of 2006 lasted from the 20th June up to the 27th July (38 days).

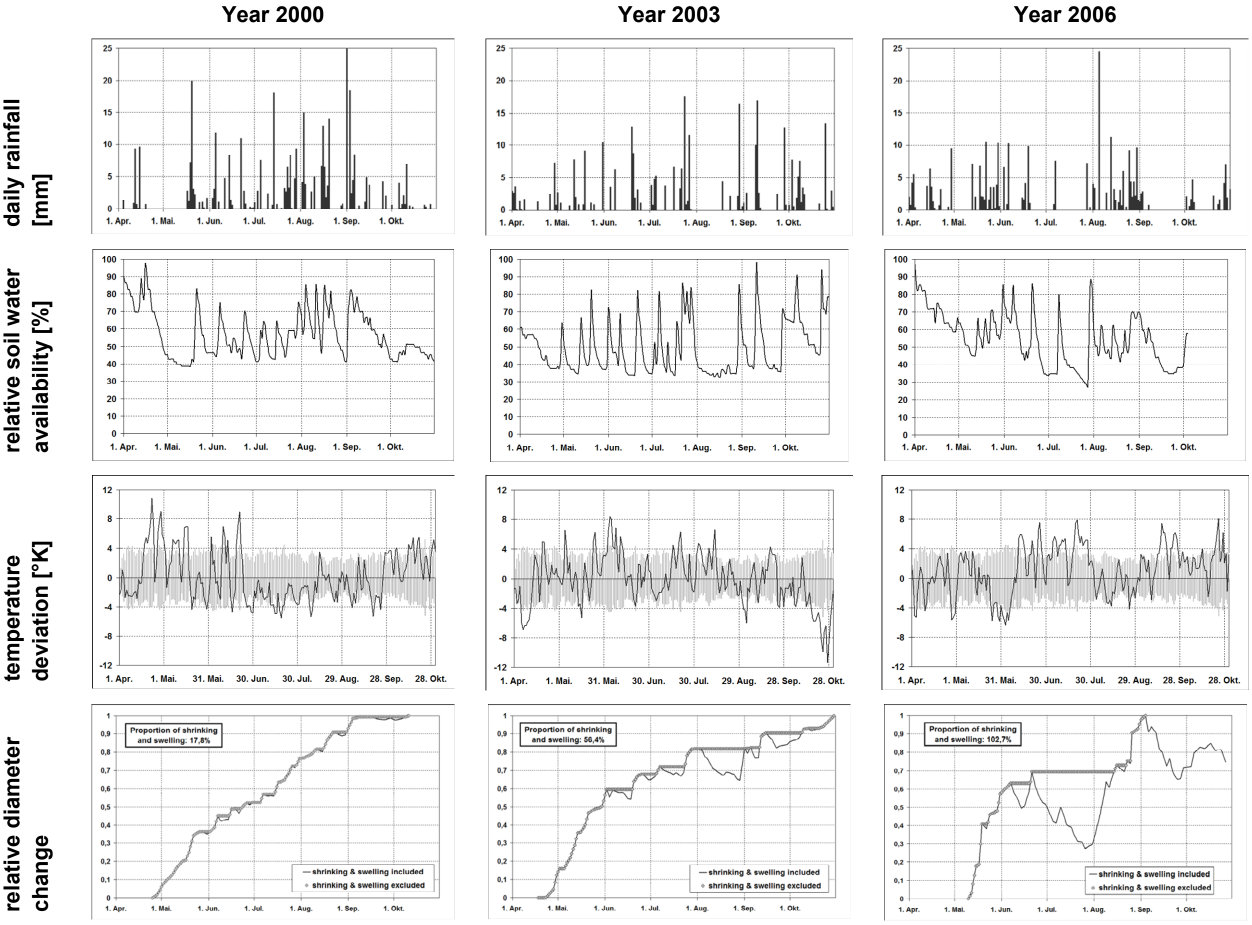


Figure 7: The causes and effects pathway during the formation of Scots pine tree rings; Periods without rainfall cause a decrease of soil water availability. Often, soil water shortage is amplified by simultaneously high temperature. Thus,, dramatic shrinkages were caused in 2003 and 2006
Row of temperature deviation: the grey shaded background shows the daily range of +/- standard deviation.

The single rainfall event on the 7th July with 8mm did not improve the situation. The drought effect was additionally amplified by simultaneously abnormally high temperatures. The August precipitation led to a rapid swelling and probably to a restart of diameter growth in terms of substance allocation. Another long lasting drought period stopped this small episode. In the period from lasting from the 31st August to the 27th October there were no precipitation events of more than 5mm. Over these 58 days there was a total amount of rainfall of about 28 mm. The new shrinkage stopped the return to the diameter maximum which was reached already on the 4th September. Until the end of the dendrometer readings at the beginning of November the diameter of the pines was lower than at the beginning of September.

Seemingly, two consecutive, long lasting drought periods, combined with extreme heat, have caused an enduring enfeeblement. Besides the comparison of the effects of weather courses of different years, comparisons of tree species specific reactions during the same growing season are possible (Fig. 8a and 8b). The Scots pine stand in Britz and the Common beech stand in Kahlenberg are around 2300m distant from each other and grow under very similar site conditions. Soil type, nutrient content and physical soil properties are nearly the same. The soil water availability in the beechstand, however, is considerably higher until June due to the fact that the beech trees are bare until May. So, canopy interception losses and water consumption for transpiration are almost zero. In the course of the summer 2003, the curves of soil water availability of the pine and the beech stand are converging.

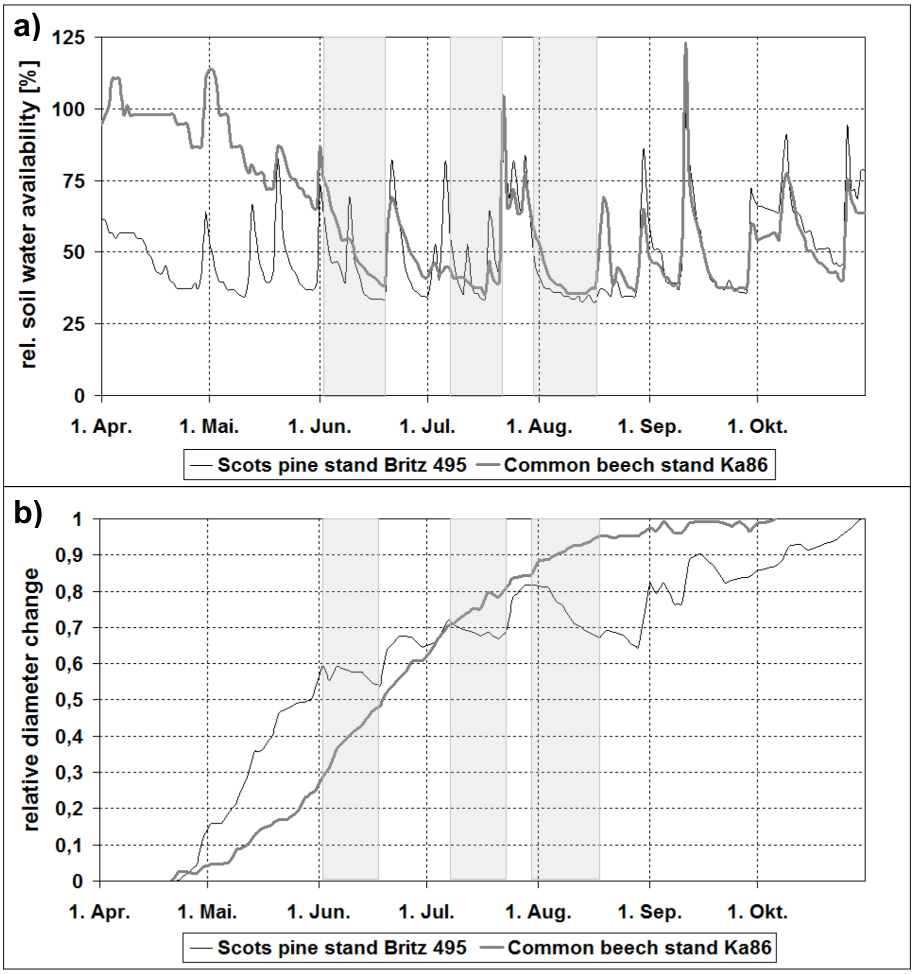


Figure 8: a) Courses of relative soil water availability up to a depth of 1m in a Scots pine and a Common beech stand during the growing season of 2003. b) Courses of relative diameter change in a Scots pine and a Common beech stand during the growing season of 2003. The grey shaded rectangles indicate phases of severe water shortage where pines shrink and beeches continue growing.

The curves are very similar regarding the temporal changes and also in the phases of the deepest consumption. In the case of abundant precipitation events there are peaks of water availability above 100% in the curve of the beech stand, due to a considerable quantity of stemflow which can percolate deeper. Despite the similarities of the soil water curves both stands the dynamics of diameter change between these two species are visibly different (Fig. 8b). According to their wood anatomical structure, broadleaved hardwoods cannot shrink and swell to the extent typical for conifers. However, there are at least three phases (grey shaded rectangles in Fig. 8b) wherein the pines already shrink whereas the beeches are able to continue their diameter increase. During the first phase in June this difference is explainable by the better soil water resources of the beech stand. Within the second drought phase in July the beech does on average not have higher soil water than the pines (Fig. 8a). The differences between the soil water availability in the beech and the pine stand within the third drought phase in August are rather small. Nevertheless, the diameter increase of beech continues whereas the pine shrinks severely. Especially the conditions of water availability of the second and third drought phase and the different growth response of pine and beech raise the question for the reasons of this deviant behaviour.

As already mentioned, the wood anatomical structures of beech wood prevent a shrinkage which would be comparable to that of pine. On the other hand, one would expect the beech stopping their diameter increase when water availability drops down to 36%; however, even this does not occur. Contrary to beech stands, pine has to cope with the competition by ground vegetation. Finally however, it is not important, whether the low water availability was caused by competition. The only explanation for the fact, that under the same conditions (Fig. 8a) beech are able to continue growing whereas pines are shrinking (Fig. 8b) is that the root system of beech is more effective than that of pine. The data of soil water availability was measured for a soil depth up to one meter. Possibly, beech is able to access water from deeper soil layers. Hornschuch (2009) found that beech can root a certain volume of soil more intensively than pines can.

Summarising conclusions

The annual diameter growth rate is not a result of a continuous increase, but it is a sequence of consecutive periods of increase, stagnations, diameter shrinking and swelling and increasing again depending on changing intra-annual weather conditions (sufficient precipitation vs. enduring drought and heat). The oscillations of diameter change, especially at the beginning and the end of the growing season complicate the exact specification of the start and the end of diameter growth. Therefore, the highest diameter increase was chosen to define the maximum. The onset of diameter growth was set to 5% of this maximum and the end is defined as 95% of the maximum. The duration of diameter growth is the 90% interval between onset and end of growth. Among the observed tree species, Scots pine shows the longest growing season (140 days), due to its frost resistance, whereas Common beech begins latest and ends first (87 days).

The processes of shrinking and swelling of the trunk of trees, which are caused by the changing weather conditions, are not only a disturbance factor at observations of intra-annual growth dynamics but these processes and their species specific differences are meaningful to understand the effects and consequences of drought events. Due to different species specific wood anatomical properties the size of shrinking and swelling of the trunk of conifers is much higher than that of Common beech. The size of swelling, which is only the compensation of a previous shrinking may be calculated and may exceed more than 100% of a full annual diameter growth rate in the case of Scots pine under extreme drought conditions. Shrinking and swelling of the trunk may be seen as a sign of stress conditions. Up to a threshold of 41% of shrinking and swelling no reduction of growth rates of Scots pines was found. The exceedance of this threshold however causes considerable increment losses.

The effects of weather events may be traced using the time series of relative soil water availability. Soil water availability below 40% causes strong shrinkage and growth depression. The effects of water shortage are amplified by high temperature.

Neighbouring stands of Scots pine and Common beech under equal weather conditions (example year 2003) and very similar soil properties show different growth response. These differences are mainly caused by different stand structures. The differences are obvious in the delayed water consumption due to the need to unfold leaves in spring and the considerable proportion of stem flow water in beech stands which reach the rooted soil zone quickly. In contrast, Scots pine stands have no mentionable stem flow but a high proportion of non-productive interception evaporation. In summers with severe heat and drought periods occur where pine already shrinks whereas beech are able to continue growing. It is to assume that beech is able to root deeper soil layers and use water resources more effectively. Additionally, beech can root a certain soil volume more intensively than pines.

These particular findings show that data from dendrometer measurements are not only useful to determine the annual growth rates, but are also useful to contribute to the understanding of the processes and conditions of tree ring formation.

References

Beck, W., Müller, J. (2007): Impact of heat and drought on tree and stand vitality – dendroecological methods and first results from level II-plots in southern Germany. In: Tagungsbeiträge zur internationalen Tagung des ICP Forests Göttingen, 25.-28.10.2006. “Forests in a changing environment – results of 20 years ICP Forests Monitoring“. J. Eichhorn, (Hrsg.). J. D. Sauerländer´s Verlag Frankfurt am Main. Schriftenreihe aus der Forstlichen Fakultät der Universität Göttingen und der Nordwestdeutschen Forstlichen Versuchsanstalt Frankfurt am Main. 2007, Bd. 142 pp. 120-127.

Hornschuch, F. (2009): Ausbreitungsstrategien der Feinwurzelsysteme von Wald-Kiefer (*Pinus sylvestris* L.) und Rot-Buche (Fagus sylvatica L.) in Rein- und Umbaubeständen, Modifikation durch Konkurrenz und kleinräumige Bodenheterogenität. Forstwissenschaftliche Beiträge Tharandt, Heft 30, Eugen Ulmer KG Stuttgart, 340 pp.

Müller, J. (2005): 30 Jahre forsthydrologische Forschung auf der Großlysimeteranlage in Britz – Zielstellung und Ergebnisse. In: Bericht über die 11. Gumpensteiner Lysimetertagung, „Lysimetrie im Netzwerk der Dynamik von Ökosystemen“ am 5. und 6. April 2005, Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft, Irdning. Raumberg-Gumpenstein, pp. 29-32.

Müller, J. (2007): Auswirkung von Trockenheit auf den Waldzustand – Ansätze zur Bewertung der Trockenheitsgefährdung von Waldstandorten. In: Lysimetrie im Konnex zu nationalen und internationalen Regelwerken. 12. Lysimetertagung am 17.und 18.April 2007. Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft Raumberg-Gumpenstein Irdning. pp. 113-116.

Müller, J., Bolte, A. (2009): The use of lysimeters in forest hydrology research in north-east Germany. Landbauforschung, vTI Agriculture and Forestry Research, Vol. 59 No. 1 03.2009, pp 1-10.

Extending the high elevation larch ring width chronology from the Simplon region in the Swiss Alps over the past millennium

D.F.C. Riechelmann [1], M. Schmidhalter [2], U. Büntgen [3] & J. Esper [1]

[1] *Department of Geography, Johannes Gutenberg-University, 55099 Mainz, Germany*
[2] *Dendrolabor Vallais, 3900 Brig, Switzerland*
[3] *Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland*
E-mail: riechelm@uni-mainz.de

Introduction

A number of tree ring-based temperature reconstructions that span the last centuries to millennia were recently published for the European Alps (e.g., Frank & Esper 2005, Frank et al. 2005, Büntgen et al. 2005, 2006, 2009, 2011). These records are generally composed of several hundred of annually resolved and absolutely dated ring width and density measurements from living conifers, historical timbers, and sub-fossil remains. A prerequisite for all this material is the origin from high-elevation Alpine sites. The Simplon region in the western Swiss Alps represents a unique source for larch (*Larix decidua* Mill.) construction timbers, with the oldest buildings dating back into late medieval times (Tab. 1). Here, we introduce a continuous tree-ring width chronology from historical high elevation larch wood from the Simplon village in the Swiss Alps spanning the 738-1852 AD period. The chronology provides an ideal basis for the development of an Alpine summer temperature reconstruction.

Data, methods and results

A total of 126 larch samples from 14 buildings in the Simplon village (46°12'N, 8°03'E, 1476 m asl; Fig. 1) were compiled and analysed over the past years, involving different studies (Tab. 1).

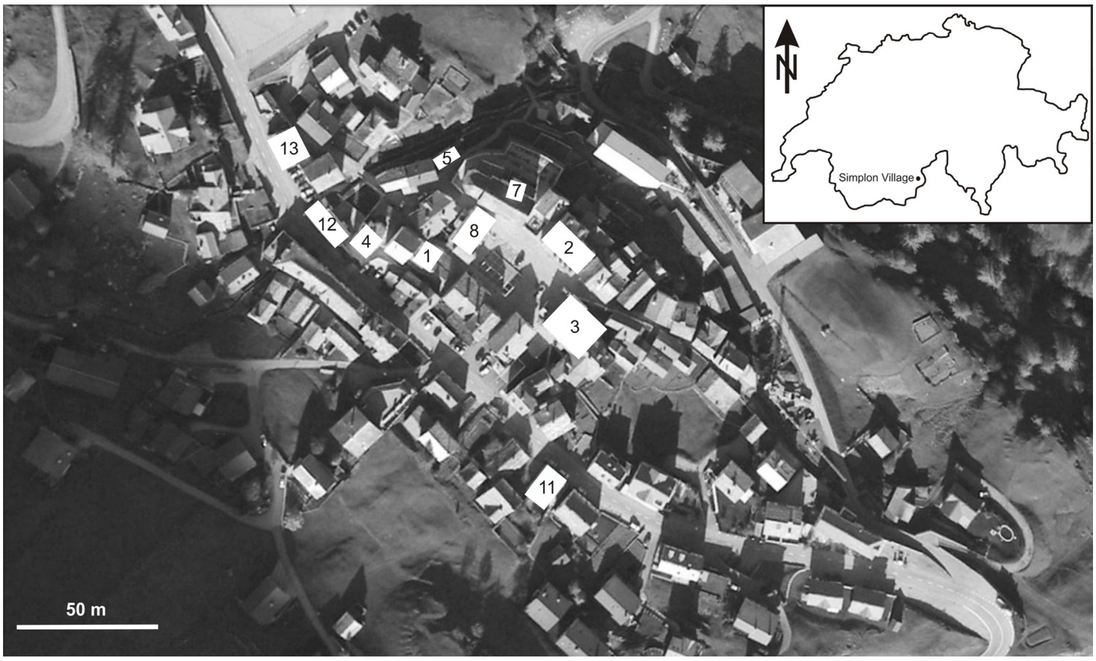


Figure 1: Aerial image of the Simplon village in the western Swiss Alps. Those buildings that were considered for tree-ring sampling are indicated: 1) Stall Dorsaz, 2) Weisses Kreuz, 3) Alter Gasthof, 4) Turru, 5) Heidenhaus Zenklusen, 7) Kirchturm, 8) Haus auf dem Dorfplatz, 11) Haus Peter Arnold, 12) Postgebaeude, and 13) Kaplanneigebaeude. Buildings 6) Hittae-Maiensaesshaus, 9) Alte Sust in der Engi, 10) Sidegga Haus Gerold, and 14) Rossbodenhuette-Andermatten Hans are located outside of the village. Location of Simplon village is marked on the map of Switzerland in the upper right.

In Büntgen et al. (2005) 64 larch samples from 7 buildings (Tab. 1, Fig. 1) were used for a 1000-year composite tree-ring proxy record to reconstruct alpine summer temperatures. This existing dataset is updated with 62 samples from 12 buildings (Tab. 1, Fig. 1). We eliminated the age-related growth inherent to the raw measurement series by calculating residuals from individually filtered negative exponential functions after power transformation (Cook and Peters 1997) and variance stabilisation (300 year spline) using the computer software ARSTAN (Cook 1985). This procedure emphasizes high- to mid-frequency variations in the resulting index chronologies, which were calculated as bi-weight robust means (Cook and Kairiukstis 1990). The existing tree-ring width chronology presented in Büntgen et al. (2005) do not have a continuous replication of ≥ 5 series throughout the entire past millennium (Fig. 2a). The new update chronology improve this existing chronology particularly during this low replication periods. The advantage is that the low replication periods in both chronologies complement one another to a sufficient replication (Fig. 2 a and b).

Table 1: Historical buildings in the Simplon village. Table lists total number of samples from each building, the existing samples (Büntgen et al. 2005), and the new samples used to update the long-term chronology from the Simplon valley.

Building	**Number of samples**	**Number of samples Büntgen et al. (2005)**	**Number of samples update**	**Time span AD**
Stall Dorsaz	27	26	1	685-1200
Weisses Kreuz	3	2	1	984-1424 and 1588-1681
Alter Gasthof	34	19	15	1160-1338, 1372-1618 and 1634-1852
Turru	4	4	/	1198-1487
Heidenhaus Zenklusen	8	8	/	1249-1416
Hittae-Maiensaesshaus	5	/	5	1292-1696
Kirchturm	10	/	10	1368-1458
Haus auf dem Dorfplatz	4	3	1	1398-1698
Alte Sust in der Engi	10	/	10	1406-1537
Sidegga Haus Gerold	7	/	7	1439-1629
Haus Peter Arnold	3	2	1	1491-1989
Postgebaeude	6	/	6	1652-1811
Kaplaneigebaeude	2	/	2	1718-1856
Rossbodenhuette-Andermatten Hans	3	/	3	1841-1922
Summ	126	64	62	685-1989

The residuum from both chronologies and the standard deviation between the Büntgen et al. (2005) and the new chronology are relatively low between 1220 and 1800 AD (Fig. 2c), indicating that the new chronology bits represent the same populations and can be used to update the chronology by Büntgen et al. (2005). A slight negative correlation between the standard deviation and the product of the two replications results in r = -0.13 (p<0.0001), indicating that the higher residuum and standard deviation from 800 to 1220 AD and after 1800 AD are due to the low replication in one or both chronologies during these periods. Because of this relatively low residuum and standard deviation between the two chronologies, we suggest that the records can be composed to one single chronology representing common TRW variability in the Simplon valley (Fig. 3).

This composite chronology has a continuous replication of ≥ 5 series from 738-1852 AD. Periods with slightly lower replication between 1600 and 1700 AD as well as after 1800 AD will be improved with samples from living trees from the Simplon region reaching ages up to 500 years. It is thus intended to combine the updated historical chronology with samples from living trees to develop an improved climate reconstruction spanning the past millennium.

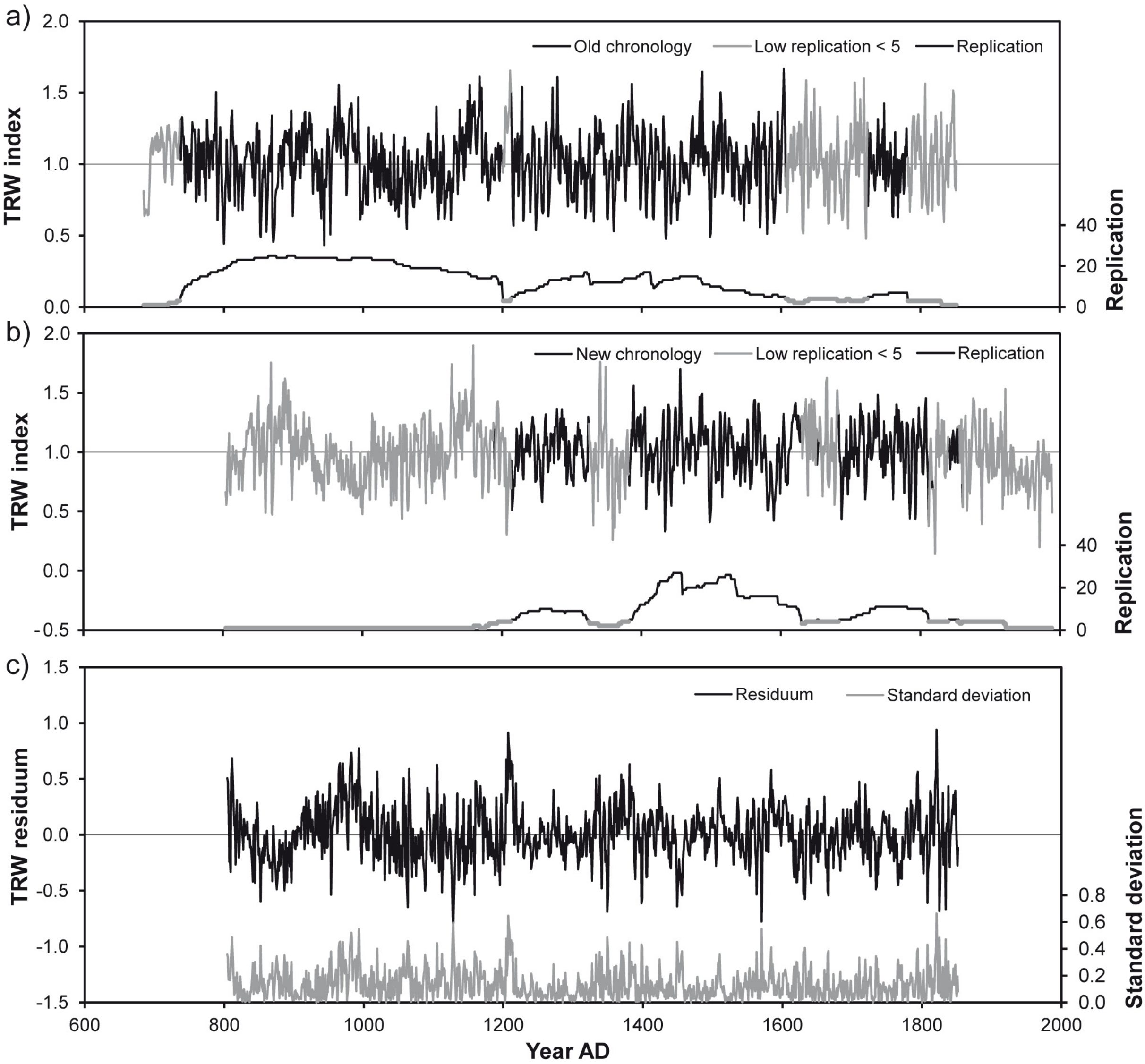


Figure 2: a) Old tree-ring width chronology (Büntgen et al. 2005) detrended with negative exponential functions together with the sample replication. b) New tree ring width chronology detrended with negative exponential functions together with the sample replication. Parts with a replication < 5 are marked in grey in both the chronologies and replication curves. c) Residuum of the old and the new chronology together with the standard deviation between existing (Büntgen et al. 2005) and new chronology.

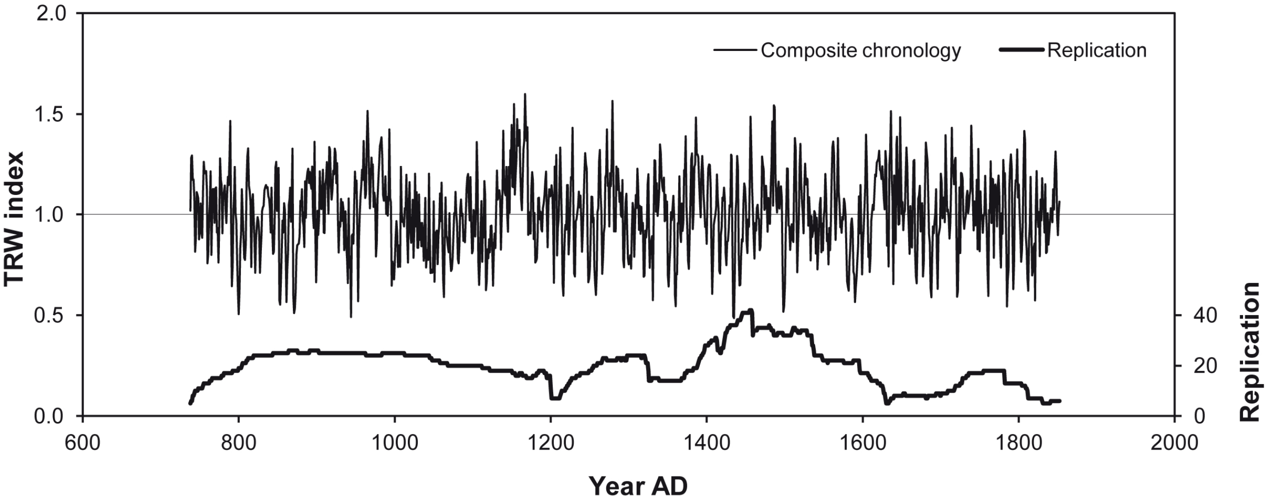


Figure 3: Composite tree-ring width chronology detrended with negative exponential functions and sample replication ≥ 5.

Conclusion and Outlook

Our new composite chronology provides a well-founded 1114-year long tree-ring record, which can serve as a basis for a homogeneous millennial-long climate reconstruction from the Simplon valley in Switzerland. Next steps include sampling of living larch trees along altitudinal transects in Simplon valley. Larch trees from different elevations from the valley bottom at 1400 m asl to the tree-line at 2200 m asl will be analysed to assess changing climate sensitivities with elevation (Affolter et al. 2010). The assessment will include southwest and northeast facing slope to evaluate the changing influence of larch bud-moth (*Zeiraphera diniana*) outbreaks on TRW data (Esper et al. 2007). These outbreaks can differ in their intensity with elevation and also with slope exposure due to preferred environmental conditions of the larch bud-moth (Baltensweiler & Rubli 1999).

Provenancing the historical wood samples with respect to elevation and perhaps even exposure will be a further step. This will be done by growth pattern analysis among the different sampling sites and historical timber samples (Wilson et al. 2005), and will support the development of a millennium-length chronology integrating ecologically homogeneous samples. It is intended to systematically reduce sample homogeneity during recent centuries to match the generally more heterogeneous character of the historical portion of the chronology. This procedure will likely enable a more realistic calibration scheme to transfer the TRW chronology into estimates of climate variability (Tegel et al. 2010).

Acknowledgments

We thank all house owners and the commune Simplon for the permission to take samples from their houses. Thanks to an anonymous reviewer and G. Helle for editorial work.

References

Affolter, P., Büntgen, U., Esper, J., Rigling, A., Weber, P., Luterbacher, J., Frank, D. (2010): Inner Alpine conifer response to 20th century drought swings. *European Journal of Forest Research* 129:289-298.

Baltensweiler, W., Rubli, D. (1999): Dispersal: an important driving force of the cyclic population dynamics of the larch bud moth, *Zeiraphera diniana* Gn.. *Forest Snow and Landscape Research* 74:74-153.

Büntgen, U., Esper, J., Frank, D. C., Nicolussi, K., Schmidhalter, M. (2005): A 1052-year tree-ring proxy of Alpine summer temperatures. *Climate Dynamics* 25: 141-153.

Büntgen, U., Frank, D. C., Nievergelt, D., Esper, J. (2006): Summer temperature variations in the European Alps AD 755-2004. *Journal of Climate* 19: 5606-5623.

Büntgen, U., Frank, D., Carrer, M., Urbinati, C., Esper, J. (2009): Improving Alpine summer temperature reconstructions by increasing sample size. *TRACE* 7: 226.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J., Herzig, F., Heussner, U., Wanner, H., Luterbacher, J., Esper, J. (2011): 2500 years of European climate variability and human susceptibility. *Science* 331: 578-582.

Cook, E. R. (1985): A time series analysis approach to tree-ring standardization. *Ph. D. thesis, The University of Arizona*: 171 pp.

Cook, E. R., Kairiukstis, L. A. (1990): Methods of dendrochronology: applications in environmental science. *Kluwer, Dotrecht*: 104-123.

Cook, E. R., Peters, K. (1997): Calculating unbiased tree-ring indices for the study of climatic and environmental change. *The Holocene* 7: 361-370.

Esper, J., Büntgen, U., Frank, D. C., Nievergelt, D., Liebhold, A. (2007): 1200 years of regular outbreaks in alpine insects. *Proceesings of the Royal Society* B 274: 671-679.

Frank, D. C., Esper, J. (2005): Temperature reconstructions and comparisons with instrumental data from a tree-ring network for the European Alps. *International Journal of Climatology* 25: 1437-1454.

Frank, D. C., Wilson, R. J. S., Esper, J. (2005): Synchronous variability changes in Alpine temperature and tree-ring data over the last two centuries. *Boreas* 34: 498-505.

Holmes, R. L. (1983): Computer-assisted quality control in tree-ring dating and measurements. *Tree Ring Bulletin* 43: 69-78.

Tegel, W., Vanmoerkerke, J., Büntgen, U. (2010): Updating historical tree-ring records for climate reconstruction. *Quaternary Science Reviews* 19: 1957-1959.

Wilson, R. J. S., Luckman, B. H., Esper, J. (2005): A 500 year dendroclimatic reconstruction of spring-summer precipitation from the lower Bavarian Forest region, Germany. *International Journal of Climatology* 25: 611-630.

Inter-annual variation in oak growth over the past century in southern England and northern France

E.L. Eaton [1*], N. Barsoum [2*], T. Levanič [3], J. Pargade [4], X. Bonnart [4] & J.I.L. Morison [1]

[1] *Centre for Forestry & Climate Change, Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK*
[2] *Centre for Human & Ecological Sciences, Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK*
[3] *Slovenian Forestry Institute, Večna pot 2, Ljubljana, SI-1000, Slovenia*
[4] *CRPF Nord-Pas de Calais-Picardie, 96 rue Jean Moulin, 8000, Amiens, France*
** These authors contributed equally.*
E-mail: edward.eaton@forestry.gsi.gov.uk

Introduction

Recent climate change has seen average temperatures in Europe rise by 1.2°C above pre-industrial levels, with a projected 1.8-4.0°C rise in temperatures by the end of the 21st century (Christensen *et al.* 2007; Murphy *et al*. 2010). Associated with these temperature changes across Europe during the 20th century are clear trends for an increasing frequency of warm extremes and a decreasing frequency of cold extremes (Klein Tank *et al.* 2002, van der Schrier *et al.* 2006, Christensen *et al.* 2007, Murphy *et al*. 2010). Given the long life-span of many trees, such rapid predicted changes in climate will occur during a single generation (Davis & Shaw 2001, St Clair & Howe 2007). There gives limited scope for rapid genetic adaptation to both changing climatic conditions and associated indirect environmental changes, such as an increasing frequency of pests, diseases, and forest fires (Logan *et al*. 2003, Westerling *et al*. 2006). A tree species' ability to survive – and even potentially to thrive – in the new and rapidly changing environmental conditions will depend instead on its phenotypic plasticity, granting some degree of physiological, biochemical and/or developmental response (Rehfeldt *et al*. 2001).

Quercus petraea (Matt.) Liebl. and *Quercus robur* L. are two of the most common native oak species in Europe, with a wide distribution – from 10°W to 59°E and 36°N to 59°N (EUFORGEN 2009, Forest Europe 2011). They are keystone species, present as a dominant tree species in a number of natural broadleaf woodland types across Europe (EEA 2008). Additionally, *Q. petraea* and *Q. robur* are important and much-valued sources of timber, widely grown in plantation stands. In the region of study (southern England and northern France) climate is not considered to be limiting for oak, though studies have found summer precipitation to be an important variable (*e.g.* Hughes *et al*. 1978, Mérian *et al*. 2011, Cooper *et al.* 2013). Veteran trees, such as the >1000 year old oaks found in Windsor Great Park, Berkshire, UK, attest to the very old age to which oaks can live, as well as their ability to survive variability in climate and other stresses. Nevertheless, over the past 20-30 years acute oak decline has emerged as a growing threat to oak trees, with climatic extremes (*e.g.* droughts and floods) thought to exacerbate the effects of a range of pests and pathogens that periodically cause damage (Denman *et al.* 2010). This study looks at past growth of oaks in even-aged plantation forestry stands, how they have responded to climate over the past century, and what any past relationships may mean for future management of such plantation oak stands in this southern England and northern France.

Materials and methods

Five regions in southern England and north-eastern France were selected (Fig. 1), covering a moderate climatic range from milder and wetter in Peninsula to warmer and drier in France (Inland). Oak trees in 22 even-aged monocultural plantation stands were sampled (Tab. 1). Up to 15 of the apparently healthiest and visually dominant or co-dominant trees were cored in each stand, with two cores per tree at 1.3m ±0.2m above ground level. Such trees were sampled to reduce the impact of varying responses to climate between oaks of different sizes (Zang *et al.*

DOI: 10.2312/GFZ.b103-13058

2012). Extracted cores were air-dried, mounted, and sanded to a high-polish finish (Stokes & Smiley 1996), then scanned using the *ATRICS* system (Levanič 2007), and ring-width measured to the nearest 0.01mm using *WinDENDRO* (Regent Instruments, Québec, Canada). Cross-dating was achieved through the *PAST-4* software (Sciem, Brunn/Geb, Austria), visual on-screen comparisons, and statistical parameters including the *t*-value after Baillie & Pilcher (1973) and Gleichläufigkeit (GLK%) (Eckstein & Bauch 1969). *COFECHA* (Holmes 1983) was used to check cross-dating accuracy. Raw ring-width series were detrended and standardised with the *dplR* library in R (Bunn 2008, Bunn *et al*. 2012, R Core Team 2012), using a cubic smoothing spline (50% frequency response at 67% of the series length) to remove non-climatic trends in tree growth. Index values were prewhitened and combined across all trees in a stand using Tukey's biweight robust estimation of the mean. The residual chronologies from this process were used in all further analyses, with the usable portion where the expressed population signal was ≥0.85 (for 50-year windows with 49-year overlap) (Briffa & Jones 1990).

Table 1: Site details.

Region	Stand number	Planting year (documented)	Location	Altitude (masl)
New Forest	1	1864	50.919°N 1.711°W	65
	2	1936	50.929°N 1.641°W	85
	3	1929	50.841°N 1.663°W	25
	4	1949	50.846°N 1.538°W	20
East Anglia	1	1934	52.436°N 0.855°E	30
	2	1938	52.503°N 0.857°E	35
	3	1932	52.515°N 0.676°E	10
	4	1934	52.427°N 0.899°E	20
Peninsula	1	1880	50.785°N 3.420°W	115
	2	1900	50.865°N 3.863°W	125
	3	1912	51.046°N 3.675°W	250
	4	1880	50.484°N 4.746°W	40
	5	1900	50.634°N 4.128°W	130
	6	1920	50.569°N 3.668°W	30
	7	1890	50.983°N 3.044°W	90
	8	1930-1949	51.187°N 3.604°W	340
France (Inland)	1	Unknown	49.153°N 3.450°E	200
	2	Unknown	49.592°N 3.843°E	75
	3	Unknown (pre-1930)	48.949°N 3.584°E	205
	4	Unknown (pre-1910)	48.891°N 3.398°E	175
France (Maritime)	1	Unknown (pre-1910)	50.327°N 2.244°E	120
	2	Unknown (pre-1950)	50.842°N 2.231°E	30

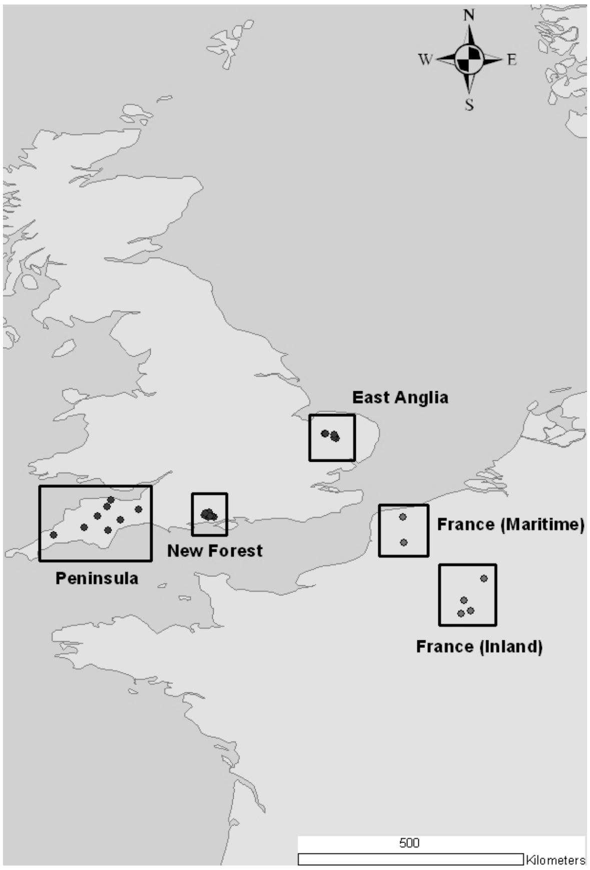


Figure 1: Map of forest stands cored and regions.

Monthly and seasonal mean temperature and precipitation sums were extracted from the CRU TS3.1 dataset (Harris *et al*. in review). These data are based on a 0.5° x 0.5° grid for the period 1901-2009; if a region covered more than one grid cell, the mean values were used (Tab. 2).

Table 2: mean temperatures and precipitation sums (bold) from CRU TS3.1, 1901-2009; standard errors in brackets.

Region	**Mean temperature (°C)**			**Mean annual precipitation sum (mm)**
	T$_{max}$	**T$_{average}$**	**T$_{min}$**	
New Forest	**13.8** (0.06)	**10.0** (0.05)	**6.3** (0.05)	**845** (12.8)
East Anglia	**13.2** (0.07)	**9.2** (0.06)	**5.3** (0.06)	**652** (8.2)
Peninsula	**13.1** (0.06)	**10.0** (0.05)	**6.9** (0.05)	**1240** (15.3)
France (Inland)	**14.7** (0.07)	**10.6** (0.06)	**6.4** (0.07)	**649** (9.2)
France (Maritime)	**13.8** (0.07)	**10.0** (0.07)	**6.5** (0.07)	**698** (10.4)

Pointer years (PYs) were determined based upon Drobyshev *et al*. (2008): for an individual tree, a pointer year was one in which the growth was outside the 5th or 95th percentiles (*i.e.* the measured ring width of that tree was beyond the mean ± 1.64sd). A pointer year at the district level was deemed to be one in which 15% or more of the trees in a district demonstrated such extreme growth in the same direction. Response function analyses were used to evaluate relationships between climatic variables and radial tree growth, using the *bootRes* library in R (Zang 2012).

Residual chronologies were compared to both monthly and seasonal mean temperatures and precipitation sums. Whilst using residual chronologies may risk losing some longer-term information, this was accepted, as this study concerns reasonably short-term effects on growth given its focus on future management.

Table 3: Stand-specific statistics.

Region	Stand no.	Trees sampled	No. of cores	Cores in analyses	Chronology length (yr)	Mean segment length	Average growth rate (mm.yr^{-1})
New Forest	1	15	30	27	141	129	1.55
	2	15	30	22	75	58	1.73
	3	15	30	26	78	76	2.08
	4	15	30	26	59	56	1.86
East Anglia	1	15	30	30	66	73	2.16
	2	15	30	28	68	62	2.14
	3	15	30	29	70	73	2.48
	4	15	30	28	68	68	2.00
Peninsula	1	15	30	16	195	64	1.36
	2	15	30	28	122	119	1.53
	3	15	30	30	145	120	1.39
	4	15	30	26	175	59	1.61
	5	15	30	30	122	117	1.68
	6	15	30	12	86	74	1.69
	7	14	29	27	231	91	1.46
	8	15	30	26	99	92	1.84
France (Inland)	1	12	24	22	139	61	2.66
	2	15	30	28	103	88	2.36
	3	15	30	30	130	107	1.81
	4	13	26	26	149	117	1.94
France (Maritime)	1	9	18	16	169	83	1.98
	2	15	30	30	74	69	2.33

Results and discussion

The regional chronologies (Fig. 2) have low GLK% values (58.3-64.3) and low mean sensitivities (0.22-0.26), indicating that within-stand agreement in growth is limited, and that the trees show only a marginal response to climate. Table 4 shows correlation coefficients and significances for between-region comparisons. For most of these, the chronologies correlate significantly ($p<0.05$); the exception to this are the New Forest and France (Inland) chronologies ($r = 0.151$, $p = 0.100$), indicating that oaks in these two districts do not show significantly similar growth, unlike those in all other regions. The strongest correlation is, unsurprisingly, between the two French chronologies ($r = 0.738$, $p<0.001$).

Table 4: correlation coefficients between regional chronologies.

	New Forest	**East Anglia**	**Peninsula**	**France (Inland)**	**France (Maritime)**
New Forest		*r* = 0.430 *p* <0.001 df = 58	*r* = 0.326 *p* <0.001 df = 118	*r* = 0.151 *p* = 0.100 df = 118	*r* = 0.223 *p* = 0.014 df = 118
East Anglia			*r* = 0.376 *p* = 0.003 df = 58	*r* = 0.255 *p* = 0.050 df = 58	*r* = 0.613 *p* <0.001 df = 58
Peninsula				*r* = 0.250 *p* = 0.003 df = 133	*r* = 0.340 *p* <0.001 df = 166
France (Inland)					*r* = 0.738 *p* <0.001 df = 118
France (Maritime)					

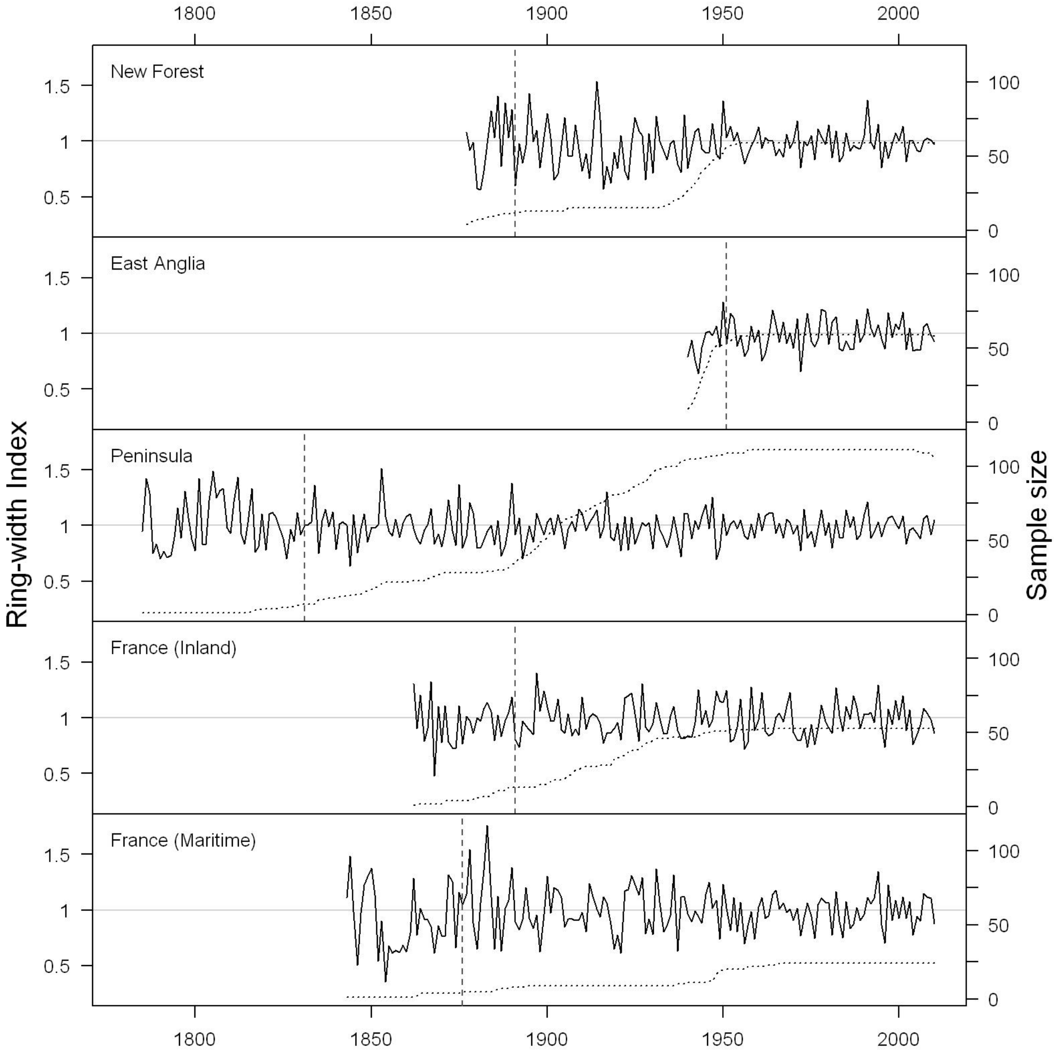


Figure 2: Regional chronologies for oaks in pure stands (solid line = mean chronology; dotted line = sample size; dashed line = year from which EPS ≥0.85).

At a regional level, there are more positive PYs than negative (Fig. 3). There is little agreement in PYs between regions: only twice does a PY in 15% or more of trees occur in two or more regions at the same time (1950 and 1991, both times positive). There are no common negative PYs. A well-documented and widespread outbreak of defoliating *Tortrix viridana* L. caterpillars followed by *Erysiphe alphitoides* Maulbec & Griffon 1912 on oaks in the study region in 1917-1926 (Robinson 1927) appears not to be reflected in the PYs. Whilst some growth depression in surviving trees might be expected, the exceptionally high mortality reported may mean that affected trees were not available for sampling in 2010, with those that survived with reduced growth possibly removed in later stand management operations, and so regional PYs are not apparent.

The second part of this study looked at potential relationships between oak growth and climate in each region, and any similarities between them, using response function analyses for the period 1902-2009 (all available climate data). Monthly response function analyses used a 14-month year, running from the June prior to ring formation through to July of the year in which the ring was laid down. Seasonal analyses (winter = December, January, February; spring = March, April, May; summer = June, July, August; autumn = September, October, November) ran from the autumn of the previous year to the autumn of the current year. When the climate-growth relationships are considered for an entire chronology (*i.e.* all years' ring-width indices) using monthly and seasonal climatic data, no climatic variable was significant in more than one region. This indicates that, despite reasonable geographic proximity and not wholly dissimilar climates across the sites, the particular climatic variables influencing radial increment of these oaks was not the same from one site to the next.

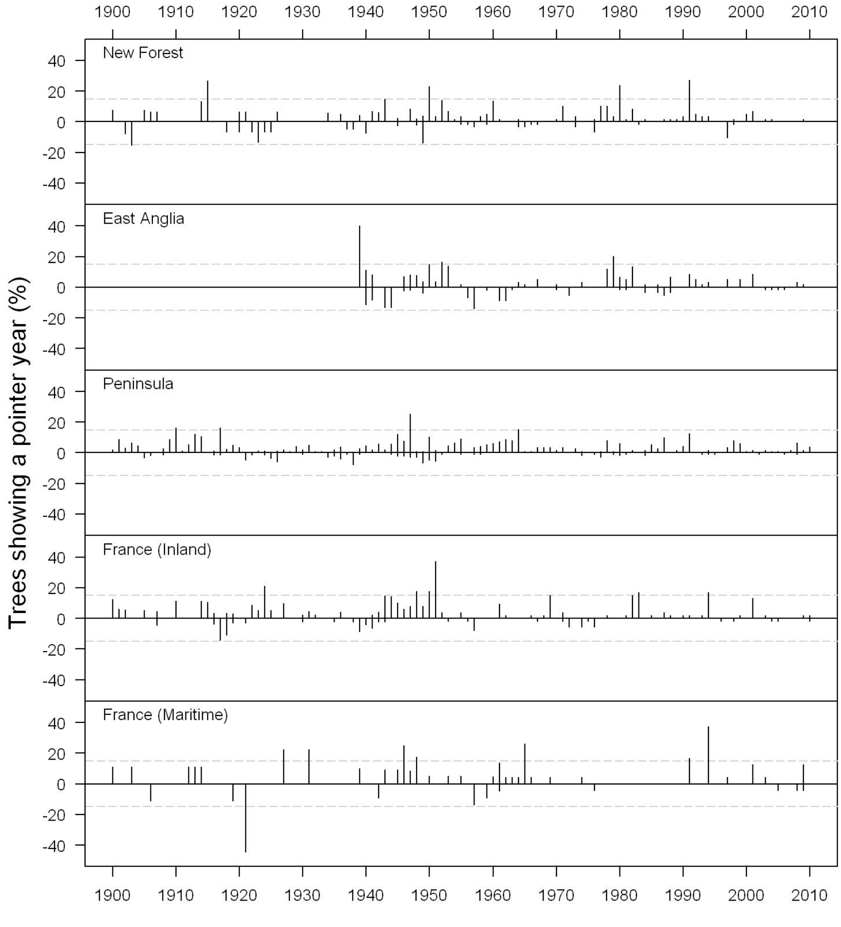


Figure 3: Pointer years - percentage of trees within each region demonstrating a pointer year (negative % indicates a negative pointer year; dashed line shows 15%, above which is a regional pointer year).

Previous studies in this area surrounding the English Channel have often combined local chronologies into broad regions, rather than considering the management-level scale of a forest district, as in this study and have generally found summer precipitation has a substantial positive impact on oak growth in this area of Europe, including north Wales (Hughes *et al*. 1978), western Germany (Friedrichs *et al*. 2009), Ireland (García-Suárez *et al*. 2009), northern France (Merian *et* *al*. 2011), eastern England (Cooper *et al*. 2013), central France (Michelot *et al*. 2012), and southern-central and south-eastern England (Wilson *et al*. 2013). Whilst this relationship is found in two (drier) regions (current June precipitation in East Anglia and France (Inland)), it is not common across the study area, as might be suggested from previous work.

As these analyses generated a single coefficient for each region for a period up to 108 years long, and there previous studies have found variation in the nature of climate-growth relationships in this area over time (Mérian *et al*. 2011, Cooper *et al.* 2013) 25-year moving response functions with 24 years' overlap were calculated. These showed no consistency in the direction or strength of the response functions for monthly or seasonal climate variables, thus showing that climatic determinants of oak growth in this region are not conserved temporally or spatially, with growth more strongly influenced by local factors, such as soil type and management.

Conclusions

From these analyses, it appears that there is generally little overall difference in the general growth of oak across the study area, as the only insignificant correlation occurred between the New Forest and France (Inland). This is not surprising, as all of the sites used are well within the natural range of both *Q. robur* and *Q. petraea*, so it may be expected that oaks are comfortably able to cope with the vast majority of the climatic conditions experienced over this range. During the best documented period of excessive oak mortality and morbidity due to a combined pest and pathogen attack on oak, the trees in this study showed little effect on their growth, with reasonably low numbers of trees showing pointer years. However, documentation of mortality rates in the studied stands at this time is very poor, and it is likely that those trees left to sample in 2010 were those that coped well enough with the infestation and infection to neither succumb at the time, nor to have such lasting damage that they were later removed during thinning operations. Whilst previous studies in southern England and northern France have largely found summer precipitation to be a determinant of oak radial increment, this study, encompassing both areas, has found that in highly managed even-aged oak plantations there is no common climate signal. Instead, it appears that local factors modify the effects of climate such that future adaptive management of these woodlands cannot be determined or derived at a broad level encompassing the English and French Channel coasts, but will need to be site-specific.

Acknowledgements

The authors wish to thank Richard Baden, Ben Jones, Rona Pitman, TSU Exeter and TSU Thetford at Forest Research; the Department of Yield and Silviculture of the Slovenian Forestry Institute; the CRPF Nord-Pas de Calais-Picardie; and the Forestry Commission's South England Forest District.

This work has been jointly sponsored by the Forestry Commission and the European Union (European Regional Development Fund) within the framework of the European INTERREG IV A 2 Mers Seas Zeeën Cross-border Cooperation Programme 2007-2013: "Investing in your future" (Project 090316 016-FR MULTIFOR: Management of Multi-Functional Forests).

References

Baillie, MGL & Pilcher, JR (1973): A simple cross-dating program for tree-ring research. *Tree-Ring Bulletin* 33: 7-14.

Briffa KR & Jones, PD (1990): Basic chronology statistics and assessment. In: Cook, ER & Kairiūkštis, LA (eds): Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic. 137-152.

Bunn, AG (2008): A dendrochronology program library in R (*dplR*). *Dendrochronologia* 26: 115-124.

Bunn, AG, Korpela, M, Biondi, F, Merian, P, Qeadan, F & Zang, C (2012): *dplR*: Dendrochronology Program Library in R. R Package version 1.5.5. http://CRAN.R-project.org/package=dplR

Carter, KK (1996): Provenance tests as indicators of growth response to climate change in 10 north temperate tree species. *Canadian Journal of Forest Research* 26: 1089-1095.

Christensen, JH, Hewitson, B, Busuioc, A, Chen, A, Gao, X, Held, I, Jones, R, Kolli, RK, Kwon, W-T, Laprise, R, Rueda, VM, Mearns, L, Menéndez, CG, Räisänen, J, Rinke, A, Sarr, A, and Whetton, P (2007): Regional climate projections. In: Solomon, S, Qin, D, Manning, M, Chen, Z, Marquis, M, Averyt, KB, Tignor, M, Miller, HL (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA, pp. 847–940.

Cooper, RJ, Melvin, TM, Tyers, I, Wilson, RJS, Briffa, KR (2013): A tree-ring reconstruction of East Anglia (UK) hydroclimate variability over the last millennium. *Climate Dynamics* 40: 1019-1039.

Davis, MB & Shaw, RG (2001): Range shifts and adaptive responses to quaternary climate change. *Science*, 292: 673–679.

Denman, S, Kirk, S & Webber, J (2010): Managing acute oak decline. *Forestry Commission Practice Note* FCPN015 Edinburgh. pp. 6.

Drobyshev, I, Niklasson, M, Linderson, H & Sonesson, K (2008): Influence of annual weather on growth of pedunculate oak in southern Sweden. *Annals of Forest Science* 65: 512. DOI: 10.1051/forest:2008033.

Eckstein, D & Bauch, J (1969): Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88: 230-250.

EEA (2008): Impacts of Europe's changing climate – 2008 indicator-based assessment. European Environment Agency. 246p.

EUFORGEN (2009) Distribution map of sessile oak (*Quercus petraea*); Distribution map of pedunculate oak (*Quercus robur*). www.euforgen.org.

Forest Europe (2011): *State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe*. Jointly prepared by FOREST EUROPE Liaison Unit Oslo, the United Nations Economic Commission for Europe (UNECE) and the Food and Agriculture Organization of the United Nations (FAO). Ministerial Conference on the Protection of Forests in Europe FOREST EUROPE Liaison Unit Oslo. 337 pp.

Friedrichs, DA, Büntgen, U, Frank, DC, Esper, J, Neuwirth, B & Löffler, J (2009): Complex climate controls of 20th century oak growth in Central-West Germany. *Tree Physiol*. 29: 39–51.

García-Suárez, AM, Butler, CJ & Baillie, MGL (2009): Climate signal in tree-ring chronologies in a temperate climate: A multi-species approach. *Dendrochronologia* 27: 183-198.

Guiot, J (1991): The bootstrapped response function. *Tree-Ring Bulletin* 25: 39-41.

Harris, I, Jones, PD, Osborn, TJ & Lister, DH (2012): Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 dataset. Submitted to *International Journal of Climatology*. Dataset retrieved from http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_1256223773328276

Holmes, RL (1983): Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69-78.

Hughes, MK, Leggett, P, Milsom, SJ & Hibbert, F.A. (1978): Dendrochronology of oak in north Wales. *Tree-ring Bulletin*, 38: 15-23.

IPCC (2007): Climate Change 2007 – The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge University Press.

Klein Tank, AMG, Wijngaard, JB, Können, GP, Böhm, R, Demarée, G, Gocheva, A, Mileta M, Pashiardis, S, Hejkrlik, L, Kern-Hansen, C, Heino, R, Bessemoulin, P, Müller-Westermeier, G, Tzanakou, M, Szalai, S, Pálsdóttir, T, Fitzgerald, D, Rubin, S, Capaldo, M, Maugeri, M, Leitass A, Bukantis, A, Aberfeld, R, van Engelen, AFV, Forland, E, Mietus, M, Coelho, F, Mares, C, Razuvaev, V, Nieplova, E, Cegnar, T, Antonio López, J, Dahlström, B, Moberg, A, Kirchhofer, W, Ceylan, A, Pachaliuk, O, Alexander, LV, Petrovic, P (2002): Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *International Journal of Climatology* 22 (12): 1441–1453.

Le Thiec, D & Dixon, M (1996): Acclimation of photosynthesis in Norway spruce and red oak grown in open-top chambers and subjected to natural drought and to elevated CO_2. *Canadian Journal of Forest Research* 26: 87-94.

Levanič, T (2007): ATRICS – a new system for image acquisition in dendrochronology. *Tree-Ring Research* 63: 117-122.

Logan, JA, Regniere, J, & Powell, JA (2003): Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and Environment* 1: 130–137.

Mérian, P, Bontemps, J-D, Bergès, L & Lebourgeois, F (2011): Spatial variation and temporal instability in climate-growth relationships of sessile oak (*Quercus petraea* [Matt.] Liebl.) under temperate conditions. *Plant Ecology* 212: 1855-1871.

Michelot, A, Bréda, N, Damesin, C & Dufrêne, E (2012): Differing growth responses to climatic variations and soil water deficits in *Fagus sylvatica*, *Quercus petraea*, and *Pinus sylvestris* in a temperate forest. *Forest Ecology and Management* 265: 161-171.

Murphy, J, Sexton, D, Jenkins, G, Boorman, P, Booth, B, Brown, K, Clark, R, Collins, M, Harris, G & Kendon, L (2010): *UK Climate Projections science report: Climate change projections*. Met Office Hadley Centre 10pp.

Pan, Y, Birdsey, RA, Fang, J, Houghton, R, Kappui, PE, Kurz, WA, Phillips OL, Shvidenko, A, Lewis, SL, Canadell, JG, Ciais, P, Jackson, RB, Paccala, S, McGuire, AD, Piao, S, Rautiainen, A, Sitch, S & Hayes, D (2011): A large and persistent carbon sink in the world's forests. *Science* 19: 988-993.

R Core Team (2012): R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org

Rehfeldt, GE, Ying, CC, & Wykoff, WR (2001): Physiologic plasticity, evolution, and impacts of a changing climate on *Pinus contorta*. *Climatic Change* 50: 355–376.

Robinson, RL (1927): Mortality among oak. *Quarterly Journal of Forestry* 21:25-27.

St Clair, J.B. and Howe, G.T. (2007) Genetic maladaptation of coastal Douglas-fir seedlings to future climates. *Global Change Biology* 13: 1441–1454, doi: 10.1111/j.1365-2486.2007.01385.x

Saxe, H, Cannell, MGR, Johnsen, Ø, Ryan, MG & Vourlitis, G (2001): Tree and forest functioning in response to global warming. *New Phytologist* 149: 369-399.

Stokes, MA & Smiley TL (1996): An introduction to tree-ring dating. Univ. of Arizona Press. 79p.

Van der Schrier, G, Briffa, KR, Jones, PD & Osborn, TJ (2006): Summer moisture availability across Europe. *Journal of Climate* 19: 2818-2834.

Westerling AL, Hidalgo, HG, Cayan, DR & Swetnam, TW (2006): Warming and earlier spring increases western US forest wildfire activity. *Science* 313: 940–943.

Wilson, R, Miles, D, Loader, NJ, Melvin, T, Cunningham, L, Cooper, R & Briffa, K (2013): A millennial long March-July precipitation reconstruction for southern-central England. *Climate Dynamics* 40: 997-1017.

Zang, C (2012): *bootRes*: Bootstrapped Response and Correlation Functions. R package version 1.2.2. http://CRAN-R-project/package=bootRes

Zang, C, Pretsch, H & Rothe, A (2012): Size-dependant responses to summer drought in Scots pine, Norway spruce and common oak. *Trees* 26: 557-569.

Reconstruction of ancient floodplain oaks on the base of subfossil oaks

F. Stenger

Otto-Friedrich-University of Bamberg, Dendrolabor, Dominikanerstraße 2a, 96047 Bamberg;
Private: Nonnenbrücke 2, 96047 Bamberg
E-mail: francois-stenger@gmx.de

Introduction

Trying to see the Holocene riverside woodlands reconstructed till up to the High Middle Ages, scientists used tree rings taken from subfossil oaks (e.g. Becker 1982, 1983, Friedrich et al. 2004, Leuschner et al. 2002, Schirmer 1979, Spurk et al. 2002). Those lay embedded in the sediments of German rivers. By identifying wood remnants from two gravel pits in northern Bavaria for the periods 5500 – 4000 BC and 550 – 850 AD, Kampmann & Schirmer (1980, Schirmer 2008) completed the spectrum of wood species in these forests.

The different shapes of subfossil oaks and the traces on the trunks were hardly taken into account so far. Now, the reconstruction of subfossil floodplain oaks was first implemented in a diploma thesis (Stenger 2010a, b). The research is continuing in a doctoral dissertation. The trunks in figures 4 and 5 are taken from a sand pit in northern Bavaria.

Subfossil oaks as ecological archives

Approach

Information on the life conditions of a floodplain oak are not only found in the tree rings. The trunk itself gives a number of references to the close environment of the former living tree. With the help of the tree ring patterns, its shape and the preserved relicts in and on the stem, the tree itself and its former close environment can be reconstructed. Concerning the environments it can be distinguished between singular trees or trees in sparsely populated stands and those in a dense stand (Fig. 1).

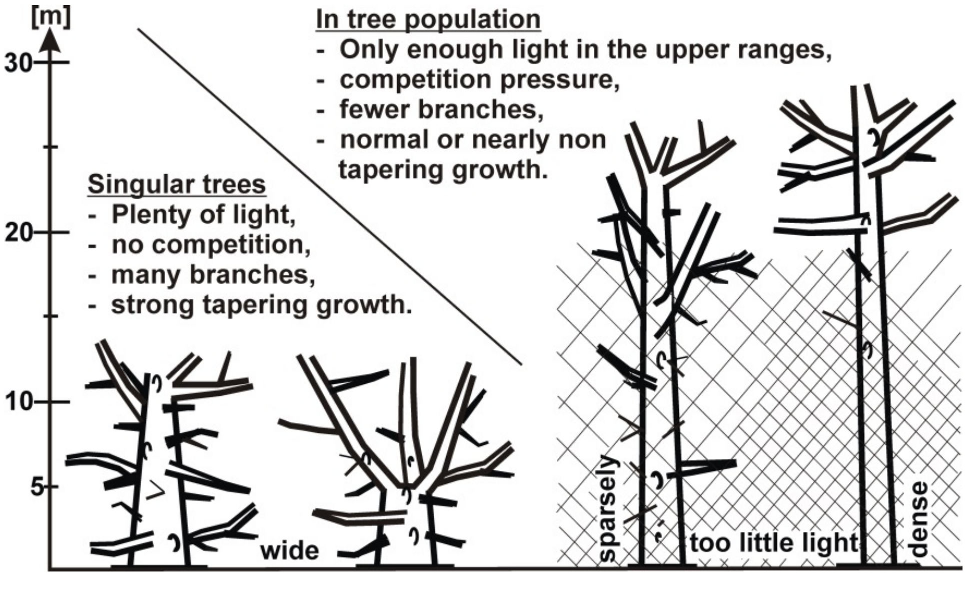


Figure 1: Sketches of floodplain forest oak trees on different sites: singular trees, a tree in a sparsely populated stand and one in a dense stand. Graphic: Stenger 2012.

In case a floodplain oak has had enough space from the beginning of its growth, the thicker branches can be found very far down the trunk when the oak has grown older. In this area of the trunk, the knot arrangements have exhibit opening angles up to around 90° (horizontal) or more (growing downwards). In the area closer to the treetop, the branches also grow at a steeper angle. Because of the living conditions in the floodplain the tree would reach a lower height than those growing in a dense stand. It would have many vestiges of branches with larger diameters and would grow strongly tapered. In contrary in a denser stand the development of the knot arrangements would be different: In the lower part of the trunk there are very few or no traces of branches. The larger branches would grow at a greater height of the tree trunk, often only building the crown. The branches in the lower part would be growing in a steeper angle, of about 60° and more (Stenger 2010a, b). In the crown area the lower branches can also have a nearly horizontal angle (dominant tree). Such an oak may reach a height of 30 m and more. One can observe that the closer the stock, the less is the tapering of the trunk.
In other words number, size, angle and position of branches are a function of stand density.

Methods

Collecting information from the trunks

After cleaning the tree trunk, the following parameters and special features were measured, mapped and described: The size of the root, the diameter of the stem in different heights from the root collar to the tree top, the preserved total length of the stem, knot holes, branch leftovers, intergrown knots, wounds, callus and cicatrisation, biogenic traces like holes from insects, beaver traces, plant remains, fungal residues; wood defects, e.g. spiral growth, bending and ring shake. The root collar is the measuring base to locate all parameters concerning the trunk. The angles of the former knot arrangements are mainly measured within the inside of the stem (knot holes). On the outside of the stem the knot arrangements are measured on the leftovers of big branches. The age of the tree trunk is determined dendrochronologically. The method is applied to the subfossil *Quercus ssp.* and *Fraxinus ssp.*

Measuring the angle of knot arrangements

The angle measurement on knot holes is based on the idea that a branch is built like a stem: it has a softer pith, heartwood, sapwood and the bark. A metal rod (D= 8 – 10 mm) with a blunt tip is set onto the visible pith of the knot hole and beaten into it with a hammer. The rod will follow the pith and displace the surrounding heartwood. More specifically, it follows the wood fibers growing in the longitude of the branch. Since it cannot escape into the surrounding wood, a falsification of the angle is not possible. Protruding from the pith the rod will display the original angle of the branch (Fig. 2).

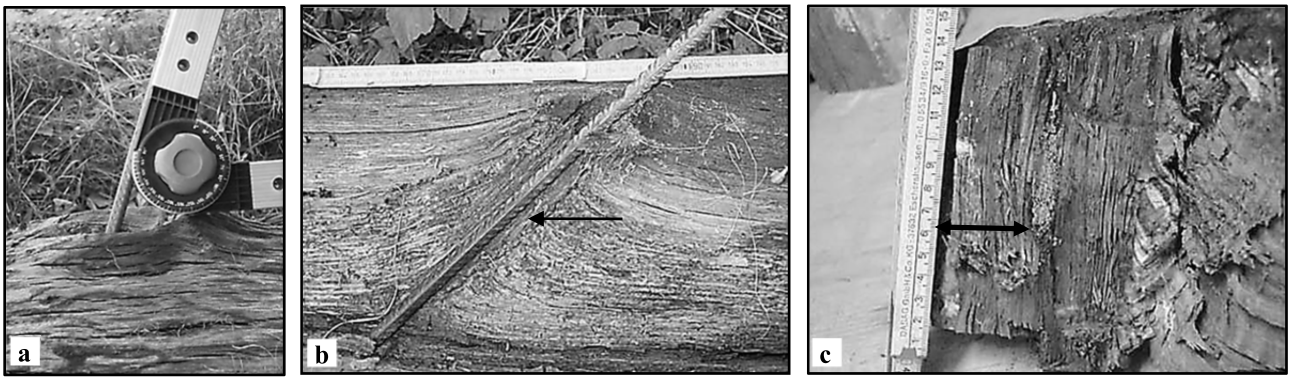
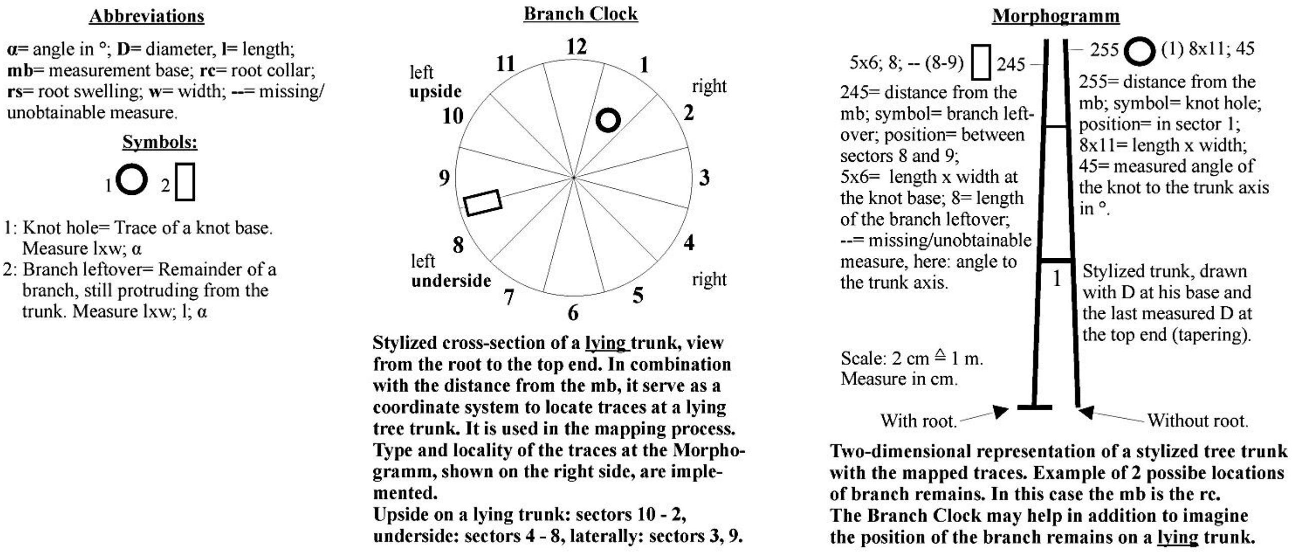


Figure 2: (a) Angular measurement on a knot hole by placing the angle meter on the metal rod and the trunk axis. (b) Example of a metal rod in a knot hole. Arrow: Pith of the knot. (c) Knot hole from figure 2 open. The arrow below indicates how deep the metal bar penetrates the pith. The trunk in (a) is dated 559 AD, the stem in (b) is not dated. Photos: Stenger 2008 (a), 2009 (b, c).

With a measuring inaccuracy of about ± 5° the opening width can be detected with an angle meter. On preserved larger branches the angle can be measured with the same method, without the help of a metal rod. The angle on a stem fork can be measured between the branches.
The course of a vanished branch can be reconstructed for a maximum of 50 cm outside the trunk. The measurements can be limited by e.g. rotten knot holes, the pith of knot holes being too short or the knot holes having diameters less than 30 mm. Because the trunk is lying on the ground, approximately 1/12 of the traces on the stem (sector 6, fig. 3) are hidden. In about 2/12 (sectors 5 and 7) the angular measurement of tree branches is, due to the length of the rod, difficult. Every stem with root or root swelling and a certain stem length (depending on the tree age) is mapped. On stems without a root and a certain length the trunk should imply, that it is not a big branch. Short pieces of stems from somewhere from the tree trunk were not worked on.

Mapping a subfossil trunk

In figure 3 the tools for mapping and the presentation of the trunks are presented. The shape of the oaks and the traces on their trunks are illustrated in the *Morphogramm*. The specifically developed *Branch Clock* with its symbols helps to specify the location of branch relicts and other features on the stem. The Branch Clock is divided in 12 sectors with 30° each. Together with the distance from the measurement base, for example the root collar, thus results a coordinate system. To describe the branch traces on a lying trunk there are two different symbols. Round ones represent knot holes, rectangular ones preserved branches.



α= angle in °; **D**= diameter, **l**= length; **mb**= measurement base; **rc**= root collar; **rs**= root swelling; **w**= width; **--**= missing/ unobtainable measure.

1: Knot hole= Trace of a knot base. Measure lxw; α
2: Branch leftover= Remainder of a branch, still protruding from the trunk. Measure lxw; l; α

Stylized cross-section of a lying trunk, view from the root to the top end. In combination with the distance from the mb, it serve as a coordinate system to locate traces at a lying tree trunk. It is used in the mapping process. Type and locality of the traces at the Morphogramm, shown on the right side, are implemented.
Upside on a lying trunk: sectors 10 - 2, underside: sectors 4 - 8, laterally: sectors 3, 9.

245= distance from the mb; symbol= branch leftover; position= between sectors 8 and 9; 5x6= length x width at the knot base; 8= length of the branch leftover; --= missing/unobtainable measure, here: angle to the trunk axis.

255= distance from the mb; symbol= knot hole; position= in sector 1; 8x11= length x width; 45= measured angle of the knot to the trunk axis in °.

Stylized trunk, drawn with D at his base and the last measured D at the top end (tapering).

Scale: 2 cm ≙ 1 m.
Measure in cm.

Two-dimensional representation of a stylized tree trunk with the mapped traces. Example of 2 possibe locations of branch remains. In this case the mb is the rc.
The Branch Clock may help in addition to imagine the position of the branch remains on a lying trunk.

Figure 3: Implements for locating traces on a lying subfossil trunk. Left: Most important abbreviations and the variations of symbols, representing the two different branch remains. Middle: The Branch Clocks, illustrated on a stylized cross section of a lying trunk, view from the base of a trunk to its top end. In the example of the Branch Clock the symbols for the traces knot hole and branch are shown in the sectors. They can be found on the Morphogramm again (sector number) and on the real trunk at their corresponding location. They do not represent traces on a stem disk respectively on a cross-section of a trunk! In practice, not all symbols come to application in each sector because of missing traces in some (or all) sectors on the whole mapped trunk. Right: A sketch of a Morphogramm and of how it can be read. Graphic: Stenger 2012/13.

All entries in the Morphogramm are also found again on the tree trunk itself (Fig. 4, 5). In figure 6 a and b examples of the two-dimensional Morphogramm without a photo of the trunks are shown.

The illustration and interpretation of reconstructed subfossil oaks

A tree is a three-dimensional object. However, currently it can just be illustrated in two dimensions. For a better understanding of the two-dimensional representation of a tree, figure 4 shows the lying and upright subfossil oak LIFMT018 with its Branch Clock and Morphogramm. In the figures 5 and 6 more examples of Morphogramms of trees in different former stands are given.

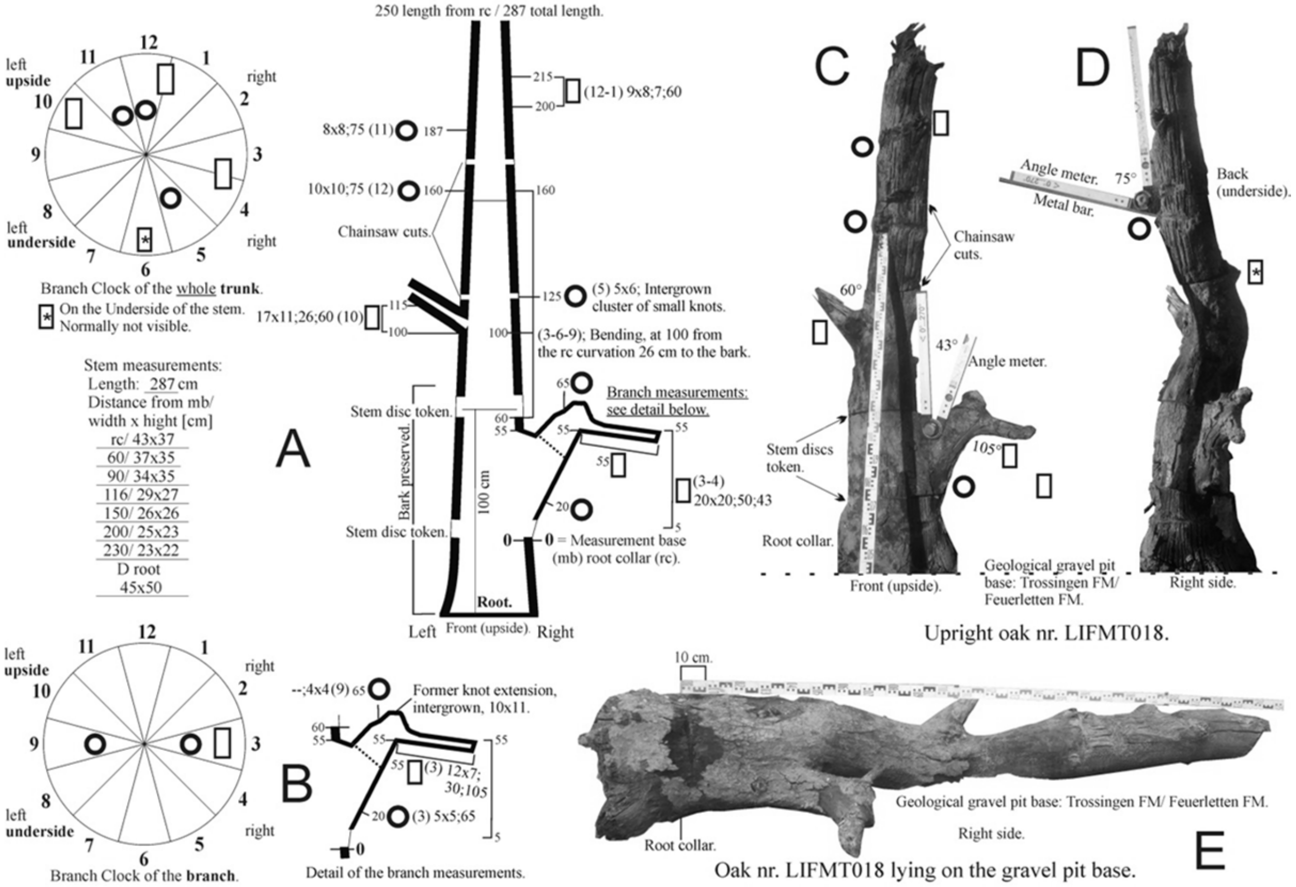


Figure 4: The Morphogramm (A) and photos in three different views of the subfossil oak nr. LIFMT018 (46 year rings, with bark, not yet been dated). The trunk in its lying position as it was found (E) and in upright position (C, D). The Branch Clock shows the mapped kind of branch traces and their position on the trunk. They can be compared with the symbols on the Morphogramm. In the stem measurements the total length and the diameter of the stem at different heights on the trunk are found. The measurement base is the root collar, marked with 0. B illustrates the detail of the branch on the right side of the Morphogramm with its Branch Clock. For longer branches a new Morphogramm would be used with the knot base as measurement base. The reference axis for the angle measurement is then the one of the branch. On a stem fork the angle would be measured between the branches, the reference axis is not the trunk axis. In C and D the upright stem with the traces on the Morphogramm can be compared. The leveling-rod in C does not show the real height of the oak. It is meant to support the trunk and keep it from falling over. Both, the Morphogramm and the oak in C are showing the front side of the trunk. It is the upside of the lying trunk (E). On photo D, the right side of the erected stem with the strong bending is illustrated. The same side is shown in E. The angular measurement on a preserved strong branch and the measured angel widths are shown in C. In D the measurement of a knot with the help of a metal bar is demonstrated, the angle width is 75°. The only trace on the back side of the trunk can be seen on photo D.
This oak is a young one which stood probably on a bank slope with its front side to the river, the back side oriented to the slope. On the front side there was more light and low pressure from grass, shrubs or trees in contrary to the back side. The reason for the curvature was not the destruction of the treetop at a certain time. For this there are no marks. By a slope slump the oak came in a skewed position. As the oak fell into the river, the balance point of the treetop had already been repositioned over the root center again (Mattheck 1991). Photos: Stenger 15.09./ 19.09.2012, graphic 09.2012.

In the figures 5 and 6 mapped trunks are illustrated with their Morphogramm. One stem has been a singular tree, two have been standing in populated stands.

Example 1, singular tree: Short, strongly tapered trunk, branches densely scattered throughout the stem, the first strong branches very low on the trunk, a large amount of branches of all sizes (Fig. 5), wide and irregular tree rings.

Example 2, one side in shadow, one with more light: Normal tapered trunk, on the light side strong branches are set lower on the stem, the knot arrangements of the first branches have more than 90°, these branches were growing downwards. Here the angle measurement was possible because there was another trunk lying under this log. The first big branch on the shaded side is set higher on the stem, most of the measured knot arrangements have angles of less than 90°, in the upper part of the tree trunk the opening angle flattens (Fig. 6a). The tree rings are regular and not as wide as in example 1.

Example 3, dense stand: This formerly probably dominant oak has got a little tapered trunk, no traces of branches until the remained top end of the trunk (Fig. 6b). The tree ring width can be described as narrow.

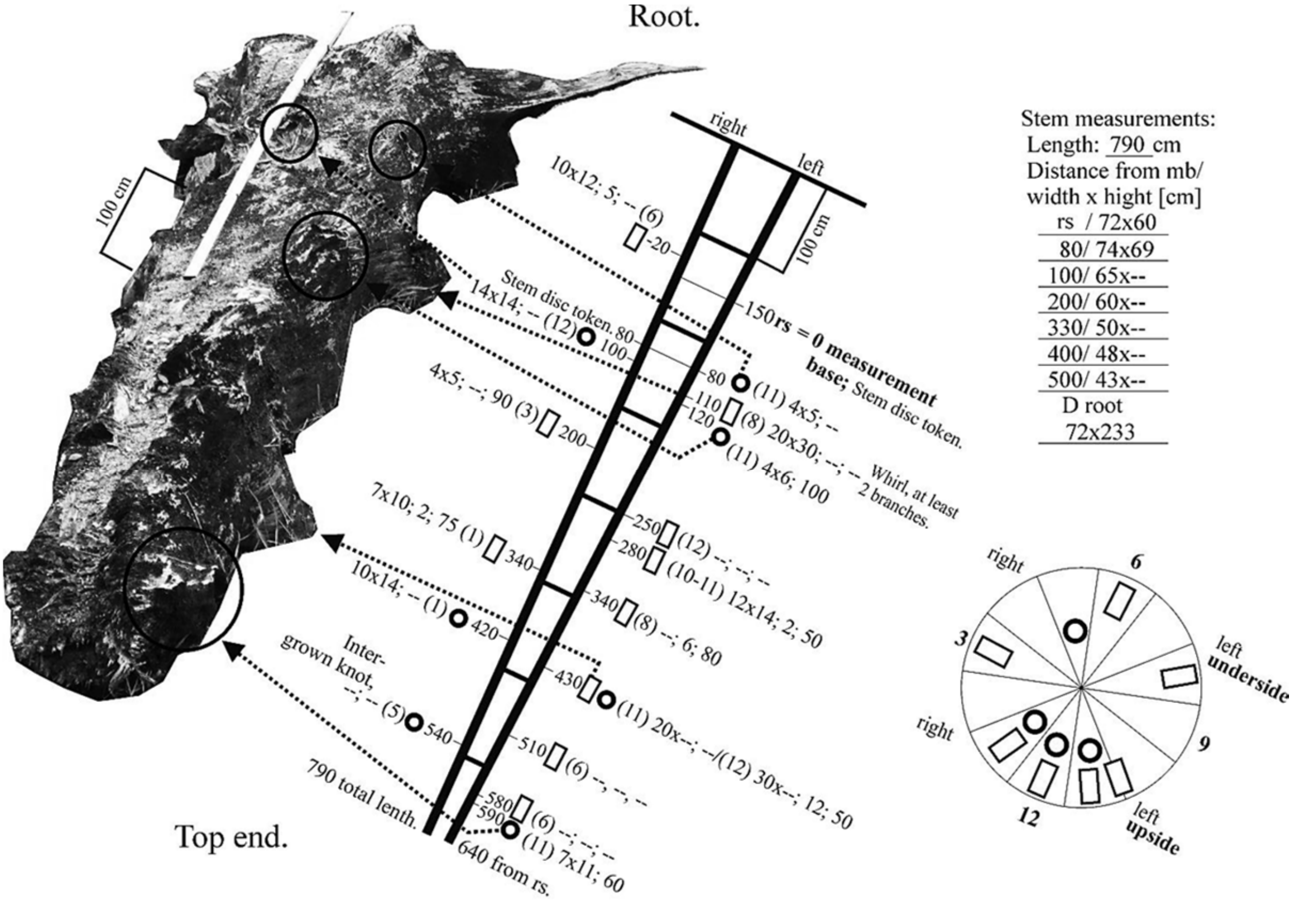


Figure 5: Photo and Morphogramm of the subfossil oak nr. 11 (96 year rings, not dated, average tree ring width: 3.48 mm in 80 cm distance from the root swelling). On the upper side the stem is grinded. It is strong tapered with many big branches. The first one is situated -20 cm from the root swelling. On the left side 3 branch remains are showing angles between 50° and 60°, one with 80°, one with 100°. On the right side two angles with 75° and 90° could be measured. The symbols in the Branch Clock represent only the mapped branch leftovers by sectors on the trunk; they say nothing about the number of the mapped traces. The dashed lines with the flashes are pointing to branch remains recognizable on the photo. This oak is an example for a former single standing, fast grown in height and width, and therefore gnarled tree. Photo: Stenger 2008, graphic 2008/ 2012.

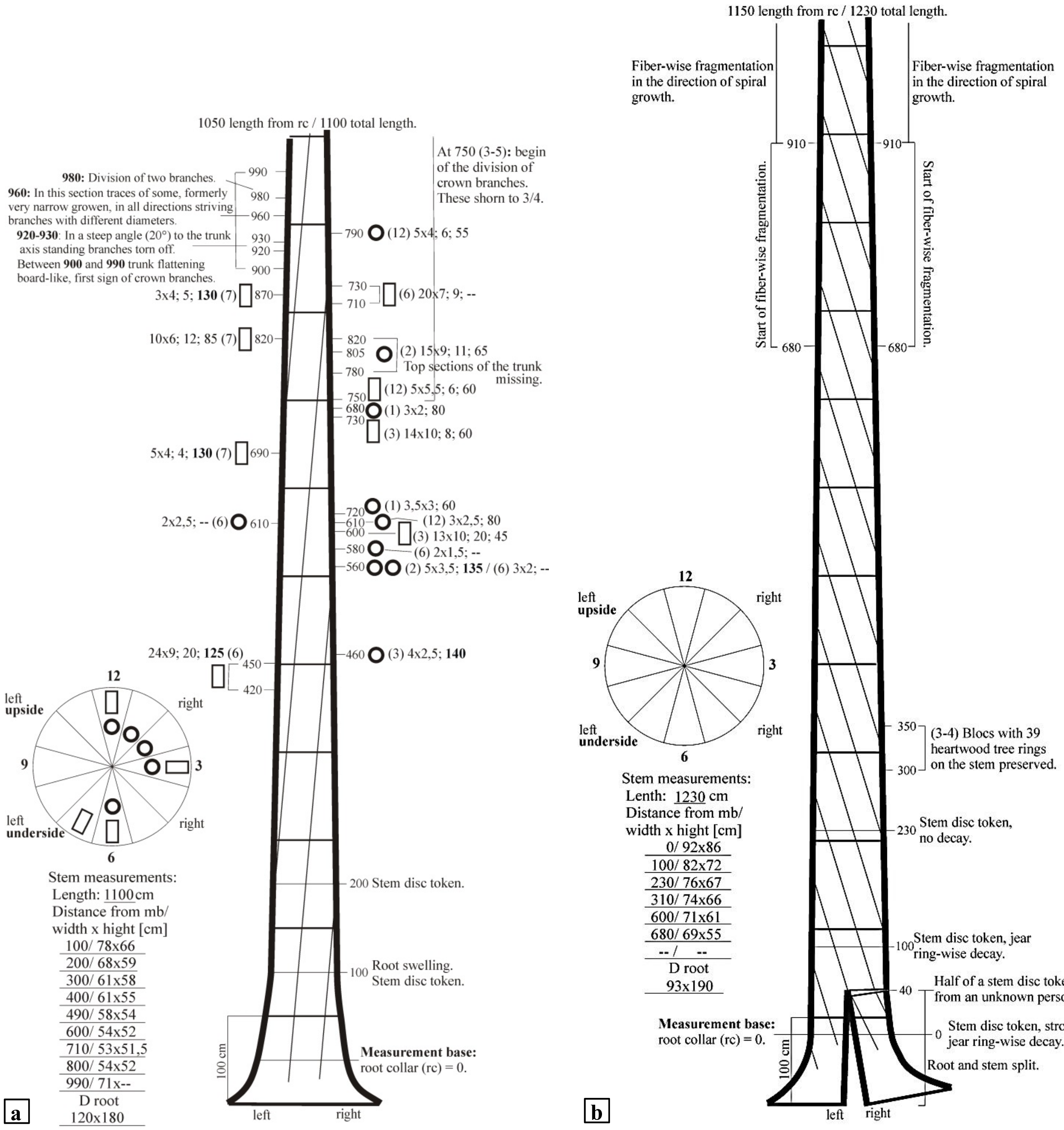


*Figure 6: **(a)** Morphogramm of the subfossil oak nr. 23 (110 year rings, dated 536 AD, average tree ring width: 2.98 mm in 250 cm distance from the root collar). The normal tapered grown stem is a sign for a regularly growth in height and width in a sparsely populated stand. There are downwards growing knots (more than 90°; angles bold) located on one side of the whole stem. This may be a sign that they were on the light side, maybe on the border or a clearing of the forest. The oak tried to reach more light by growing branches out of their own shadow. Most of the angles of the branches on the other (shadowy) side have angles much lower than 90°. Spiral grown from the left to the right side, deviation about 5° from the stem axis (dash signature). **(b)** Morphogramm of the subfossil oak nr. 29 (310 year rings, dated 4251 BC the year rings of the tree ring blocs added. Average tree ring width: 1.46 mm in 100 cm distance from the root collar). The tree stood in a former dense stand, probably it was a dominant oak. It has a little tapered grown trunk and no branch remains. Strong spiral grown from the right to the left side, deviation about 17° from the stem axis (dash signature). Graphic a, b: Stenger 2009/ 2012.*

Note: Due to the living conditions in the floodplain the tree ring width classifications wide, normal and narrow grown for historic oak construction timber cannot be compared with the ring width of these subfossil oaks.

Results

The research is still in the basics. Whether all the collected information are important or not will be seen after analyzing a larger quantity of trunks. The Branch Clock is an effective and practicable implement to locate traces on a stem. In combination with the Morphogramm it is also a useful tool for a first two-dimensional visualization of the shape and the distribution of branch remains on the trunk. In addition with the angular measurement on knot holes and on remains of big branches protruding from the trunk, the arrangements of the branches can be reconstructed. But this gives us an imagination of how a single oak has grown with a view at the close environment of this single oak. The tree trunks as unique biological archives are available only for a relatively short time: They are sold, decomposed by natural processes or the localities are no longer accessible. All undocumented information are lost information. So, the more information we can collected from a trunk, the better will be the understanding of the former living tree and its close environment.

To reconstruct the living environment in a, for example floodplain forest, there is a need of a great collective of trunks as a kind of scaffold trees. The preconditions for this are: They shared approximately the same lifetime in a close area, the finding spot or area in the pit (bog, etc.) is known, and, depending of the tree ages, they have to have a certain stem length. For statistical analysis on a large collective of trunks, the mapped stems can be divided into classes according to their places in the floodplain forest. By way of example, there are oaks amidst and on the border of a forest. Tree trunks with a similar height and similar living conditions (here two different collectives) can be merged. Trunks from single or dominant oaks must be considered separately.

For instance, in the diploma thesis (Stenger 2010a, b) 49 stems respectively pieces of oak-stems were analyzed. 25 stems were dated between 426 AD and 628 AD. Of those dated oaks only 12 trunks have been in good condition. The preserved height of 2 stems was 4.9 and 6.1 meters (m). 9 trunks had a length between 9.1 and 11.05 m and one 13.7 m. The tapering of 6 of the larger trunks was normal, which means that these trees have been standing in a more or less sparsely populated stand. The variation of the angles was between 30° and 80° (and larger: nr. 23). The branch settings on the trunks were starting between 2.0 and 3.0 m above the root collar. 5 oaks had less tapered trunks (thinning of about 1 cm/m), the first branches set higher than 4 m. Most of the branches had angles between 35° and 50°. They have been standing in a dense populated stand. A probably dominant oak had 13.7 m of length obtained with just 16 branches, but more than 75% large ones (D > 10 to 75 cm). The first visible branch was set in a height of 4.1 m and the branch settings on 8 measurable branches were between 18° and 48° (the other branches were rotten or the angles not measurable).

For the 12 oaks can be said in summary, that about 50% of the branches are set in between 4/ 5 m and 8/ 9 m from the root collar. In the upper part of the stems there were less, but more large branches.

However, it is absolutely not easy to get a suitable collective.

Conclusion and outlook

With the developed and presented tools it is possible to reconstruct individual trees, within the limits that have been identified. Looking at the preserved features, it can be inferred to many things, such as the shape of the tree including the knot arrangement of the stem, the nature of the close environment, whether the tree has been alive, partly or totally dead before it was covered with sediments. By collecting further information from the trunk we gain more insight into the ecological setting of an ancient floodplain forest. With this we can start an extended interpretation of year ring sequences to detect possible local, non-climatic influences on the tree ring patterns.

This will have more significance when a larger amount of trees, which lived at the same time in a narrow spatial area, is scientifically processed.
However, after further researches it could be possible to verify changes in the habitus of the oaks in the course of the millennia. Maybe we will detect traces of direct influence of anthropological influence on the growth of trees (e.g. by cutting off branches), and a lot more. In addition with the determination of wood findings near the oak stems the picture of Holocene floodplain forests will be more detailed. Perhaps this, or a modified method will as well be applicable in archeology, for example at the investigation of stems from boardwalks made from trunks, on preserved stems in bogs, in paleontology on fossil stems, on stems coming out due to the melt of mountain glaciers, on tree trunks from the lignite mining or on trunks lying on the ground of lakes or the sea, and the like. The measurement of the angle of knot arrangements may not be possible on all kind of wood. But just the mapping of a trunk gives a lot of information. As a future target, maybe it will be possible to reconstruct ancient floodplain forests in the course of the millennia with oak and ash as scaffold trees. The reconstruction of forests with other tree species may be possible, too. For some time, a computer program is developed in which the trees can be represented three-dimensional. It will be available for scientific purposes at leisure. This will be the first step for further investigations in prehistoric and historic Holocene floodplain forests.

Acknowledgements

Prof. Dr. G. Schellmann, University of Bamberg, first supervisor of the thesis and now in the dissertation, Prof. Dr. A. Bräuning, University of Erlangen-Nürnberg, second supervisor in the dissertation, Dr.-Ing. Dipl.-Holzwirt T. Eißing, head of the dendrolaboratory of the University of Bamberg, second supervisor of the thesis, for granting free usage of the dendrolaboratory in the thesis and in the dissertation, Dipl. agr. biol. M. Friedrich, University of Hohenheim, free dendrochronologically dating of the subfossil oaks in the thesis and in the dissertation, ANDREAS STIHL AG & Co. KG, respectively the EVA MAYR-STIHL foundation, for lending a chain saw STIHL$^{©}$ MS 660 with equipment in the thesis and in the dissertation (in March 2013, the author received the saw as a gift), Mr. Leppert, Kaspar Röckelein KG, factory Altendorf, for the possibility to do the thesis in their sand pit and Mr. Grosse for his support and the opportunity to continue the work in this sand pit in the dissertation, Mr. Stephan F. H. Schöpplein, Ziegelhöfer Holz Breitengüßbach, for various support in the dissertation, Mr. Gökhan Tura, head of EXPOLIO GmbH, Nürnberg, for the just ongoing, free developing of a software to present the trees three-dimensionally, and many others.

References

Becker, B. (1982): Dendrochronologie und Paläoökologie subfossiler Baumstämme aus Flussablagerungen. Ein Beitrag zur nacheiszeitlichen Auenentwicklung im südlichen Mitteleuropa. Mitteilungen der Kommission für Quartärforschung der Österreichischen Akademie der Wissenschaften 5. Verlag der Österreichischen Akademie der Wissenschaften. 120 p.

Becker, B. (1983): Postglaziale Auwaldentwicklung im mittleren und oberen Maintal anhand dendrochronologischer Untersuchungen subfossiler Baumstammablagerungen. In: Bundesanstalt für Geowissenschaften und Rohstoffe, Geologische Landesämter der Bundesrepublik Deutschland (ed.): Holozäne Talentwicklung - Methoden und Ergebnisse. *Geologisches Jahrbuch* Reihe A 71: 45-59.

Friedrich, M., Remmele, S., Kromer, B., Hofmann, J., Spurk, M., Kaiser, K. F., Orcel, C., Küppers, M. (2004): The 12,460-year Hohenheim oak and pine tree-ring chronology from Central Europe - A unique annual record for radiocarbon calibration and paleoenvironment reconstructions. *Radiocarbon* 46(3), 1111-1122.

Kampmann, T., Schirmer, W. (1980): Hölzerspektren aus Flußablagerungen. In: Schirmer, W. (ed.): Geology of the Main-Valley. Holocene valley development – methods and results. Guidebook for the Symposium Franken. Department of Geology of the University of Düsseldorf. 36-41.

Leuschner, H. H., Sass-Klaassen, U., Jansma, E., Baillie, M. G. L., Spurk, M (2002): Subfossil European bog oaks: population dynamics and long-term growth depressions as indicators of changes in the Holocene hydro-regime and climate. *The Holocene* 12(6), 695-706.

Mattheck, C., (1991): Die Baumgestalt als Autobiographie. Einführung in die Mechanik der Bäume und ihre Körpersprache. Kernforschungszentrum Karlsruhe GmbH. 137 p.

Schirmer, W. (1979): Rannen im Mainschotter. *Fränkische Heimat am Obermain* 16. Self-publishing: Meranier-Gymnasium of Lichtenfels. 43 p.

Schirmer, W. (2008): Der Naturraum Main-Regnitz im ersten Jahrtausend n. Chr. In: Bergmann, R., Dippold, G., Haberstroh, J., Lang, C., Weiß, W (eds.): Missionierung und Christianisierung im Regnitz- und Obermaingebiet. *Historischer Verein Bamberg* 41: 46-60.

Spurk, M., Leuschner, H. H., Baille, M. G. L., Briffa, K. R., Friedrich, M. (2002): Depositional frequency of German subfossil oaks: climatically and non-climatically induced fluctuations in the Holocene. *The Holocene* 12(6): 707-715.

Stenger, F., 2010a, b: River sediments and subfossil oaks in the floodplain of the river Regnitz between Sassanfahrt and Seußling (District of Bamberg, Upper Franconia) - a river historical, dendrological and dendrochronological study. Volume I (a): Text with 153 figures, 15 tables. Volume II (b): 76 appendixes. *[Diploma Thesis, German, unpublished].* I 233 p, II 85 p.

Late-Holocene peatland expansion and tree succession at Viss mosse, southern Sweden, inferred from subfossil trees and peat stratigraphy

J. Edvardsson [1], A. Poska [2], D. Hammarlund [1], H. Linderson [1] M. Rundgren [1],
N. Van der Putten [1] & A. Hansson [1]

[1] *Quaternary Sciences, Department of Geology, Lund University, Sölvegatan 12, 223 62, Lund, Sweden*
[2] *Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, 223 62, Lund, Sweden*
E-mail: Johannes.edvardsson@geol.lu.se

Background and aims

In connection with an on-going study of bog-pine establishment and die-off phases believed to reflect climatically induced hydrological changes in South Swedish ombrotrophic bogs (Edvardsson et al., 2012a, b), trunks of oak (*Quercus robur*), ash (*Fraxinus excelsior*) and alder (*Alnus glutinosa*) were found at the peat bog Viss mosse. The main part of the pine material covers the period 5284-4559 BC (Edvardsson et al. 2012b). However, most of the deciduous trees were found closer to the margins of the bog and can therefore be assumed to reflect subsequent forest establishment phases following lateral expansion of the peat deposit.

To combine bog-tree dendrochronology and peat stratigraphy have proved to be useful for reconstruction of both site development and regional climate variations (Eckstein et al. 2010, 2011, Edvardsson et al. 2012b). As opposed to the pine-based study of Viss mosse by Edvardsson et al. (2012b), this study focuses on: (1) deciduous tree species (oak, alder and ash), (2) a later period (3000-1000 BC) and (3) more detailed peat stratigraphy based on humification, pollen and macrofossil analysis. Our aims are to; (1) clarify the development and expansion of the peat bog based on bog-tree dendrochronology and peat stratigraphy, (2) assess these local palaeohydrological data in the context of regional climate reconstructions based on other proxy records, and (3) explore climate-related interactions between different species of bog trees.

Material and methods

Site description and fieldwork

The study is based on material form the peat bog Viss mosse, southern Sweden ($55^0 51'$N, $13^0 49'$E), a peat bog used for extensive peat harvesting and described by Edvardsson et al. (2012b). During fieldwork campaigns in 2010, 2011 and 2012 samples from 75 deciduous trees were collected with a chainsaw. Three peat sequences were taken with a Russian peat sampler. Exact positions of trunks and peat profiles were obtained during fieldwork with a GPS. Depths of the remaining organic deposits were measured with a probe along transects in the area where most of the *in situ* trunks were found.

Laboratory work

Ring-width (RW) records from each sampled tree were measured using standard dendrochronological equipment (Schweingruber 1988). The wood material was treated, controlled and standardized using the methods described by Edvardsson et al. (2012b).

Stratigraphic boundaries of the three peat sequences were identified based on peat characteristics and degree of humification. Thereafter, each peat-stratigraphic boundary was dated by radiocarbon. Pollen samples were taken at 2 cm intervals in the stratigraphies beneath the tree trunks and at 5 cm intervals in peat collected from the remaining stratigraphy above the tree trunks. Samples for peat bulk density, a physical parameter commonly used as a proxy for peat humification (Chambers et al. 2011), were taken over the entire stratigraphic unit. Generally, the degree of humification reflects bog surface wetness when the peat was formed.

Preliminary results

Ring-width records

Based on 41 oak samples, four ring-width chronologies have been developed, One of these has been absolutely dated to 1724-1399 BC by cross-correlation with Danish material (Christensen et al. 2007), while the other will be dated by radiocarbon. So far, radiocarbon dating results from one oak chronology have yielded an age span of 1282-1076 ± 113 BC.

Due to numerous missing rings and wide age distributions only five of the 33 alder samples were possible to cross-date. Therefore, several individual trunks have been radiocarbon dated, yielding ages in the range of 5700-1400 BC. One RW record composited of five alder samples has been developed, covering the period of 2592-2344 ± 38 BC.

Initially, some alder samples were erroneously identified as beech trees during fieldwork and subsequent measuring. These trees were also presented as beech (*Fagus sylvatica*) at the TRACE conference in Potsdam-Eberswalde in 2012. However, wood anatomical results obtained thereafter proved that they were indeed alder. These alders are characterized by (1) unusually thick, but false medullary rays, (2) a more yellowish colour than other alder samples from the site, and (3) anomalously long life spans (more than 200 years) as compared to the normal maximum age of alder of about 120 year (McVean 1953). It is presently unclear why these alders have developed such apparent beech-like features.

Peat stratigraphic studies

The stratigraphic successions obtained at Viss mosse exhibit eight consecutive units in the marginal part of the peat deposit. Radiocarbon dating of these units provides evidence of a rapid expansion of the bog with an onset at about 2500 BC.

Discussion and continued work

Preliminary pollen stratigraphic data in combination with the temporal distribution of dated tree trunks suggest an establishment of alder before the oak population spread across the investigated area. So far, no fire scars have been observed on the oak trunks, but a layer of charcoal in the peat indicates a fire event c. 1600 BC followed by a rapid increase in the *Betula* pollen frequency. The pollen record also shows decreasing frequencies of *Quercus* and *Alnus* immediately after the assumed fire. However, this is likely to be a ‘percentage effect’ of the large increase in *Betula* pollen rather than an indication of decline in the absolute pollen production of other species. However, the oak population seems not to have suffered from the fire as the tree-ring data show several germinating and no dying oak trees.

Most likely there were trees growing in the area before 2500 BC at the site where the deciduous trees were found. However, in this marginal zone of the bog no trees were preserved until the peat bog started to expand after c. 3000 BC. This expansion of the peat deposit took place during the onset of the so-called neoglaciation (Nesje et al. 1991). In southern Sweden this transition to generally colder, wetter and more unstable climatic conditions has been dated to 2650–1450 BC (Jessen et al. 2005).

This work is still in progress. Radiocarbon dating of the two undated oak records will lead to improved precision of the reconstruction and additional evidence of the interaction between oak and alder, i.e. whether similar patterns occurred during different establishment phases. Results from an on-going macrofossil analysis of the peat stratigraphy will probably contribute more valuable information on the development of the peat deposit during this major climatic transition phase towards generally colder and wetter conditions, as well as on related interactions between different species.

References

Chambers, F.M., Beilman, D.W., Yu, Z. (2011): Methods for determining peat humification and for quantifying peat bulk density, organic matter and carbon content for palaeostudies of climate and peatland carbon dynamics. *Mires and Peat* 7: 1–10.

Christensen, K., Eckstein, D., Schmidt, B. (2007): Bronze Age oak coffins in Denmark and North Germany – dendrochronological dating and archaeological implications. *Germania* 85: 35-46.

Eckstein, J., Leuschner, H.H., Giesecke, T., Shumilovskikh, L., Bauerochse, A. (2010): Dendroecological investigations at Venner Moor (northwest Germany) document climate-driven woodland dynamics and mire development in the period 2450-2050 BC. *The Holocene* 20: 231–244.

Eckstein, J., Leuschner, H.H., Bauerochse, A. (2011): Mid-Holocene pine woodland phases and mire development – significance of dendroecological data from subfossil trees from northwest Germany. *Journal of Vegetation Science* 22: 781–794.

Edvardsson, J., Leuschner H.H., Linderson, H., Linderholm, H.W., Hammarlund, D. (2012a): South Swedish bog pines as indicators of Mid-Holocene climate variability. *Dendrochronologia* 30: 93–103.

Edvardsson, J., Linderson, H., Rundgren, M. and Hammarlund, D. (2012b): Holocene peatland development and hydrological variability inferred from bog-pine dendrochronology and peat stratigraphy – a case study from southern Sweden. *Journal of Quaternary Science* 27: 553–563.

Jessen, C.A., Rundgren, M., Björck, S., Hammarlund, D., 2005: Abrupt climatic changes and an unstable transition into a late Holocene Thermal Decline: a multiproxy lacustrine record from southern Sweden. *Journal of Quaternary Science* 20: 349–362.

McVean, D.N. (1953): *Alnus Glutinosa* (L.). *Journal of Ecology* 41: 447-466.

Nesje, A., Kvamme, M., Rye, N., Løvlie, R. (1991): Holocene glacial and climate history of the Jostedalsbreen region, western Norway; evidence from lake sediments and terrestrial deposits. *Quaternary Science Reviews* 10: 87–114.

Schweingruber, F.H. (1988): Tree Rings: Basics and Applications of Dendrochronology. Reidel: Dordrecht. 276.

Genetic parameters of wood density in European larch families from seedling seed orchards

M. Klisz, S. Jastrzębowski & J. Nowakowska

Forest Research Institute, Department of Silviculture and Genetics, 3 Braci Leśnej Street, Sękocin Stary, 05-090 Raszyn, Poland
E-mail: kliszm@ibles.waw.pl

Introduction

The investigations on genetic parameters of wood structure of European larch from two seedling seed orchards from northern Poland were carried out in 2008-2010. Genetic parameters for wood density traits were estimated in 389 25-year-old trees of 8 half-sib families of European larch. Wood density traits of individual rings were determined by X-ray densitometry (Bergsten et al., 2001). Genetic parameters such as narrow-sense heritability and genetic correlation were calculated using the formulas developed by Wright (1976). Genetic parameters were estimated on the basis of variance components for each trait and covariance components between different traits, obtained from the MANOVA procedure of the SAS 9.2 PL software (SAS, 2002). Estimated values of narrow-sense heritability of latewood density and maximum wood density were 0.97 and 0.98 respectively. The narrow-sense heritability of annual ring density and earlywood density fluctuated in the studied period. Maximum wood density showed strong positive genetic correlation with latewood density ($r_g = 0.98$) and minimum wood density showed strong positive genetic correlation with earlywood density ($r_g = 0.96$). The genetic correlations between wood density traits were increasing with cambial age. Similar trends in genetic parameters changes in time are shown by Fujimoto et al. (2008) for hybrid larch.Stabilisation of genetic correlations between wood density traits was observed in mature wood - from 16th annual ring. This confirms the correctness of decisions to select trees on the basis of genetic parameters obtained for mature wood (early tests). Wood density is the most important indicator of wood suitability for various kinds of utilization. Wood density is correlated with several wood properties. Mean ring density depends on the proportion of earlywood and latewood in annual rings (Warren, 1979). Ring density results from different combinations of all these components (Hylen, 1999).

High growth rate in juvenile trees implies the dynamic nature of changes in the values of genetic parameters estimated for the first annual rings (Baltunis et al. 2007, Hannrup et al. 2000, Lenz et al. 2010). The mentioned tendency can be observed in the increase of individual tree heritability and genetic correlations in wood density traits (Loo, Tauer 1984, Lenz et al. 2010, Louzada, Fonseca 2002). Rapid growth of individual tree heritability is typical for ring density, earlywood density and for minimum wood density (Gaspar et al. 2008, Lenz et al. 2010, Louzada, Fonseca 2002). While for latewood density and maximum wood density an opposite trend is observed in terms of heritability. The increase of individual heritability of wood density traits is inhibited after several years at a level which later on remains constant (Loo, Tauer 1984). According to various authors, the age-age genetic correlations for wood density traits between the youngest annual rings in juvenile wood and rings in mature wood reach the highest value in the first years of growth (Gaspar et al. 2008) or in later periods: 15-20 years – 1.0 (Fujimoto et al. 2006), 8-11 years – 0.88 (Hanrup, Ekberg 1988). A different trend in genetic correlations was determined for Pinus radiata, for which the highest values (2-3) for this parameter were observed in the tree age, a value close to zero was observed in the transition wood 6-8 and a stable and moderate value of genetic correlation was determined from the cambial age of 10 (Zamudio et al. 2002). Age-age analysis of genetic parameters enables a precise examination of the heritability trends and an estimation of genetic gain in a given year. Variability of heritability along the tree age clearly indicates how the time, when selection is performed, determines the potential genetic gain (Lenz et al. 2010).

Analysis of trends in genetic parameters variability in time allows for an improvement in selection intensity and efficiency by applying early tests (Gaspar et al 2008).

A clear change in the value of genetic parameters of wood density traits is observed in the transition zone between juvenile and mature wood. In various species the nature of the said changes shows different trends: Pinus sylvestris (Hanrup, Ekberg 1988, Hannrup et al. 2000), Pinus radiata (Zamudio et al. 2002), Pinus taeda (Loo, Tauer 1984), Pinus Elliottii (Hodge, Purnell 1993), Hybrid larch (Fujimoto et al. 2008).

The main purpose of the study was to determine the age of stabilisation for the value of genetic parameters of wood density traits in European larch grown in seedling seed orchard conditions. We assumed that the stabilisation age for genetic parameters of wood density traits in European larch should be similar to the analogous period determined for the hybrid larch (*Larix gmelinii var. japonica* × *L. kaempferi*).

Material and methods

In 2007 from two European larch seedling seed orchards located in the Młynary and Zaporowo forest districts (northern Poland) materials were sampled and used for the analysis of wood density. Among 22 families represented in both seedling seed orchards, based on the pilot study of wood density traits, 8 families were selected for further studies. The selection of sample trees for this examination was based on the assumption of an average representation of each family by 25 individuals in each seedling seed orchard. In total there were 188 trees selected from the Młynary forest district and 201 trees from Zaporowo forest district. Two increment cores were sampled from each tree at breast height (1.3 m). Wood samples were subject to standard preparation procedure for the X-ray examination. Thickness was standardised by longitudinal cutting (Larsson et al., 1994) and at the next stage the resins were extracted in distilled water (Grabner et al., 2005). The final stage of preparations covered the stabilisation of water content in the samples at the level up to 15% (Zobel & Jett, 1995). Increment cores were scanned from the core to the bark using X-ray densitometry (Bergsten et al., 2001). Analysis of X-ray images using WinDENDRO™ software provided the following values of wood density traits: mean ring density, earlywood density, latewood density, maximum wood density, minimum wood density. In order to estimate quantitative genetic parameters (genetic correlation and narrow-sense heritability) we calculated variance components using the SAS 9.2 PL VARCOMP procedure and covariance components for each combination of traits using the MANOVA procedure (SAS, 2002).

The narrow-sense heritability is given by the following formula (Falconer & Mackay, 1994):

$$h_i^2 = 4\sigma_F^2/(\sigma_F^2 + \sigma_{PF}^2 + \sigma_E^2)$$

where: σ_F^2 – family variance,
σ_E^2 – residual variance,
σ_{PF}^2 – family×seed orchard variance.

The genetic correlation was calculated as follows (Wright, 1976):

$$r_{gxy} = Cov_{Fxy}/(\sigma_{Fx}^2\,\sigma_{Fy}^2)^{1/2}$$

where: σ_{Fx}^2 – family variance components for traits X and Y, respectively,
Cov_{Fxy} – family covariance components for traits X and Y.

Results and discussion

In the following years, similar fluctuations in heritability for all traits were seen (Fig 1).Maximum wood density and latewood density had generally the highest heritability ranging from 0.48 to 0.98 and from 0.25 to 0.97 respectively.

Obtained heritability values are significantly higher than the minimum and maximum values quoted by other authors: hybrid larch LD – 0.44; MAX – 0.41 for Pinus pinaster LD – 0.26; MAX – 0.44 for Norway spruce LD – 0.59; MAX – 0.51(Fujimoto et al. 2008, Gaspar et al. 2008, Lewark 1982, Zhang, Morgenstern 1995). The seen differences may occur due to a different relatedness nature of the research material (full-sib families, half-sib families, clones), various age of trees, and most of all due to different species of trees. The lowest value of narrow-sense heritability, all density traits reached at the age of 14 (in 1999).

The seen decrease of this genetic parameter might be related to thinnings carried out on the tested surfaces, however, the previously mentioned interventions occurred in years: 1997, 2000 and 2005. Therefore, it does not explain the occurring phenomenon. Another noticed decrease in the heritability of wood density traits at the age of 19 (year 2004) did not find its justification in the thinning interventions. Probably the low heritability of wood density traits is associated with the heterogeneous response of trees to the disturbance of growth conditions due to drought occurring in year 2003 (Rebetez et al. 2006).The low heritability of minimum density and a slow upward trend at the age of 14 corresponds with the results cited for Norway spruce (Lewark 1982). Most authors report higher values of this genetic parameter indicating a slow upward trend along with age (Gaspar et al. 2008, Fujimoto et al. 2008, Louzada, Fonseca 2002). Despite a strong correlation between earlywood density and a minimum density of wood, the heritability of minimum density reaches much lower values than the heritability of earlywood density. This suggests that this trait is only remotely genetically controlled and it strongly succumbs to environmental conditions.

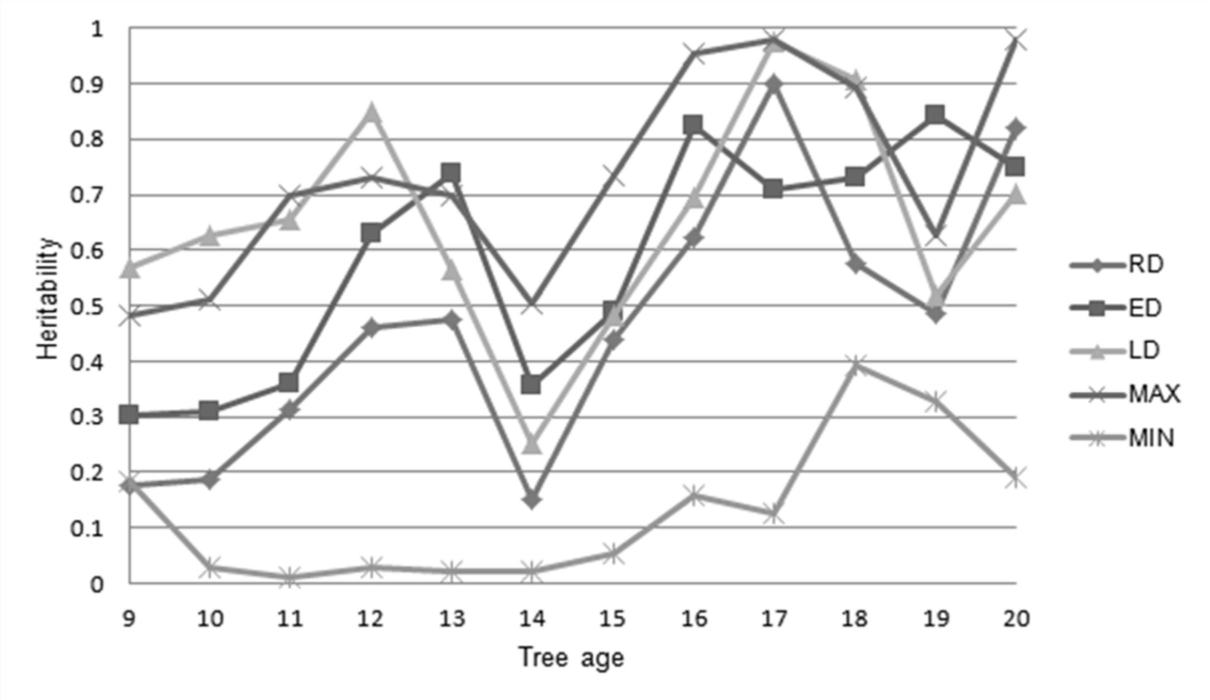


Figure 1: Chronology in narrow-sense heritability for wood density traits: mean ring density (RD), earlywood density (ED), latewood density (LD), maximum wood density (MAX), minimum wood density (MIN).

Estimated genetic correlations between wood density traits were high for the entire analyzed period. After the age of 15 all genetic correlations reached the value raging from 0.67 to 0.98 (Fig 2). For most correlations four (4) characteristic periods of changes in particular genetic parameter can be determined (according to tree age trend). In the first period (associated with the evolution of juvenile wood), up to the age of 11, correlations increased. In the second (typical for transition wood), between 11 and 15, correlations stabilized. In the third period, a short time between the age 15 and 16, correlations again rapidly increased and reached their maximum at the 16th ring. In the last - fourth period (typical for mature wood), from the age of 17, correlations stabilized again.

The values of the genetic correlation between the mean ring density and the wood density traits correspond to the results obtained for hybrid larch (Fujimoto et al. 2008). Authors of these studies suggest that due to a strong genetic correlation between wood density traits, these traits are of a limited use when it comes to a selection targeted at the improvement of the quality of wood. According to them, the selection should be carried out on the basis of the overall wood density. The highest noticed values of genetic correlations of wood density traits for the age between 16-20 correspond to mature wood. This suggests that the selection carried out to improve the overall density of wood can be based both on a mean ring density, as well as on the other density traits. One should however note that these density traits have various heritability.

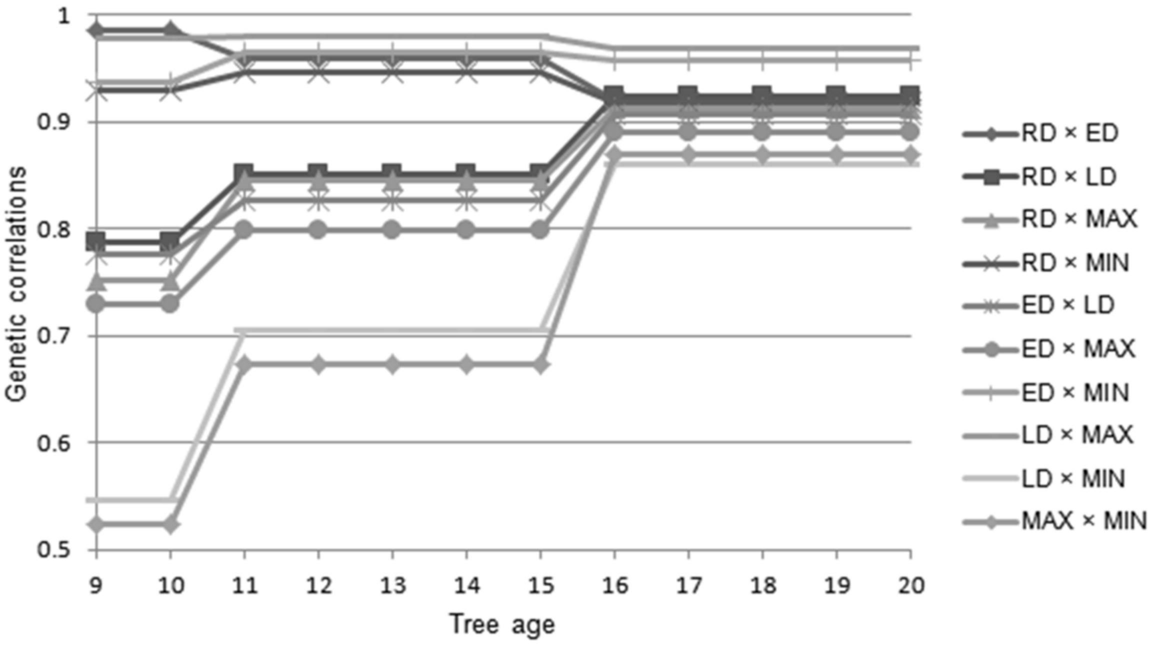


Figure 2: Chronology in genetic correlation between wood density traits: mean ring density (RD), earlywood density (ED), latewood density (LD), maximum wood density (MAX), minimum wood density (MIN).

Conclusions

1. The unstable nature of the heritability of wood density traits typical for the transition period (from juvenile to mature wood) can be the cause of wrong selection decisions concerning wood density, which may result in wrong estimation of genetic gain.
2. Genetic parameters of wood density traits present stable and strong correlation for mature wood.
3. Heritability of wood density traits is characterized by a visible increasing time-trend.
4. The minimum density of wood is a trait which is probably poorly genetically controlled and is subject to strong environmental influences.

References

Baltunis B.S., Wu H.X., Powell M.B. 2007. Inheritance of density, microfibril angle, and modulus of elasticity in juvenile wood of *Pinus radiata* at two locations in Australia. Can. Jour. For. Res. 37, 2164–2174

Bergsten, U., Lindeberg, J., Rindby, A., Evans, R. 2001. Batch measurements of wood density on intact or prepared drill cores using x-ray microdensitometry. Wood Sci. Tech. 35, 435–452

Falconer D. S., Mackay T. F. C. 1994. Introduction to quantitative genetics. Longman,

Fujimoto T., Kita K., Uchiyama K., Kuromaru M., Akutsu H., Oda K. 2006. Age trends in the genetic parameters of wood density and the relationship with growth rates in hybrid larch (*Larix gmelinii var. japonica* × *L. kaempferi*) F1. Jour. For. Res. 11,157–163

Fujimoto T., Kita K., Kuromaru M. 2008. Genetic control of intra-ring wood density variation in hybrid larch (*Larix gmelinii var. japonica* × *L. kaempferi*) F1. Wood Sci. Tech. 42, 227−240,

Gaspar M.J., Louzada J.L., Silva M.E., Aguiar A., Almeida M.H. 2008. Age trends in genetic parameters of wood density components in 46 half-sibling families of *Pinus pinaster*. Can. Jour. For. Res. 38, 1470–1477,

Grabner M., Wimmer R., Gierlinger N., Evans R., Downes G. 2005. Heartwood extractives in larch and effects on X-ray densitometry. Can. Jour. For. Res., 35, 2781–2786,

Hannrup B., Ekberg I. 1998. Age-age correlations for tracheid length and wood density in *Pinus sylvestris*. Can. Jour. For. Res. 28, 1373–1379,

Hannrup B., Ekberg I., Persson A. 2000. Genetic correlations among wood, growth capacity and stem traits in *Pinus sylvestris*. Scand. Jour. For. Res. 15, 161–170,

Hodge G.R., Purnell R.C. 1993. Genetic parameter estimates for wood density, transition age, and radial growth in Slash pine. Can. Jour. For. Res. 23, 1881–1891,

Hylen G. 1999. Age trends in genetic parameters of wood density in young Norway spruce. Can. Jour. For. Res. 29, 135-143,

Larsson B., Pernestål K., Jonsson B. 1994. A wood sample preparation method for direct scanning x-ray microdensotometry. Umeå, Swedish University of Agricultural Sciences, Report 29, 1-19,

Lenz P., Cloutier A., MacKay J., Beaulieu J. 2010. Genetic control of wood properties in *Picea glauca* – an analysis of trends with cambial age. Can. Jour. For. Res. 40, 703–715,

Lewark S. Von 1982. Etude des propriétés du bois de jeunes épicéas provenant de clonage par bouturage. (Original article: Untersuchungen von Holzmerkmalen junger Fichten aus Stecklingsklonen. Forstarchiv 52(1), 14–21.)

Loo J.A., Tauer C.G. 1984. Juvenile–mature relationships and heritability estimates of several traits in Loblolly pine (*Pinus taeda*). Can. Jour. For. Res. 14, 822–825,

Louzada J.L.P., Fonseca F.M.A. 2002. The heritability of wood density components in *Pinus pinaster* Ait. and the implications for tree breeding. Ann. For. Sci. 59, 867–873,

Robetez M., Mayer H., Dupont O., Schindler D., Gartner K., Kropp J. P., Menzel A. 2006. Heat and drought 2003 in Europe: a climatic synthesis. Ann. For. Sci. 63, 569-577,

SAS/STAT 2002. User's guide, version 9.2 SAS Institute, Cary NC online,

Warren W. G. 1979. The contribution of earlywood and latewood specific gravities to overall wood specific gravity. Wood Fiber Sci. 11, 127-135,

Wright, J. W. 1976. Introduction to forest genetics. Academic Press, New York San Francisco London,

Zamudio, F., Baettyg, R., Vergara, A., Guerra, F., Rozenberg, P. 2002. Genetic trends In wood density and radial growth with cambial age in radiata pine progeny test. Ann. For. Sci. 59, 541-549,

Zhang S. Y., Morgenstern E. K. 1995. Genetic variation and inheritance of wood density in black spruce (*Picea mariana*) and its relationship with growth: implications for tree breeding. Wood Science and Technology 30, 63–75,

Zobel J. B., Jett B. J. 1995. Genetics of wood production. Springer-Verlag, N. York-Berlin.

Dendroecological networks to investigate forest dynamics: The case of European beech in Italy

A. Di Filippo [1], F. Biondi [2], E. Ziaco [1] & G. Piovesan [1]

[1] *DendrologyLab, DAFNE - Università della Tuscia, Viterbo, Italy*
[2] *DendroLab, Department of Geography, University of Nevada, USA*
E-mail: piovesan@unitus.it

Introduction

European beech (*Fagus sylvatica* L.) can be considered a focal species in dendroecological studies of forest dynamics (e.g. Dittmar et al. 2003, Piovesan et al. 2005). Beech grows from Mediterranean to cold temperate environments with broad geographical and altitudinal ranges (more than 20° latitude, 30° longitude and 1500 m in elevation). As a late-successional species, beech has a long potential lifespan (400-500 years; Di Filippo et al. 2012; Trotsiuk et al. 2012). Beech populations are ideally suited for biomonitoring purposes given their high sensitivity to environmental changes related to climate (Biondi 1993, Piovesan & Adams 2005, Peñuelas & Boada 2003, Jump et al. 2006, Di Filippo et al. 2007, Piovesan et al. 2008), forest fragmentation (Barbeta et al. 2011), pollution (Šebesta et al. 2011) and forest management (Merino et al. 2007, Ziaco et al. 2012).

Bioclimatic studies generally follow two approaches: *process-based* (e.g ecophysiological models, dynamic vegetation models; e.g. Hartig et al. 2012) or *correlative* (e.g. bioclimatic maps, bioclimatic envelopes; e.g. Araujo & Peterson 2012). Dendroclimatology provides a third approach, based on the principle that common climatic factors control growth variations between trees in the same site and between sites experiencing similar environmental conditions. Tree-ring chronologies integrate the biological expression of the effects of climatic variability on vegetative and reproductive processes. Climatic signals in tree-rings vary with the main ecological gradients, defined in terms of latitudinal/altitudinal site ecology, and expressed as differences in growing season length, drought intensity and duration, occurrence of frost events. Bioclimatic classifications of forests can be built according to the spatial variation of the growth-limiting climatic factors, identifying homogeneous areas of climatic influence. In this sense bioclimatic units reflect latitudinal or altitudinal areas where tree-growth is controlled by the same climatic factor(s). For this reason tree-ring networks can be used a) to reveal homogeneous bioclimatic areas according to similar growth patterns at different spatial scales and b) for monitoring temporal variations of such patterns through long-term tree-ring chronologies. Such approach allows for drawing synoptic maps based on long (at least decades) time spans ranging from local to continental scales.

Italian beech forests are widespread over the entire country (1035103 ha, INFC 2005) and characterized by complex dynamics because of their distribution along elevational/latitudinal gradients, together with remarkable ecological continuity and integrity. Central-southern Italy was a glacial refuge for European beech (Magri 2008) as shown by the higher genetic diversity found in the southernmost beech populations (e.g. Italian peninsula) compared to those pertaining to the central and northern areas of the species distribution (Magri et al. 2006). Moreover, despite a long history of human utilization, patches of primary and secondary old-growth beech stands are still present in remote montane areas of both the Apennines and the Alps (Piovesan et al. 2010). Individuals exceeding five century have been reported for Central Italy (Piovesan et al. 2011), while in the Eastern Alps the oldest known beech stand (Lateis) is about 400 years old. However, in both areas ages >300 years are not uncommon (Di Filippo et al. 2012).

In 2002 a national tree-ring network mainly focused on beech was established to describe the bioclimatology of Italian forests (Schirone et al. 2002), recently enlarged with support from the Scientific Research Program of National Relevance 2007AZFFAK project ("Climate change and

DOI: 10.2312/GFZ.b103-13058

forests – Dendroecological and ecophysiological responses, productivity and carbon balance on the Italian network of old-growth beech forests”). Currently the network includes more than 40 beech stands sampled along a wide latitudinal (from 37° 52' to 46° 34' N) and altitudinal (200 – 2100 m asl) transect.

The beech tree-ring network can be a paradigm for the application of dendroecological methods in forest ecology concerning: a) forest bioclimatology, describing the spatial organization of tree-ring based bioclimatic classification of beech stands in Italy; b) assessment of global change impacts on forest stands, by checking the temporal stability of bioclimatic relationships and by exploring the link between bioclimate and tree longevity, growth rates, and disturbance processes.

Material and methods

The tree-ring network is a combination of 45 beech chronologies developed over the past 20 years (Biondi 1992, Schirone et al. 2002, Di Filippo et al. 2007, Piovesan et al. 2010; Fig.1). The main network features are: a) distribution over the entire peninsula; b) broad elevational range, from low hills to high mountains; c) presence of old trees within forest stands with no intense human disturbance in the recent past (Piovesan et al. 2005). The most intensively sampled areas were Central Apennines (Piovesan et al. 2005) and Eastern Alps (Di Filippo et al. 2007). Field collections were made by selecting at least 20 among the largest dominant or codominant trees. One wood increment core was collected the lower bole at breast height (along the contour line whenever possible). All wood samples were prepared for dendrochronological analysis using standard methods (Stokes and Smiley 1996).

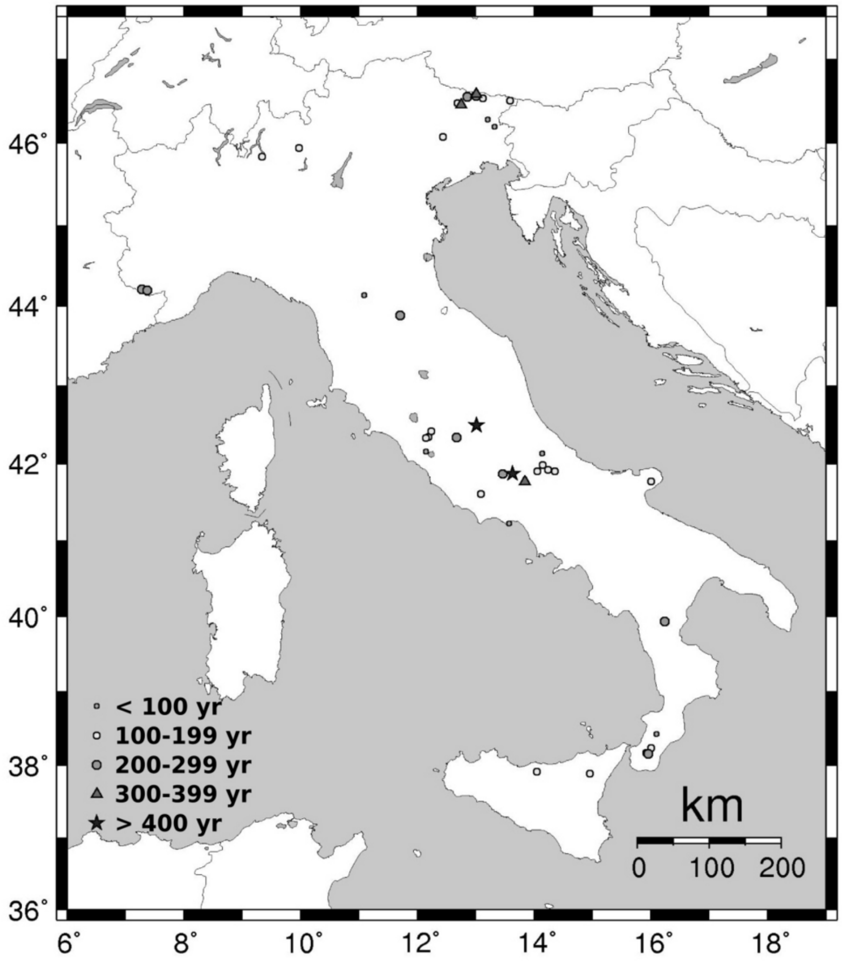


Figure 1: The tree-ring network and maximum longevity detected within each beech population.

We used ring width to quantify diameter increment, and ring areas to quantify basal area increment (BAI; Piovesan et al. 2008). BAI, an indicator of tree productivity, was used to assess stand productivity dynamics. BAI chronologies, obtained by averaging individual BAI series, were smoothed by cubic splines with a 50% frequency-response cutoff at 50-year periods to represent long-term productivity trends. Standardized tree-ring chronologies, representing the expression of the high-frequency climatic signals controlling tree-growth variability of that tree population, were produced for each site using the following formula:

$$\bar{I}_t = \frac{\sum_{i=1}^{i=n_t} \left(w^{0.5} - y\right)_{it}}{n_t} + c_{it}$$

with $\bar{I}_t$ = chronology value at year t; n_t = number of samples for year t, with $n_t \geq 3$; w = crossdated ring width of sample i in year t; y = value of sample i in year t computed by fitting a modified negative exponential with asymptote ≥ 0 or a straight line with slope ≤ 0 to the i^{th} ring-width series; c_{it} = constant added to sample i in year t so that the standardized chronology has mean equal to 1 (Di Filippo et al. 2007). Each standardized chronology was validated according to its EPS (Expressed Population Signal) and prewhitened by fitting autoregressive (AR) models to enhance its climatic signal (Cook et al. 2001).

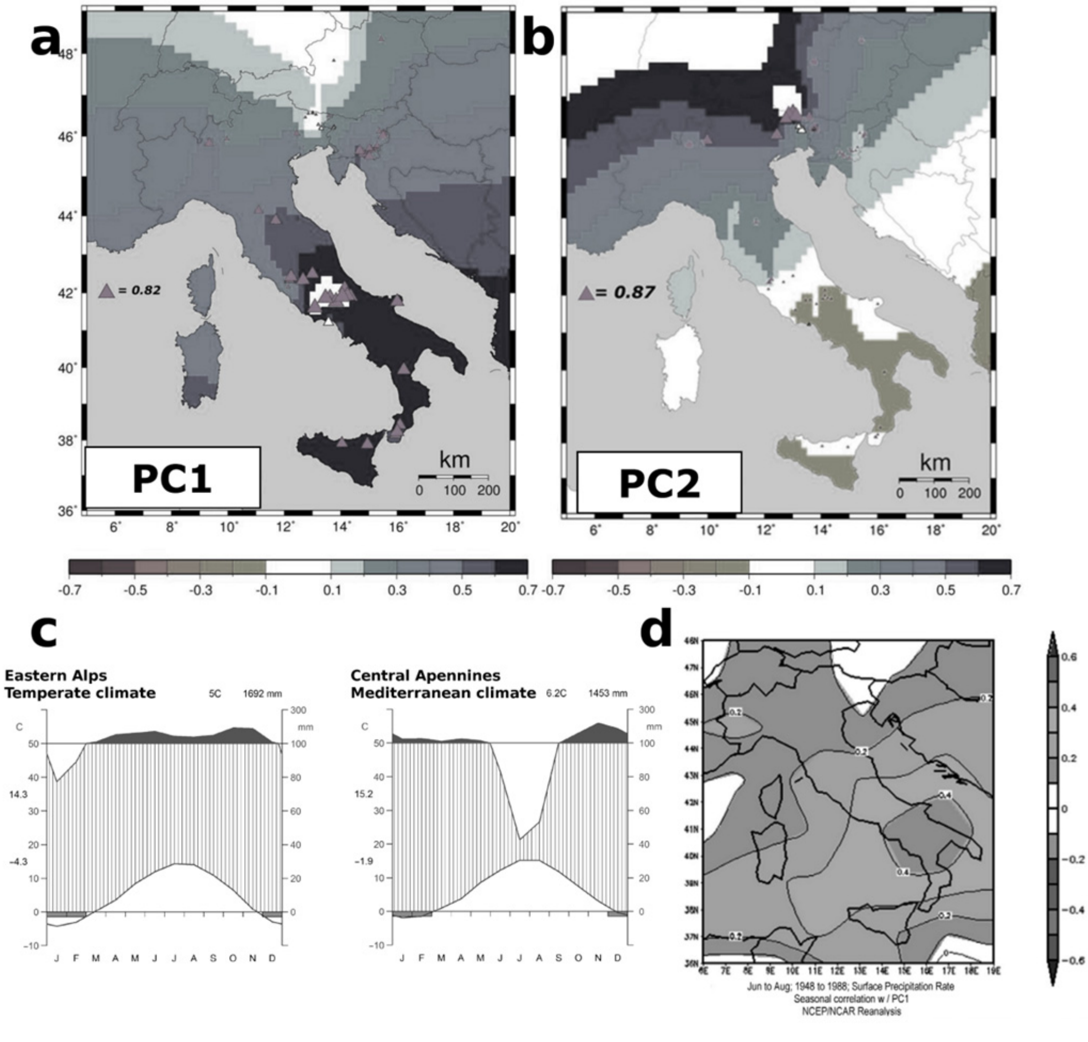


Figure 2: Correlation maps of the first 2 PC scores representing the Mediterranean (a) and Alpine (b) signals for the period 1942-1988. Grey intensity and symbol's dimensions are proportional to PC loadings. c) Walter–Lieth climatic diagrams referred to high-mountain beech populations on eastern Alps and central Apennines. d) Interpolated correlation maps between PC1 scores and gridded Summer precipitation.

A bioclimatic classification of the standardized chronologies according to their dominant climatic signal was obtained by a Hierarchical Cluster Analysis (HCA) (Piovesan et al. 2005, Di Filippo et al. 2007). Multivariate analysis, including Hierarchical Cluster Analysis (HCA) and Principal Components Analysis (PCA), were performed based on the correlation matrix between prewhitened chronologies: HCA separates groups of homogeneous climatic control e.g. Bioclimatic Units (discrete approach), while PCA identifies common macroclimatic signals responsible for the observed classification at a regional scale thought Principal Component (PC) scores, or amplitudes (continuous approach) (Piovesan et al. 2005). Selection of PCs was guided by Kaiser's Rule. Composite chronologies were obtained by pooling together all ring-width series from sites whose prewhitened chronologies were associated by multivariate analysis and the same formula reported above was used to compute prewhitened composite chronologies.

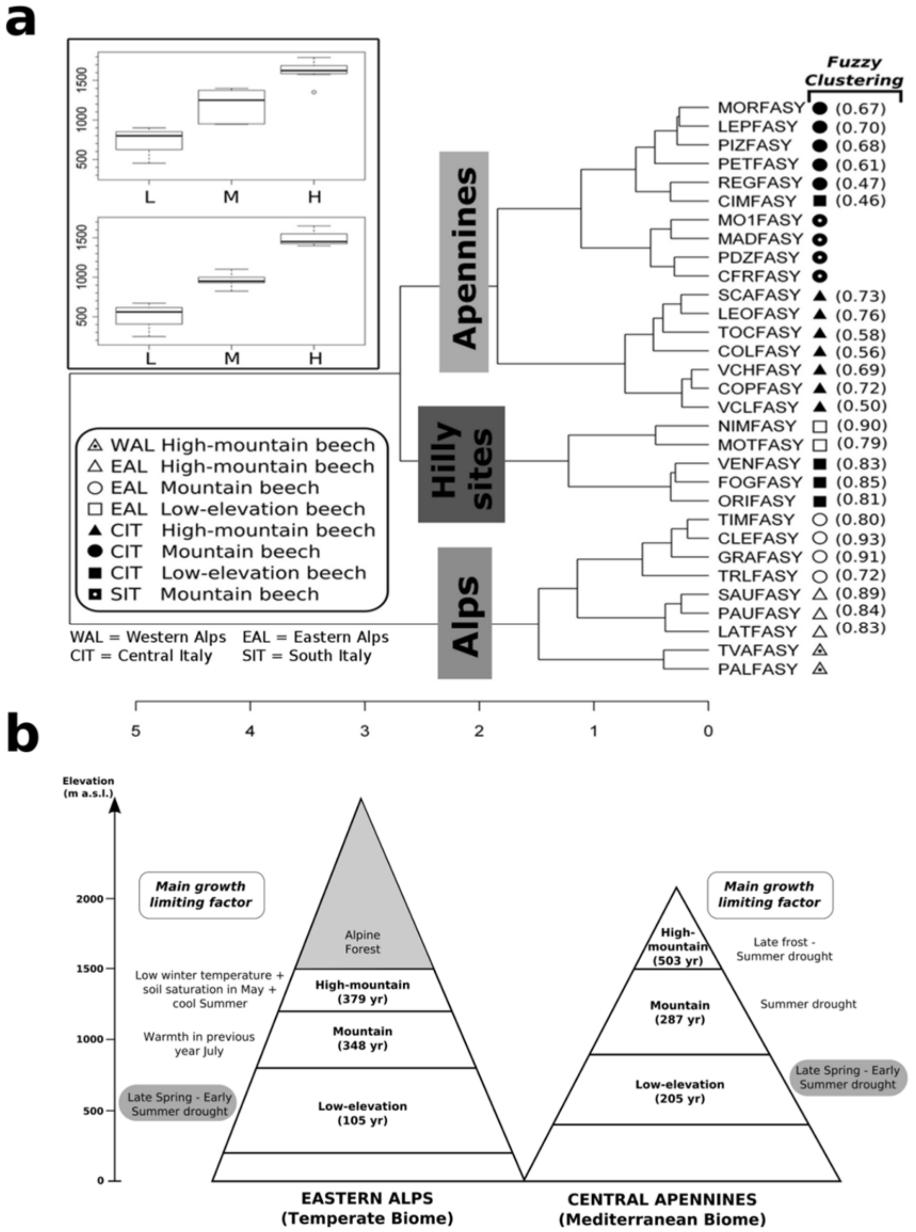


Figure 3 a) Hierarchical clustering dendrogram of beech prewhitened chronologies from Eastern Alps, Central and Southern Apennines; boxplots: elevation range of the low-elevation (L), mountain (M) and high-mountain (H) belt in central Apennines (above) and eastern Alps (below). b) Elevation range covered by altitudinal bioclimatic zones of beech on the eastern Alps and the Central Apennines, showing beech lifespan (years in parentheses), and the main climatic factors limiting beech growth within each zone.

Climate-growth relationships were determined using both dendroclimatic and synoptic procedures.

Dendroclimatic correlation and response functions were calculated between principal component scores of prewhitened tree-ring chronologies and monthly climate variables using DendroClim2002 (Biondi & Waikul 2004). Explanatory climate variables spanned a 17-month window, from October of the current growth year to June of the previous year. Climate was quantified by monthly total precipitation (P) and monthly mean air temperature data (see Piovesan et al. 2005, Di Filippo et al. 2007). Temperature and precipitation climatologies were obtained from Brunetti et al. (2009a, b).

Results and Discussion

Bioclimatic classification of the tree-ring network

The Italian tree-ring network consists of high-frequency tree-ring chronologies distributed along a wide geographic/climatic gradient (Fig. 1). According to the multivariate analyses, Italian beech populations were arranged *horizontally* in two bioclimatic *zones* according to their latitude (Temperate vs. Mediterranean biome; Fig. 2) and *vertically* in bioclimatic *belts* according to their elevation (Fig. 3). The separation between the Mediterranean and the Temperate biome was well described by the spatial extent of the first two principal components (PCs) of the network, which demonstrated the existence of two main macroclimatic signals dominating high frequency tree-growth variability in the two areas (Fig. 2a-b). The two biomes are characterized by quite different precipitation regimes (more abundant and concentrated in the growing season on the eastern Alps, lower amounts with summer drought in the Apennines; Fig. 2c). In fact their boundary runs across the Northern Apennines and corresponds to the limit of summer drought control over growth variability (Piovesan et al. 2005, Di Filippo et al. 2007; Fig. 2d). Interestingly, this bioclimatic boundary coincides with what found in other studies based on *Abies alba* tree-ring network (Carrer et al. 2010), and it matches to the boundary between the northern and the central Italian climatic regions identified by Brunetti et al. (2006) on the base of interannual precipitation variability.

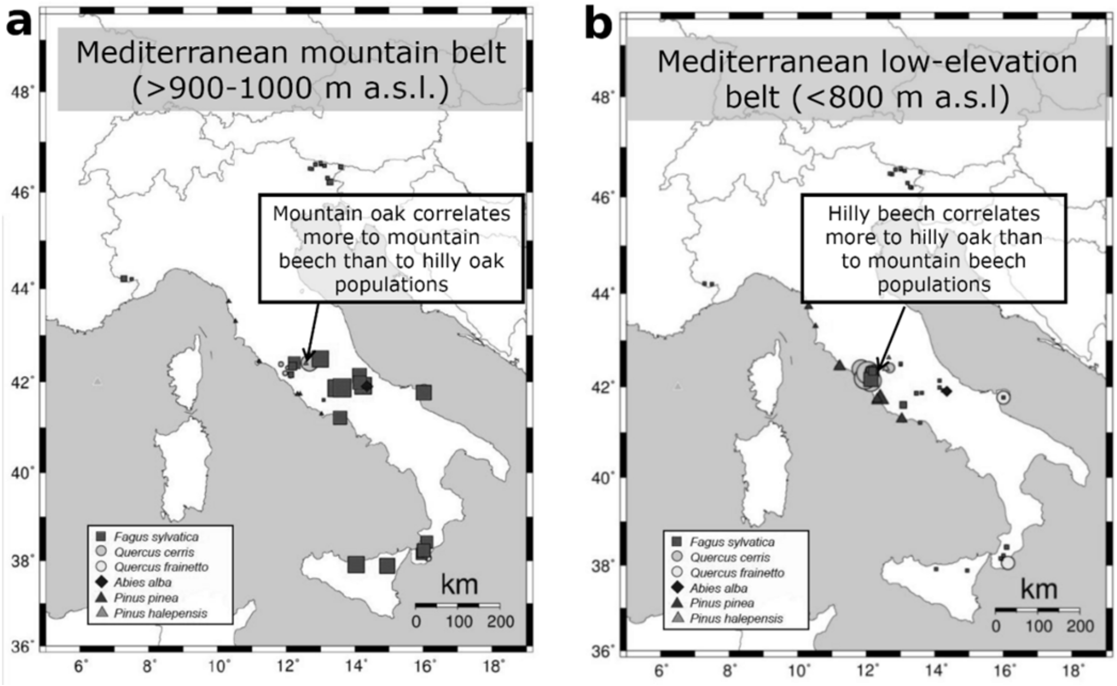


Figure 4: Teleconnection patterns within a multispecific tree-ring network: climatic signal of the first (a) and second (b) PC scores.

Within each biome, elevation is the leading factor controlling the main climate signal, as it determines mean temperature regime as well as growing season onset and duration. In both the Alps and the Apennines *Fagus sylvatica* populations were arranged by HCA in three altitudinal bioclimatic belts: low-elevation, mountain and high-mountain beech stands (Fig. 3). Each bioclimatic belt composite chronology had its own limiting climatic factor. However, while summer drought was the dominant climatic factor across all elevations in Central Italy, the Alpine stands were controlled mainly by thermal limitations (Piovesan et al. 2005, Di Filippo et al. 2007). In the Mediterranean biome we observed, with increasing elevation, a shortening of the dry period (from May-August to July-August) and an increasing need for warmth in early spring. Substantial differences in growing season length (one month delay among low-elevation and high-mountain belts) were detected in central Italy by matching dendroecological data with the Normalized Difference Vegetation Index (NDVI; Alessandrini et al. 2010). On the Eastern Alps instead the influence of heat/drought stress remained limited to low-elevation stands, in opposition to high-mountain populations where warmer temperature favors growth during all the vegetative period (in summer months too). It is also noteworthy noticing that at mid-elevations on the Alps (mountain belt) the climatic factors of the year preceding ring formation are the main signals, possibly in relation to previous summer climate control on floral induction in beech trees. In fact the mast seeding phenomenon in beech (as in spruce) is synchronized by climate, and the antagonism between vegetative growth and reproduction is reflected in growth variability (Piovesan & Adams 2005).

When matched within a tree-ring network including different tree species, the bioclimatic constrains seemed to exert a stronger influence than genetic features on growth variability, especially in sites at the altitudinal limit of the species range (Fig. 4). In Central Italy, low mountain to hilly beech populations spread at the same elevations of Turkey oak and downy oak (*Quercus cerris* and *Q. pubescens*) populations (Fig. 4). Moving upward, the uppermost oak population (900 m asl in central Apennines) was linked more to mountain beech chronologies than to hilly oak records (Fig. 4a), while hilly beech stands were more strongly correlated to hilly oak than to mountain beech populations (Fig. 4b).

The factors affecting beech longevity within the tree-ring network

Our dendroecological investigations uncovered a number of multi-century old trees, with the oldest ones found in high-mountain areas of central Italy (Fig. 1). Tree lifespan and growth rates are affected by climate (spring–summer temperature) and are inversely related to one another along elevation gradients (Di Filippo et al. 2012). For this reason high-mountain beech trees in both the Alps and Apennines have a longer life span compared to middle- and low-elevations stands. Older individuals are often not characterized by large dimensions, since they are subjected to worse site conditions (e.g. high-mountain environments, close to the tree-line). In Italy the oldest beech stands are found at the timber line, as in the case of the Valle Cervara and Coppo del Morto (maximum age: 560 yrs at DBH), two old-growth forests of Central Italy growing around 1700-1850 m asl. On the Alps the oldest stand is the high-mountain beech forest of Lateis (380 yrs, 1450 m asl). However, in both biomes several mountain stands with 300-350 yrs old trees were found. Low-elevation populations showed considerably lower ages (100-200 yrs). At lower elevations, e.g. on hilly areas of Central and North-eastern Italy, sustained growth rates speed up forest turnover rates: the structural cycle of such forests is thereby accelerated and their maximum potential longevity strongly reduced.

The tree-ring network as a tool to understand climate-change impacts on forest ecosystems

Our bioclimatic classification allowed to frame climate-change impacts on forests considering the spatial organization of the main growth-limiting climate factors. Average Basal Area Increment (BAI) showed diverging trends for different biomes and altitudinal zones (Fig. 5; see also Fig. 5 in Di Filippo et al. 2012). Beech in the Apennines lost productivity across the entire elevation gradient following the progressive increase in summer drought (Piovesan et al. 2008). This decline in tree productivity began during the 70s and, especially in low-elevation and mountain stands, accounted on average for 20-30% of BAI losses (Piovesan et al. 2008). In the eastern Alps we instead observed increasing productivity, especially in mountain and high-mountain areas, possibly in connection with global change (e.g. an improved thermal regime probably plus CO_2 fertilization and nitrogen depositions; Di Filippo et al. 2012).

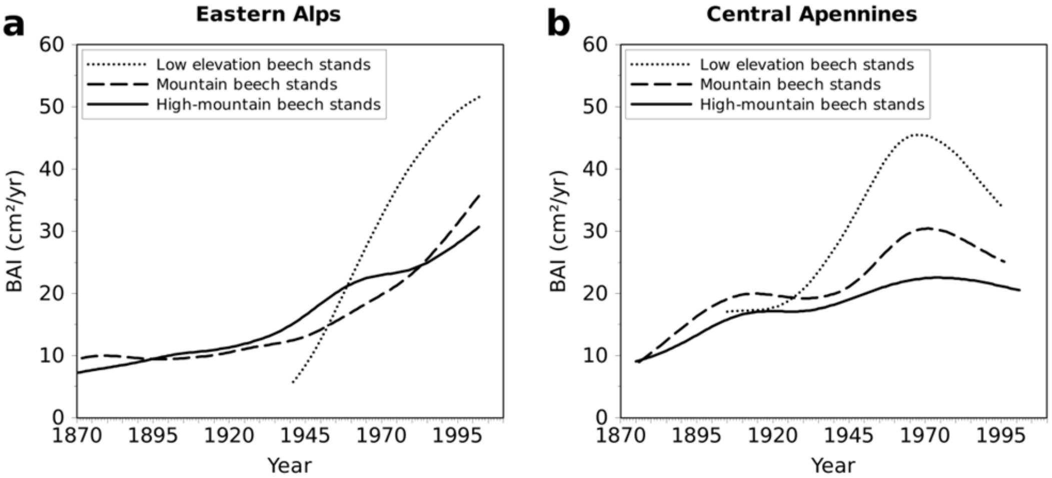


Figure 5: Average Basal Area Increment (BAI) per bioclimatic belt in the Alps and the Apennines. Curves are 50-yr cubic smoothing splines.

Similar productivity losses were detected in central Italy oak stored coppices, whose productivity is strongly coupled to the hydrologic balance, and the declining growth anticipated the observation of dieback phenomena (Di Filippo et al. 2010). Mediterranean stored coppices are destined to be affected by growth decline because drought periods generally occurs at decadal scale, so that growth of tree pertaining to different cohorts results to be highly synchronized, implying a lower growth potential for recent generations (Fig. 6a). In declining trees, tree-ring analyses outlined the existence of a progressive shift in the importance of the climatic factors controlling growth, from current to previous years of ring formation (Fig. 6b; Di Filippo et al. 2010). Dendroecology thus revealed to be a useful tool for predicting decline/dieback phenomena before the manifestation of pathological symptoms. In a global warming scenario, increased frequency/intensity of dry periods will affect especially hilly stands, with dieback potentially leading to local extinction of mesophilous species.

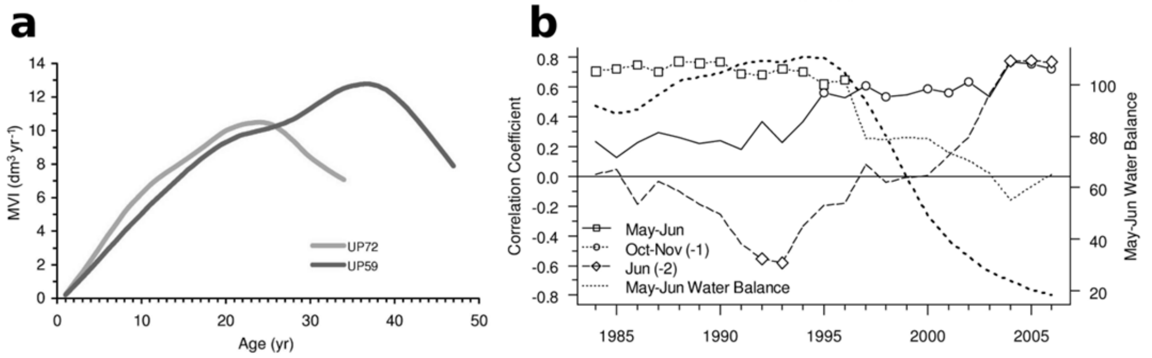


Figure 6: Productivity losses in Mediterranean oak stored coppices. a) Mean volume increment (MVI), 11-y splines of cohorts born in 1959 and 1972 as a function of age. b) 11-y window Moving Correlation Function of volume increment with selected climatic factors; each value represent the last year of each interval (symbols on each line denote correlation $p < 0.05$; dotted line: May–June water balance 11-y spline).

The bioclimatic influence on tree productivity is connected to the capacity of trees to respond to natural disturbance events. Recent work by Ziaco et al. (in press) using the boundary line method (Black & Abrams 2003) demonstrated the importance of calibrating beech growth release potential to the bioclimatic context for an effective reconstruction of forest disturbance history, especially when studying populations living at marginal (i.e. latitude or altitude) sites.

Other important effects of climate warming may lead to differences in the potential longevity expressed by beech at different elevation. Since tree lifespan (and growth rates) are controlled by climate, we estimated a reduction in beech lifespan of 23±5 years for each degree of warming (Di Filippo et al. 2012). The existence of divergent productivity trends between the Alps and the Apennines could thus point to the presence diversified, even opposite, climate change effects in different bioclimatic contexts of the same region. In the Mediterranean region, drought could either increase longevity by reducing growth rates or cause mortality of older trees. On the Alps, instead, if warming continues beech maximum lifespan could be reduced by faster growth.

References

Alessandrini, A., Vessella, F., Di Filippo, A., Salis, A., Santi, L., Schirone, B., Piovesan, G. (2010): Combined dendroecological and normalized difference vegetation index analysis to detect regions of provenance in forest species. Scandinavian Journal of Forest Research 25(SUPPL. 8):121-125.

Araújo, M. B., Peterson, A. T. (2012): Uses and misuses of bioclimatic envelope modeling. Ecology 93:1527-1539.

Barbeta, A., Peñuelas, J., Ogaya, R., Jump, A.S. (2011): Reduced tree health and seedling production in fragmented Fagus sylvatica forest patches in the Montseny Mountains (NE Spain). Forest Ecology and Management 261:2029-2037.

Biondi, F. 1992. Development of a tree-ring network for the Italian peninsula. Tree-ring Bulletin 52: 15–29.

Biondi, F. (1993): Climatic signals in tree rings of Fagus sylvatica L. from Central Apennines, Italy. Acta Oecologica 14:57-71.

Biondi, F., Waikul, K. (2004): DENDROCLIM 2002: a C++ program for statistical calibration of climate signals in tree-ring chronologies. Computers and Geosciences 30:303-311.

Black, B., Abrams, M.D. (2003): Use of boundary-line growth patterns as a basis for dendroecological release criteria. Ecological Applications 13:1733-1749.

Brunetti, M., Lentini, G., Maugeri, M., Nanni, T., Simolo, C., Spinoni, J. (2009a): Estimating local records for Northern and Central Italy from a sparse secular temperature network and from 1961–1990 climatologies. Advances in Science and Research 3:63-71.

Brunetti, M., Maugeri, M., Monti, F., Nanni, T. (2006): Temperature and precipitation variability in

Italy in the last two centuries from homogenised instrumental time series. International Journal of Climatology 26:345-381.

Brunetti, M., Lentini, G., Maugeri, M., Nanni, T., Simolo, C., Spinoni, J. (2009b): 1961–90 high-resolution Northern and Central Italy monthly precipitation climatologies. Advances in Science and Research 3:73-78.

Carrer, M., Nola., P., Motta, R., Urbinati, C. (2010): Contrasting tree-ring growth to climate responses of Abies alba toward the southern limit of its distribution area. Oikos 119: 1515-1525.

Cook, E.R., Glitzenstein, J.S., Krusic, P.J., Harcombe, P.A. (2001): Identifying functional groups of trees in West Gulf Coast forests (USA): a tree-ring approach. Ecological Applications 11:883-903.

Di Filippo, A., Biondi, F., Čufar, K., De Luis, M., Grabner, M., Maugeri, M., Presutti Saba, E., Schirone, B., Piovesan, G. (2007): Bioclimatology of beech (Fagus sylvatica L.) in the Eastern Alps: spatial and altitudinal climatic signals identified through a tree-ring network. Journal of Biogeography 34:1873-1892.

Di Filippo, A., Alessandrini, A., Biondi, F., Blasi, S., Portoghesi, L., Piovesan, G. (2010): Climate change and oak decline: Dendroecology and stand productivity of a Turkey oak (Quercus cerris L.) old stored coppice in Central Italy. Annals of Forest Science 67: 706.

Di Filippo, A., Biondi, F., Maugeri, M., Schirone, B., Piovesan, G. (2012): Bioclimate and growth history affect beech lifespan in the Italian Alps and Apennines. Global Change Biology 18:960-972.

Dittmar, C., Zech, W., Elling, W. (2003): Growth variations of common beech (Fagus sylvatica L.) under different climatic and environmental conditions in Europe—a dendroecological study. Forest Ecology and Management 173:63-78.

Hartig, F., Dyke, J., Hickler, T., Higgins, S.I., O'Hara, R.B., Scheiter, S., Huth, A. (in press): Connecting dynamic vegetation models to data - an inverse perspective. Journal of Biogeography.

INFC (2005): Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio. – Ministero delle Politiche Agricole Alimentari e Forestali, Ispettorato Generale. Corpo Forestale dello Stato. CRA – Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura.

Jump, A.S., Hunt, J.M., Peñuelas, J. (2006): Rapid climate change-related growth decline at the southern range edge of Fagus sylvatica. Global Change Biology 12:2163-2174.

Magri, D., Vendramin, G.G., Comps, B., Dupanloup, I., Geburek, T., Gömöry, D., Latałowa, M., Litt, T., Paule, L., Roure, J.M., Tantau, I., van der Knaap, W.O., Petit, R.J., de Beaulieu, J.L. (2006): A new scenario for the Quaternary history of European beech populations: palaeobotanical evidence and genetic consequences. New Phytologist 171:199-221.

Magri, D. (2008): Patterns of post-glacial spread and the extent of glacial refugia of European beech (Fagus sylvatica). Journal of Biogeography 35:450-463.

Merino, A., Real, C., Alvarez-Gonzalez, J.G., Rodriguez-Guitian, M.A. (2007): Forest structure and C stocks in natural Fagus sylvatica forest in Southern Europe: The effects of past management. Forest Ecology and Management 250:206-214.

Peñuelas, J., Boada, M. (2003): A global change-induced biome shift in the Montseny mountains (Spain). Global Change Biology 9:131-140.

Piovesan, G., Adams, J.M. (2005): The evolutionary ecology of masting: Does the environmental prediction hypothesis also have a role in mesic temperate forests? Ecological Research 20:739-743.

Piovesan, G., Biondi, F., Bernabei, M., Di Filippo, A., Schirone, B. (2005): Spatial and altitudinal bioclimatic zones of the Italian peninsula identified from a beech (Fagus sylvatica L.) tree-ring network. Acta Oecologica 27:197-210.

Piovesan, G., Biondi, F., Di Filippo, A., Alessandrini, A., Maugeri, M. (2008): Drought driven growth reduction in old beech (Fagus sylvatica L.) forests of the central Apennines, Italy. Global Change Biology 14:1265-1281.

Piovesan, G., Alessandrini, A., Baliva, M., Chiti, T., D'Andrea, E., De Cinti, B., Di Filippo, A., Hermanin, L., Lauteri, M., Scarascia Mugnozza, G., Schirone, B., Ziaco, E., Matteucci, G. (2010): Structural patterns, growth processes, carbon stocks in an Italian network of old-growth beech forests. L' Italia Forestale e Montana 65:557-590.

Piovesan, G., Alessandrini, A., Biondi, F., Di Filippo, A., Schirone, B., Ziaco, E. (2011): Bioclimatology, growth processes, longevity and structural attributes in an Italian network of old-growth beech forests spreading from the Alps to the Apennines. In: Beech Forests - Joint Natural Heritage of Europe, BfN-Skripten n. 297 (eds Knapp HD, Fichtner A), pp. 173–192. Bonn-Bad Godesberg, Bonn, Germany.

Schirone, B., Piovesan, G., Romagnoli, M., Bernabei, M. & Lo Monaco, A. (2002): Una rete di monitoraggio dendroecologico per identificare i cambiamenti climatici e valutarne l'effetto sulle foreste italiane. Agenzia Italiana per la Protezione dell'Ambiente (ANPA), Rapporto Tecnico Finale.

Šebesta, J., Šamonil, P., Lacina, J., Oulehle, F., Houška, J., Buček., A. (2011): Acidification of primeval forests in the Ukraine Carpathians: Vegetation and soil changes over six decades. Forest Ecology and Management 262:1265-1279.

Stokes, M.A., Smiley, T.L. (1996): An introduction to tree-ring dating. University of Arizona Press, Tucson.

Trotsiuk, V., Hobi, M.L., Commarmot, B. (2012): Age structure and disturbance dynamics of the relic virgin beech forest Uholka (Ukrainian Carpathians). Forest Ecology and Management 265: 181–190.

Ziaco, E., Di Filippo, A., Alessandrini, A., D'Andrea, E., Piovesan, G. (2012): Old-growth attributes in a network of Apennines (Italy) beech forests: disentangling the role past human interferences and biogeoclimate. Plant Biosystems 46: 153-166.

Ziaco, E., Biondi, F., Di Filippo, A., Piovesan, G. (in press): Biogeoclimatic influences on tree growth releases identified by the boundary line method in beech (Fagus sylvatica L.) populations of southern Europe. Forest Ecology and Management

SECTION 4

ARCHAEOLOGY

Revision of dendrochronological data in the Rhineland, Germany. An interim report on a generational transfer of dendrodata.

Th. Frank, B. Diethelm & R. Busch

Laboratory of Dendroarchaeology, Institute of Prehistoric Archaeology, University of Cologne, Germany
E-mail: dendro.prehistory@uni-koeln.de

Introduction

The article is dealing with the topic of structural and technical generational change in an archaeological Dendrolab and first basic results from the pilot scheme are presented.

The Laboratory of Dendroarchaeology at the University of Cologne is a close partner of the cultural heritage services in North Rhine-Westphalia. Since 1972 about 50,000 digital dendrochronological measurements, mostly from archaeological timbers, were stored in binary coded single data files in different directory structures on the lab's computers. The files contain a short header followed by the sequence of year ring distances. All of the other metadata are stored on paper archived in ring binders. This heterogeneous storage structure requires time-consuming preparations for scientific analysis.

In 2008 the single binary data-files were converted into single ASCII text-files stored in a key number-based directory structure. Simultaneously the data were transferred into a preliminary SQL-database. These two steps were a first data backup that allowed an easy access to the formerly proprietary data. The next step was to find out which data structure will suit a modern scientific database that contains both all existent digital and analogue (meta-) data and that is open for additional information.

For this purpose in 2010 a pilot scheme was started focussing on the dendrodata of timbers from archaeological excavations in the open cast lignite region in the Rhineland (Fig.1).

In 2011 we switched to the Windows-based software TSAPWin Professional for our daily dendrochronological measurements and analysis. At the same time we transferred the old measurement data from ASCII text-files to the Heidelberg format structure. But most metadata are still on paper.

DOI: 10.2312/GFZ.b103-13058

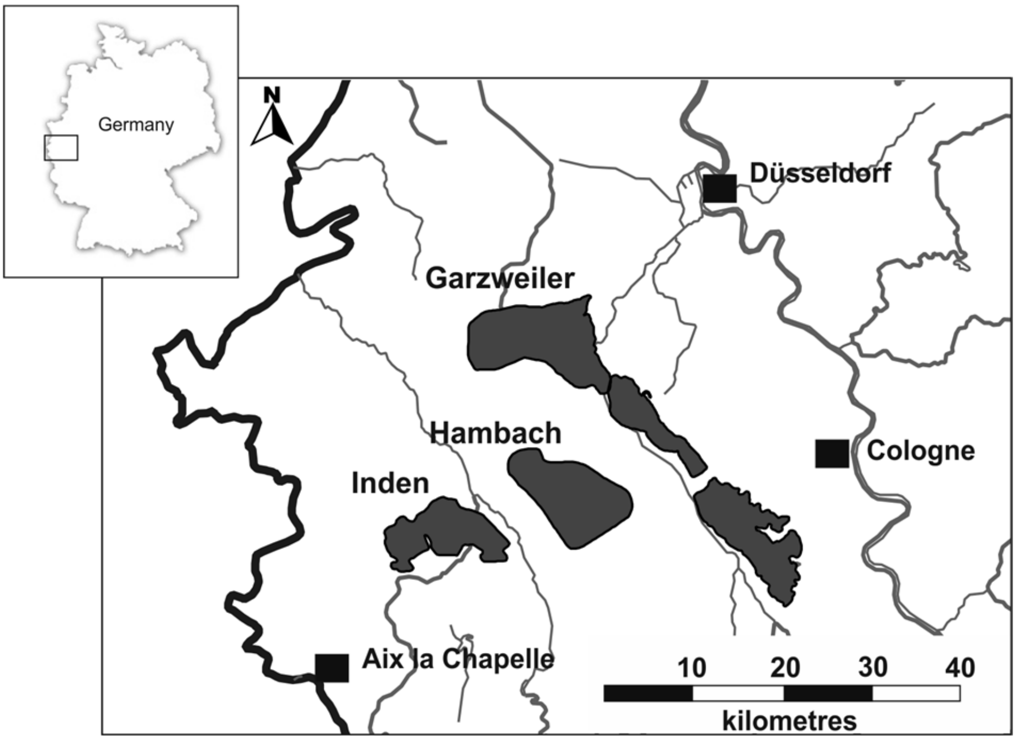


Figure 1: The lignite mining area of the Rhineland and its open cast mines Garzweiler, Hambach and Inden (shaded areas, including recultivated open cast pits).

Initial situation at the Dendrolab Cologne

The former system of data storage comprised analogue and digital data. The analogue metadata, printed and handwritten, are archived in about 150 folders. Some of these metadata are stored separately from the tree ring series in an MS-Access database with 15 data fields per record to allow some comfort in data access. The associated measurement data of tree ring series was stored in binary files, one file per series, which allowed only for a small amount of metadata to be saved. The backup of these series comprises about 100 floppy discs (5¼”).

The setup of a database containing all existing information on each measurement was essential to escape from that uncomfortable and unsafe situation. At the same time the data recorded with TSAPWin since 2011 must be integrated too. So our approach is not only to transfer the previous, partly analogue data into a digital future. We also need new structures for the digital recording of timbers that arrive from current excavations. The structure and function of the new database should be tested in a pilot project before all of the lab’s data would be transferred to it. We chose the archaeological dendrodata from the lignite mining area of the Rhineland (Fig. 1). Their revision and integration into a database would at the same time sharpen our structural demands and ameliorate the data.

Data of the pilot scheme

During the past 40 years about 1,600 archaeological wooden elements from excavations in the mining area were sampled and examined at the Dendrolab Cologne (Diethelm 2012). At 31% of these elements it was impossible to measure the ring distances because the wood was damaged in some way. But more than 1,000 elements were measured, resulting in nearly 1,800 tree-ring series (radii) and 533 dated elements. So roughly the half of the measured elements is dated (Fig. 2). This is the pool of dendrochronological data that is to be revised. We hope to raise our proportion of dating in the course of the revision. Information as to the proportion of successful dendrodating is rare in literature. Schweingruber suggests that a maximum of 66% of all delivered samples can be dated (Schweingruber 1983:87).

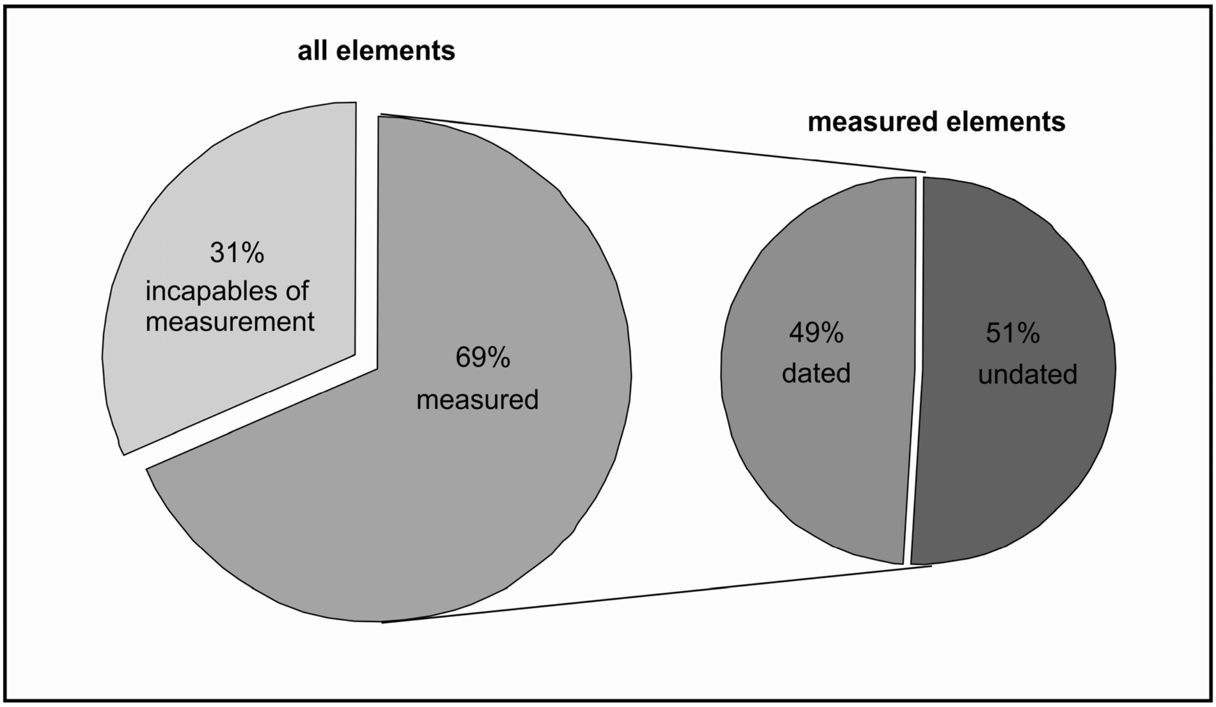


Figure 2: The ratio of measured to unmeasured elements (left) and the ratio of dated to undated elements (right).

The chronological distribution of the 533 dated elements in the past 2,000 years is erratic (Fig. 3). The ordinate of figure 3 shows the number of dated elements whose latest tree rings end in the same calendar year. Although the lignite mining area is an archaeologically well studied region, there are periods where the number of dated elements per year is very low or no timbers are available at all, resulting in dendrochronological gaps.

There is a badly represented period from the late Antiquity to the Migration Period (AD 230-500), a dendrochronological gap well known for large parts of Western Europe (Fig. 3). In this span of 270 years a total of only 21 dated elements exist. 15 of these elements come from the same archaeological site and cover 50 years from AD 340-390. Another gap covers the period from the Early to High Medieval times (AD 650-1250). There are several reasons for these poorly represented periods in the dendrochronological calendar. In the lignite mining area of the Rhineland it is a mixture of cultural and environmental factors which cause a poor replication in the reference-curves too.

DOI: 10.2312/GFZ.b103-13058

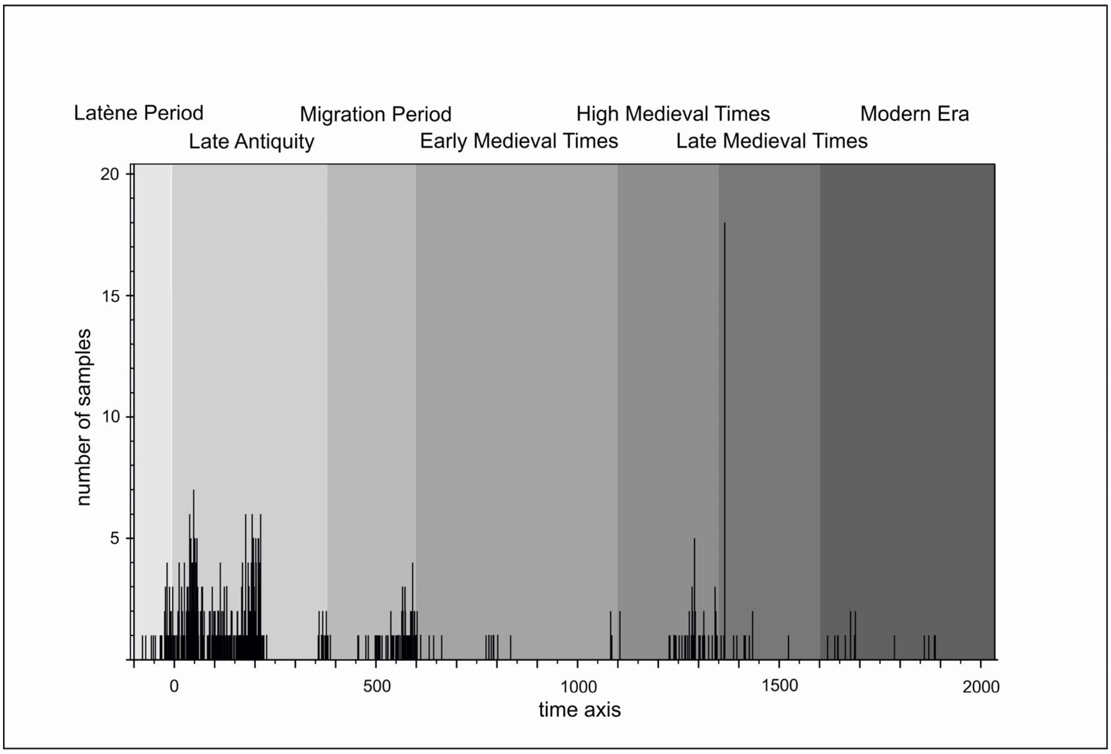


Figure 3: *Chronological distribution of dated elements (n=533) from the lignite mining area of the Rhineland.*

Demands of the data base

In 2010, when the project started, we set up the following demands for the database:

- Maintenance of old and new data in the same structure
- Storage of old data in their original condition (library / backup)
- Storage and analysis of dendrochronological measurements and their metadata including information on the location of the archived samples
- Application of an "easy to learn" open source software (easy access and cost reasons)
- Systematic software updates and backups

At the same time other dendrochronologists were facing similar data base problems especially concerning the handling of metadata in an exchangeable way (van Lanen & Jansma 2009, Jansma et al. 2010, 2012a, b, Brewer et al. 2011).

Accessing the metadata has become more important in the past years. For storing and accessing metadata TRiDaBASE was developed recently (Jansma et al. 2012). But we want to store measurement data along with their metadata in the same structure and later on also the average curves and chronologies shall be integrated. So TRiDaBASE does not really suit our needs.

In our work environment it is also important that the database serves multiple users. Another important criterion is the possibility to port the database to another operating system or even another database system one day. Although at the moment the Dendrolab Cologne uses MS-Windows as the primary operation system, we want to stay open for future changes. This led us to the conclusion that an SQL based database might be best suited. It is available as open source software, it has a relatively simple syntax which is semantically close to English and it is a powerful and proven tool to depict complex data settings and execute even comprehensive queries. We decided in favour of the widely used and free of charge MySQL database. This decision was strongly supported by the facts that the Computing Centre at the University of Cologne (RRZK) offers MySQL with a phpMyAdmin administration plus software support, maintenance, updates and backup facilities. At the end of the project we will consider publishing all database relevant information.

Dating in Dendroarchaeology

Timbers from archaeological excavations are mostly modified by man. That is why sapwood is seldom and elements with preservation of a waney edge are very rare. Due to the anthropogenic modifications several elements of an object may have different last years. Dating in Dendroarchaeology generally pursues the goal to date the onset and lifetime of an object which may have many elements in terms of Jansma (2010:101-102). But in contrast to Jansma (2010) in the Dendrolab Cologne the multiple sampling of an element is not documented by multiple sample numbers. All pieces taken from the same element are treated as the same sample and they have the same sample number. The radii measured are continuously labelled with small letters suffixed to the sample number. We admit that in doing so it is not possible to identify the position of a radius within an element. But in our workflow it has no practical meaning to differ between several slices of wood (Jansma's 'sample') cut from the same element. For us the element's felling date is most important. The way to that goal has three levels. The first one is the date of the youngest measured ring for each radius. The second level is the date of the element. That means all radii and their dates are drawn into consideration along with statistical data on expectancy of sapwood rings (in the absence of a waney edge) to achieve a felling date. The third level is particularly important for archaeology. It holds the dates of onset and lifetime of an object. For example a wooden well, the object, has many elements, boards, and their earliest felling date will probably represent the onset of the construction while the youngest felling date may represent the latest modification or repair. The aforesaid conditions affect the design of our dendroarchaeological database.

Database Design

In 2010 Jansma et al. present their universal data model TRiDaS for exchanging dendrochronological data and metadata. The authors point out the distinction between a data-transfer standard and a data-storage standard (Jansma et al. 2010:101). They recommend a local database to store the administrative and specific data of the Lab.

Of course the design of our database aims at a user-friendly handling for everyday use. The concept is adapted to timbers from archaeological excavations and dating of frame houses. Therefore it makes no sense to provide attributes that will never be used, like sprout year, slope angle or soil depth.

We also want to hold all information in a single database to avoid any additional work steps. That is why we designed an 'active section' and a 'library section' in this database (Tab. 1). While the first one holds the revised old data and the new data in the same table structure the second is just a backup to archive the old unaltered data from the single binary files.

As the basic concept of relations between data entities in the TRiDaS data model corresponds mostly to our demands we adopted parts of it to our 'active database'. Its basic structure contains five layers (Tab. 1).

The first layer 'project' contains administrative information like customer, contact person and addresses.

The second layer 'object' is the assignment layer. In most cases this is information on the delivery of elements from an excavation or from the roof framework of a building. This is a dendrochronological object in our view. Geographical information is located in this layer as well.

The third layer 'element' is our sample layer. Independent from the amount of pieces cut from one element they all receive the same sample number (see chapter "Dating in Dendroarchaeology" above). The metadata related to them are stored here.

The fourth layer 'radius' contains information on a radius like its quality, number of sapwood rings, waney edge.

The fifth layer 'value' simply holds the information of year ring widths of each radius. Its index, ring positions and ring widths are stored here.

Table 1: Structure of the SQL-database organized in five layers. The terms of the entities are analogue to Jansma et al. 2010.

	active database		**library**
	revised & new data		original data
	additional attributes	summarised attributes	
project	administration		administration
object	titleExcavation dating reparation expertise	type category period file location	titleExcavation dating expertise location
element	dating deathYear 14C data	identifier type taxon marks	type taxon identifier dating
radius	qualityComment dating	title identifier sapwood	dating
value		index ringPosition value	index ringPosition value

Revision and Database Input

As already mentioned it is one important criterion of this project to backup the original and unaltered data from the old binary files in the 'library section'. They are the base for the step by step revision of all data of the Dendrolab. After revision they are stored in the 'active section'. During the manual input the information from different sources is revised and corrected if necessary and it is completed with further metadata, for example geographic coordinates.

Preliminary scientific results

Now, after running the project for 18 months, the revision of the data arise a first result. At first check of the revised data it was possible to reduce the gap between the late Antiquity and the Migration Period. (cp. Fig. 3 and 4). In this period we now can date around 25% of the former undated tree ring series. They helped to fill in the gaps from AD 300-340 and from AD 390-500. In future we hope to fill up the remaining gap AD 230-300 completely.

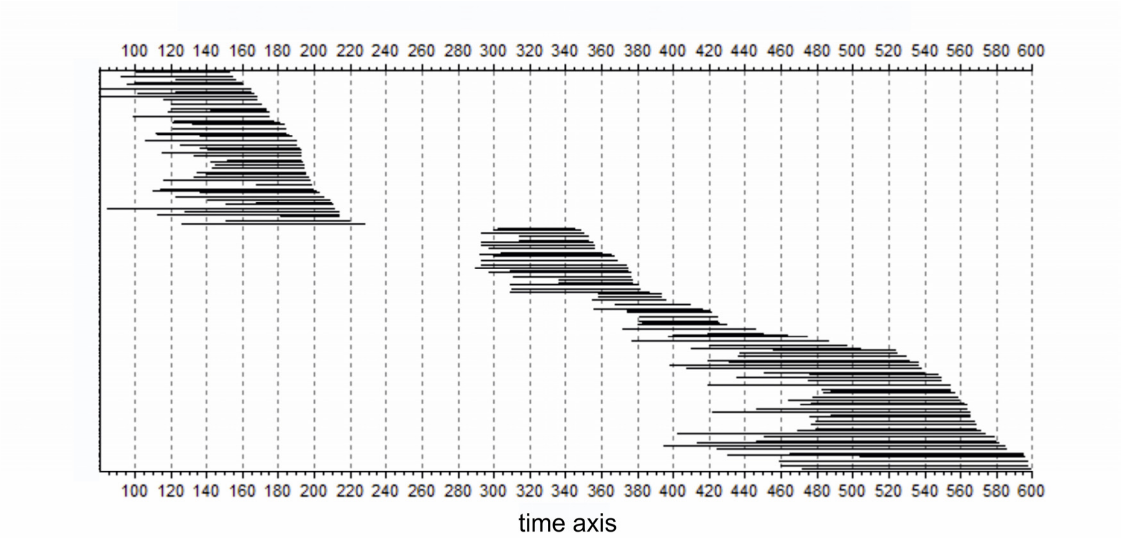


Figure 4: Replication of tree ring series dated AD 150-600 (last rings) from archaeological timbers excavated in the lignite mining area of the Rhineland.

Next the setup of regional chronologies will be started. In addition we will test statements concerning the forest management in Roman Period following the work of Billamboz & Köninger (2008) and Billamboz (2009).

This initial success by the revision of the data from the lignite mining area emphasizes the importance to ensure and revise the whole data set of the Dendrolab Cologne.

Acknowledgments

The project could have never started without the initial support of graduate engineer Dipl.-Ing. Georg Bissing (Computing Centre at the University of Cologne, RRZK) who helped us to design the basic structure of the preliminary SQL-database “dendro” and who programmed the transferring and backing up software. Thanks a lot Georg! We are very grateful for the support of the Foundation for Archaeology in the lignite area of the Rhineland (Stiftung zur Förderung der Archäologie im rheinischen Braunkohlenrevier) which enables the project. We also thank the technical assistant of the Dendrolab Cologne, Mrs. E. Höfs and student assistant M. Broich for helpful suggestions.

References

Billamboz, A., Köninger, J. (2008): Dendroarchäologische Untersuchungen zur Besiedlungs- und Landschaftsentwicklung im Neolithikum des westlichen Bodenseegebietes. In: W. Dörfler und J. Müller (eds.): Umwelt- Wirtschaft - Siedlungen im dritten vorchristlichen Jahrtausend Mitteleuropas und Südskandinaviens. Internationale Tagung Kiel 4.-6. November 2005, Bd. 84. Neumünster: Wachholtz (*Offa Bücher 84*), 317–334.

Billamboz, A. (2009): Der Stand der Dendrochronologie für die Römerzeit in Baden-Württemberg. In: J. Biel, J. Heiligmann, D. Krausse u. a. (eds.), Landesarchäologie. Festschrift für Dieter Planck zum 65. Geburtstag. *Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg Bd. 100*, 655-676.

Diethelm, B. (2012): Revision dendrochronologischer Daten im Rheinischen Braunkohlenrevier. *25 Jahre Archäologie im Rheinland 1987-2011*: 31-33.

Brewer P., Murphy D., Jansma E. (2011): Tricycle: A universal conversion tool for digital tree-ring data. *Tree-Ring Research* 67(2): 135-144.

Jansma E., Brewer P., Zandhuis I. (2010): TRiDaS 1.1: The tree-ring data standard. *Dendrochronologia* 28: 99-130.

Jansma, E., van Lanen R., Sturgeon, K., Mohlke St., Brewer, P. (2012a): TRiDaBASE: A stand-alone database for storage, analysis and exchange of dendrochronological metadata. *Dendrochronologia* 30: 209-211.

Jansma, E., van Lanen, R., Brewer, P., Kramer, R. (2012b): The DCCD: A digital data infrastructure for tree-ring research. *Dendrochronologia* 30: 249-251.

van Lanen R. J., Jansma E. (2009): Towards Exchangeability of Tree-Ring Data – The Digital Collaboratory for Cultural Dendrochronology. *14th International Congress "Cultural Heritage and New Technologies" Vienna*: 246-258

Schweingruber F. H. (1983): Der Jahrring. Standort, Methodik; Zeit und Klima in der Dendrochronologie.

Beyond dating: Archeological wood as a source of information of environmental changes in High Asia

A. Bräuning [1], A. Scharf [2], W. Kretschmer [2] & I. Burchardt [1]

[1] *Institute of Geography, University of Erlangen-Nuremberg, Germany*
[2] *Erlangen AMS Laboratory, Institute of Physics, University of Erlangen-Nuremberg, Germany*
E-mail: abraeuning@geographie.uni-erlangen.de

Introduction

The number of dendroarchaeological studies carried out in High Asia is still rather scarce (Gutschow 1994, 2001, Schmidt 1993, Schmidt et al. 1999, 2001, Sheppard et al. 2004, Xinguo et al. 2003). In dendroarchaeology, wood is commonly used as a source of dating historic or prehistoric objects. Dating is accomplished either by dendrochronological dating or by radiocarbon dating, in the latter case often by applying the wiggle-matching approach (Bronk Ramsey et al. 2001). Beside useful information in the chronological or human historical context, wood may contain additional information which may be of great relevance for reconstructing former environmental conditions, especially for extending chronologies from living trees for reconstructing past climate changes (Tarasov et al. 2003, Sheppard et al. 2004). In this study we investigate the ring-width variations of wood from living trees and historic wood samples for their indications of changes in the tree growth vigor and forest structure.

Study material and methods

Studied sites and wood material

We collected wood from historical buildings in the southern part of the Tibetan plateau around Lhasa, and in the Dolpo region of western Nepal (Bräuning 2001, Bräuning et al. 2011). Beside the historic material, wood from living trees was collected form tree stands of the same area of the historic wood. At Dolpo, living and historic wood samples come from the close neighborhood (29°26‘N/ 82°54‘E, 3850 m a.s.l.) and are from *Pinus wallichiana*. Tree-ring chronologies from Tibet come from relict stands of living *Juniperus tibetica* trees in the surrounding of Lhasa (28°58'-30°18’N/ 90°28`-91°58‘E, 4140-4450 m a.s.l.; Bräuning 2001). These chronologies from living trees cover the periods 1748-1998 and 1081-2005, respectively. However, many samples of historic wood could not be successfully crossdated with these chronologies. Thus, we carried out ca. 300 AMS ^{14}C datings to date historic samples. It is worth to note that all sites are at present strongly impacted by human influence, namely fire in Dolpo and grazing at all Tibetan sites.

Methods

Samples from living trees were collected with an increment corer at breast height, samples from historic wood was collected either with an increment corer or as disks. In cases of missing innermost rings in historic samples or in samples from living trees, the number of missing rings to the pith was estimated according ring curvature and width of the inner rings. Ring width was measured with a LINTAB V measuring table (Rinntech, Heidelberg, Germany) with a precision of 0.01 mm. We aligned the raw ring-width measurement series of samples beginning in each century according to their cambial ages and compared the cumulative growth during the first 100 years of tree growth. Since tree ages were much higher for the studied juniper trees from Tibet, now growth curves for trees established during the 20th century could be produced. For further discussion, we selected graphs from some centuries that have a minimum number of 3-4 trees starting growth in the respective century and that show differences in the mean growth behaviour.

DOI: 10.2312/GFZ.b103-13058

Results and discussion

The cumulative growth curves of *P.wallichiana* from Dolpo for the 16th, 17th, 19th and 20th centuries are shown in Figure 1. Although the data replication is rather low it is obvious that growth in the first 100 years of tree live was more homogeneous in the 16th, 17th, and 20th centuries than during the 19th century, in which the ring-width series show an extremely wide spread between fast-growing and slow-growing individuals. Average cumulative growth was lowest in the 17th century and highest during the 20th century. Since pine trees are light demanding species we interpret the results as low growth during unfavourable climatic conditions during the 17th century, an increasing human influence on the regional forests during the 18th century when some trees are strongly favoured possibly by removing competitors, and by very high growth rates in the very open tree stands surviving in the 20th century.

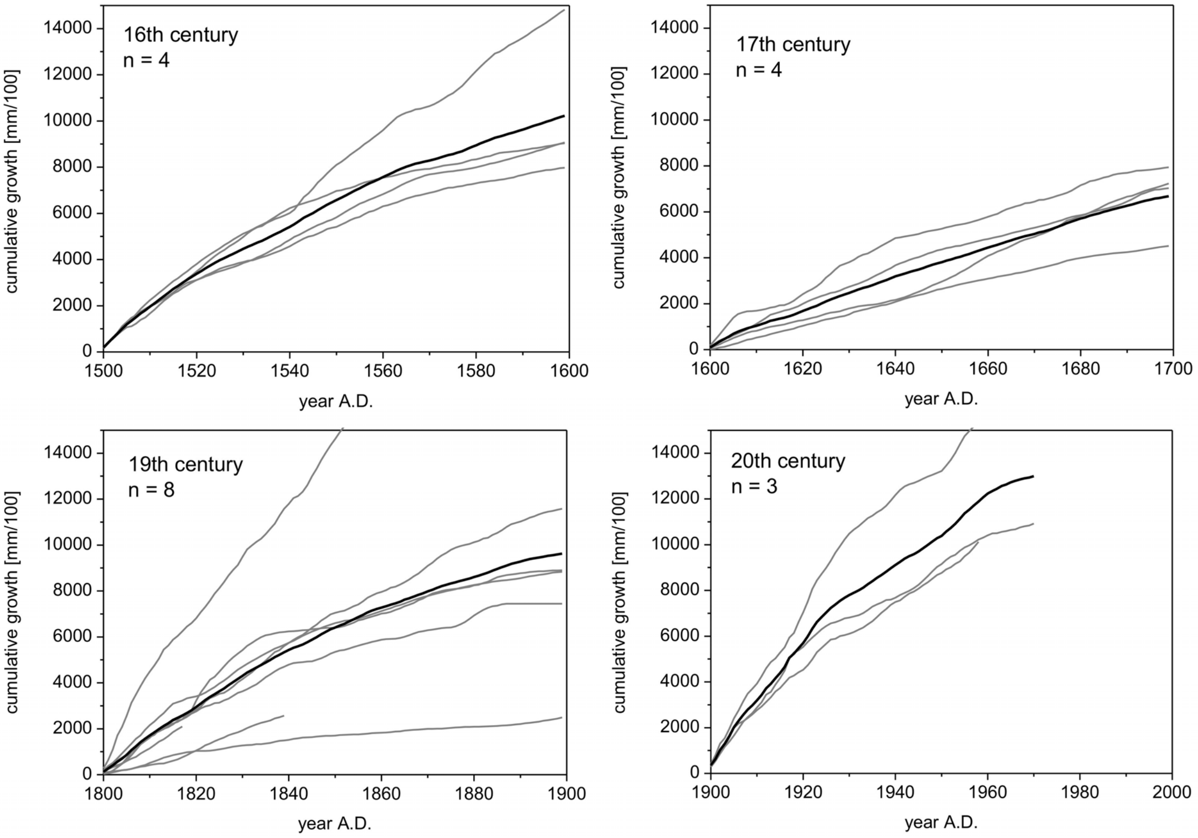


Figure 1: Cumulative growth curves from Pinus wallichiana from Dolpo region, Nepal. Single trees are shown in grey, mean growth curves in black.

The cumulative growth curves of *J. tibetica* from the southern Tibetan plateau also show strong variations during the past 2000 years (Fig. 2). Tree growth during the 1st century B.C. and during the 15th century A.D. was quite consistent and rather slow. However, during the 11th and 19th centuries, cumulative growth curves during the first 100 years of juniper growth varied strongly with higher average growth rates. Although the better growth performance of the trees may also be at least partly caused by better climatic conditions, we assume that human impact on the local forests had a strong impact especially in the 11th century, when the monastery of Reting was founded that is located in the centre of the forest with the oldest living trees (Bräuning 2001). On the other hand, impact on the forest during 19th century might also have been high since there is no indication for favourable summer moisture conditions at this semi-arid site (Grießinger et al. 2011).

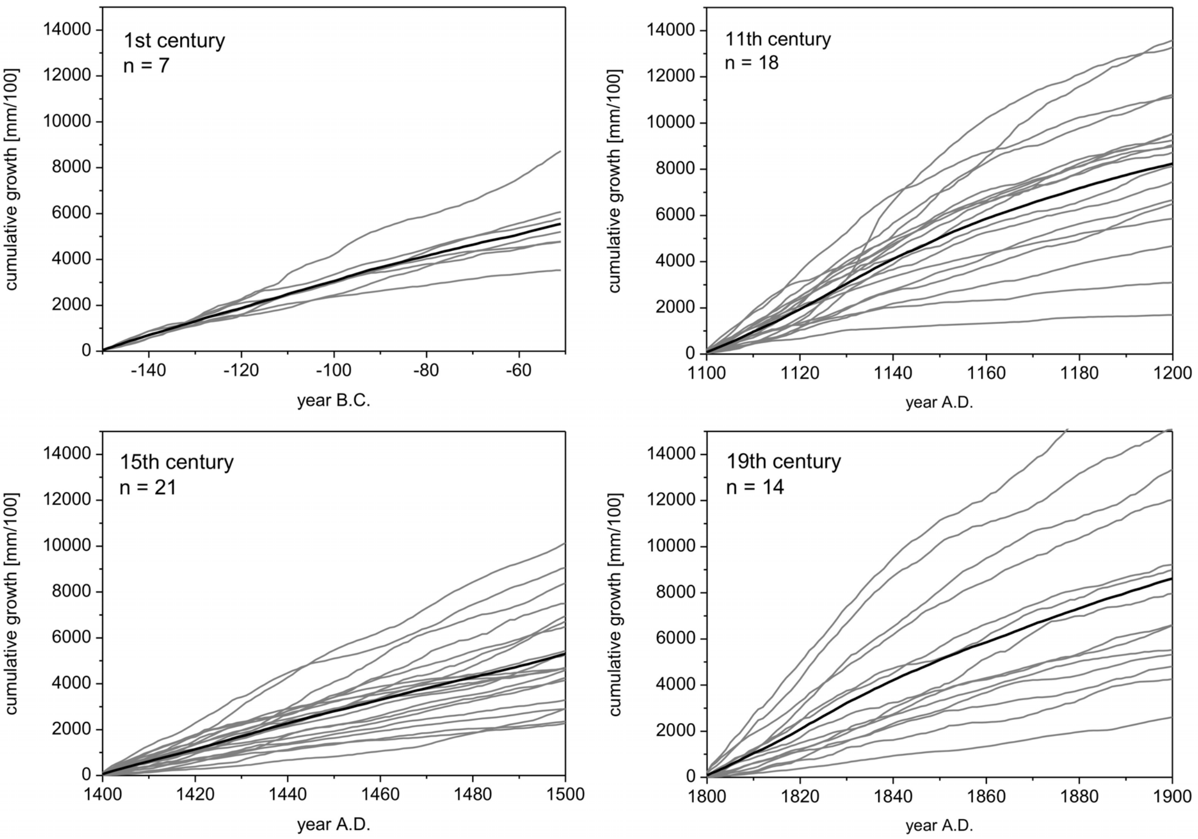


Figure 2: Cumulative growth curves from Juniperus tibetica from the Lhasa region, Tibetan plateau. Single trees are shown in grey, mean growth curves in black.

Figure 3 compares the average growth performance during the first 100 years of growth during different time periods. It becomes apparent that maximum growth rates of *P.wallichiana* can be much higher than those for the high-elevation species *J. tibetica*. On the other hand, the enhanced growth rates during the 20th century in Dolpo and during the 19th century in Tibet indicate that human impact on forest structure has been increasing during the recent decades and forests probably showed a more open structure with better light conditions for remaining trees.

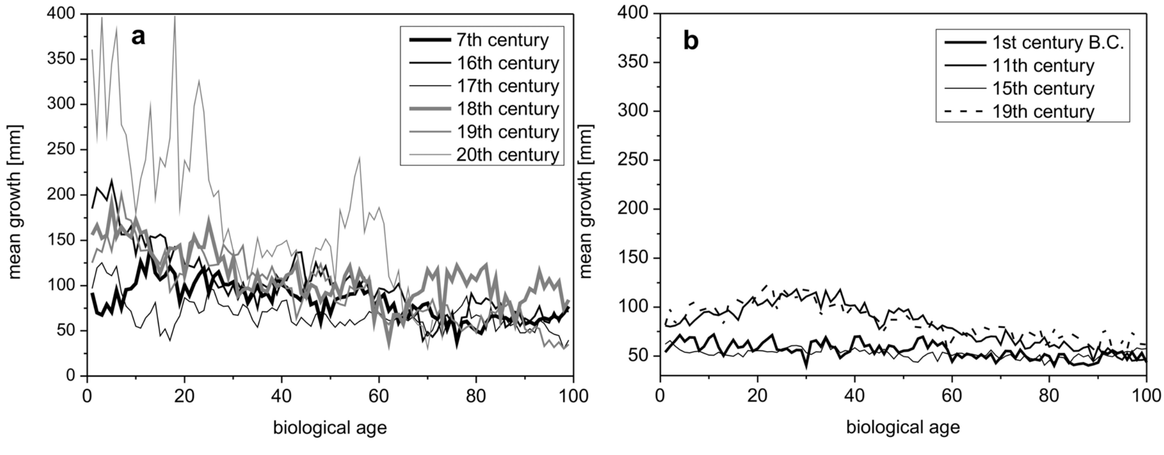


Figure 3: Average growth curves during different time periods of (a) Pinus wallichiana from Dolpo and (b) of Juniperus tibetica from the Lhasa region.

Due to low sample sizes especially during older time periods, our results are of preliminary character and should be improved by further inclusion of older trees, if those become available. The purpose of our study was to demonstrate that historic wood may contain a wealth of information about former environmental growing conditions and human-environment interactions that should be used as a source of historical environmental development.

Acknowledgments

We are indebted to the German Research Council (DFG) to support the collection of the historic wood samples (BR 1895/2-1) and the radiocarbon dating (BR 1895/18-1). Furthermore, we thank Klaus-Diether Matthes and the lately passed away André Alexander for helping to collect the tree-ring material.

References

Bräuning, A. (2001): Climate history of the Tibetan Plateau during the last 1000 years derived from a network of Juniper chronologies. *Dendrochronologia* 19: 127-137.

Bräuning, A., Scharf, A., Kretschmer, W., Gierl, S., Leichmann, K., Burchardt, I. (2011): The development of a long pine (*Pinus wallichiana*) chronology from western Nepal from living trees and 14C-dated historic wood samples. *TRACE* Vol. 9: 110-113.

Bronk Ramsey, C., van der Plicht, J., Weninger, B. (2001): 'Wiggle matching' radiocarbon dates. *Radiocarbon* 43 (2A): 381-389.

Grießinger, J., Bräuning, A., Helle, G., Thomas, A., Schleser, G. H. (2011): Late Holocene Asian summer monsoon variability reflected by δ18O in tree-rings from Tibetan junipers. *Geophysical Research Letters* 38, doi:10.1029/2010GL045988.

Gutschow, N. (1994): Kagbeni: structural analysis of dendrochronological data. *Ancient Nepal* 136: 23-50.

Gutschow, N. (2001): Kāgbeni: structural analysis of dendrochronological data. *Giessener Geographische Schriften* 77: 125-146.

Schmidt, B. (1993): Dendrochronological research in south Mustang. *Ancient Nepal* 130-133: 20–33.

Schmidt, B., Wazny, T., Kuber Malla, Höfs, E., Khalessi, M. (1999): Chronologies for historical dating in High Asia/Nepal. In: Wimmer, R. & R. E. Vetter (eds.): Tree-Ring Analysis. Biological, Methodological and Environmental Aspects. CABI Publishing: 205-211.

Schmidt, B., Gruhle, W., Thomalla, E., Khalessi, M., Malla, K. (2001): Dendrochronological dating of timber: a contribution to the architectural history and settlement processes at Kāgbeni. *Giessener Geographische Schriften* 77: 161-168.

Sheppard, P. R., Tarasov, P. E., Graumlich, L. J., Heussner, K. U., Wagner, M., Österle, H., Thompson, L. (2004): Annual precipitation since 515 BC reconstructed from living and fossil juniper growth of northeastern Qinghai Province, China. *Climate Dynamics* 23: 869–881.

Tarasov, P., Heussner, K. U., Wagner, M., Österle, H., Wang, S. (2003): Precipitation changes in Dulan 515 BC - 800 AD inferred from tree-ring data related to the human occupation of NW China. *Eurasia Antiqua* 9: 303–321.

Xinguo, X., Wei, W., Wagner, M., Heussner, K. U., Tarasov, P. E., Griess, B., Shishan, N., et al. (2003): Results of the first archaeological excavation and environmental survey at Fengtai, Qinghai Province, PR China in 2001. *Eurasia Antiqua* 9: 85–111.

SECTION 5

WOOD ANATOMY

On the importance of anatomical classification in Arctic driftwood research

L. Hellmann [1,2], W. Tegel [3], Ó. Eggertsson [4], F.H. Schweingruber [1], R. Blanchette [5], A. Kirdyanov [6], H. Gärtner [1] & U. Büntgen [1,2]

[1]Swiss Federal Research Institute, WSL, Birmensdorf, Switzerland
[2]Oeschger Centre for Climate Change Research, Bern, Switzerland
[3]Institute for Forest Growth IWW, University of Freiburg, Freiburg, Germany
[4]Iceland Forest Service, Reykjavik, Iceland
[5]University of Minnesota, Dept. of Plant Pathology, St. Paul, Minnesota
[6]V.N.Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russia
E-mail: hellmann@wsl.ch

Introduction

Annually resolved and absolutely dated patterns of tree-ring width, ideally driven by one dominating climate factor, such as summer temperature at the upper and northern distribution limits of tree growth (Fritts 1976), can provide unique opportunities for reconstructing past climate conditions (Esper et al. 2002). A combination of living trees and relict material may even allow continuous chronologies to be developed over centuries to millennia (Büntgen et al. 2011), which ultimately denote important paleo-environmental archives (IPCC 2007).

Arctic driftwood, exclusively originating from the circumpolar boreal forest zone, rifted by the ocean currents and deposited along shallow coastlines, is exceptional regarding its spatial dispersal distance and ability to be preserved over most of the Holocene (Funder et al. 2011). Driftwood may therefore constitute an important proxy record at the interface of marine and terrestrial processes. In fact, it may contain information on past environmental conditions that occurred during a tree´s lifespan, but also reflects changes in forest management, as well as associated logging and floating activities (Johansen 1998). Insight into past changes in the rate of river runoff, the dynamics of ocean currents, and the amount of postglacial uplift might be further gained from large driftwood collections if the absolute age and precise origin of each sample is determined via the application of traditional dendrochronological and wood anatomical techniques.

Early explorers at the end of the 19th century were pioneers in scientifically collecting and analyzing driftwood (e.g. Agardh 1869, Kindle 1921, Eurola 1971) (Fig. 1). The amount of material considered in these studies was, however, restricted to a few samples only. From the 1990s onward, more sophisticated surveys with enhanced sample replication took place with a main interest in assessing paleo-environmental changes including variations in sea-ice cover, as well as in linking driftwood abundance to human settlement (e.g. Eggertsson 1993, 1994a, 1994b, Dyke et al. 1997, Johansen 1998, 1999, Alix 2005). Nevertheless, highly replicated and systematic Arctic driftwood compilations and their subsequent wood anatomical and dendrochronological evaluation are still missing.

Near Holocene-long estimates of fluctuations in Arctic sea-ice cover and ocean currents were recently obtained from radiocarbon dates of ~80 driftwood samples (Funder et al. 2011), which originated from northeast Greenland. This 10’000-year long record was combined with careful analyses of ancient shell and plant remains, as well as lake isolation lines. Situated at the forefront of modern paleo-climatology and -oceanography, and focusing on the Arctic region – one of the world’s most sensitive environments to climate change – this cross-disciplinary study clearly emphasizes the potential of driftwood research to generate unprecedented datasets that combine information from both, terrestrial and marine ecosystems. However, some of the results remain partly debatable and thus raise an array of stimulating questions: Were wood anatomical and/or dendrochronological analyses applied to define the genus or species of each driftwood sample,

DOI: 10.2312/GFZ.b103-13058

and if yes, were these methods able to properly differentiate between spruce, larch, and pine? Why was the potential Siberian source region restricted to the boreal forest east of ~85°E only? How were different ocean currents that may transport driftwood from the Russian White Sea, the Barents Sea, and the more eastern Kara Sea considered? Why was the natural species distribution of the boreal forest zone simplified, yielding to the assumption that spruce predominantly originates from northern North America and larch mainly derives from eastern Siberia?

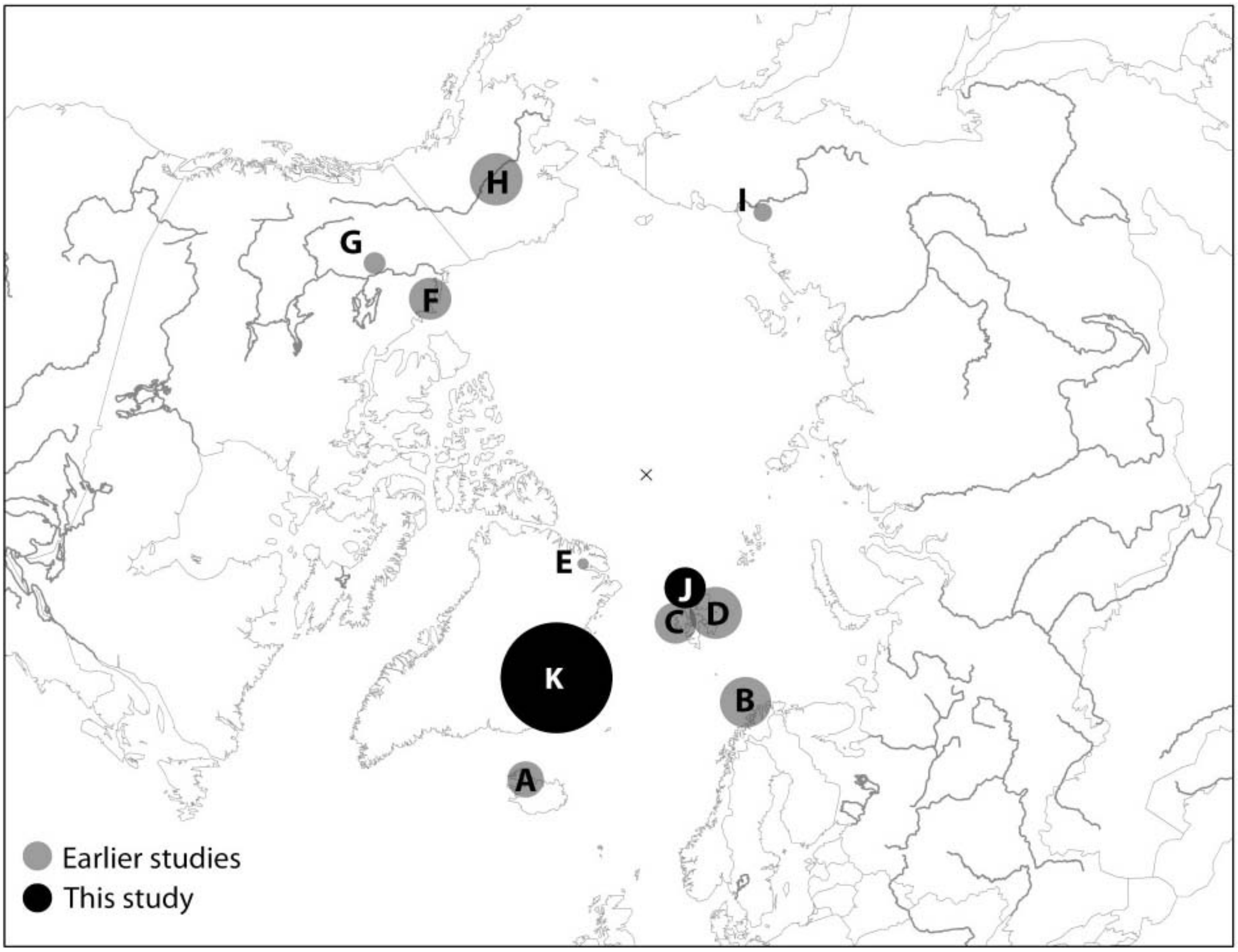


Figure 1: History of Arctic driftwood research per region: A. Iceland, B. Northern Norway, C. Svalbard, D. Jan Mayen, E. Northern Greenland, F. Northern Canada, G. Central Canada, H. Alaska, I. Siberia (Kolyma), J. Svalbard (This study), K. Eastern Greenland (This study). More than one study was often conducted per region and circle sizes therefore indicate the number of collected samples per region.

Data and Methods

In seeking to provide further methodological insight and to possibly also answer some of the above questions, we reanalyzed a total of 1’445 driftwood samples from coastal east Greenland (1’055) and Svalbard (390). All samples, ranging from small branches to large stems, were collected as discs and represent a random compilation of Arctic driftwood. The samples were differentiated between logged and natural material in the field. Logged stems derive from timber rafting on the boreal rivers, while naturally fallen stems enter the rivers due to storm events, erosion processes, or changing soil conditions. Missing rootstocks and snags characterize logged material, and clearly distinguish it from natural wood showing a root collar and/or evidence of branches.

All samples were sanded and macroscopically categorized. Macroscopic characteristics include sap-to-heartwood contrast, wood color, resin ducts, and the transition from early- to latewood. Odor and gloss of driftwood samples do not provide reliable information. Reddish heartwood is indicative for larch and pine. Spruce and fir are bright colored. Large resin ducts are typical for pine, whereas small resin ducts are common in larch and spruce. Fir is characterized by the absence of resin ducts or solely contains traumatic rows. Sharp boundaries between bright earlywood and reddish latewood are indicative for larch. To further identify the genus, respectively species of each sample, their corresponding radial cuts were microscopically analyzed. Larch, spruce, and fir have small pits in the ray cross-fields. Pine has large pinoid pits in the rays. Scots pine differs from Siberian pine by tooth-shaped in comparison to smooth tracheid walls.
Geographical online data (Little 1971, EUFORGEN 2009, Malyshev 2008) were combined with historical Russian inventories (pers. comm. S. Shyatov) and documentary evidence (Berg 1950), to map the circumpolar distribution of the main boreal conifer species. The main Eurasian and American river systems and dominant Arctic Ocean currents supplemented the bio-geographical mapping.

Results and Discussion

Our macroscopic classification separated pine, other coniferous (larch, spruce, and fir) and a few deciduous genera. Additional microscopic anatomical analyses specified *Pinus sylvestris* and *Pinus sibirica*, as well as *Larix sp.*, *Picea sp.*, *Abies sp.*, *Salix sp.*, *Populus sp.*, and *Betula sp.* Microscopic differentiation was possible for fir, willow, poplar and birch at genus-level, at species-level for pine (Scots pine and Siberian pine). Similar structure and frequent fungi infestation complicated the distinction between spruce and larch.
Uniseriately (biseriately) arranged bordered pits most often indicate spruce (larch). The different shape of cross-sectioned bordered pits in radial cuts enables the certain differentiation between the two species (Bartholin 1979). Angular-shaped pits characterize spruce, while smooth-shaped pits are typical for larch (Fig. 2).

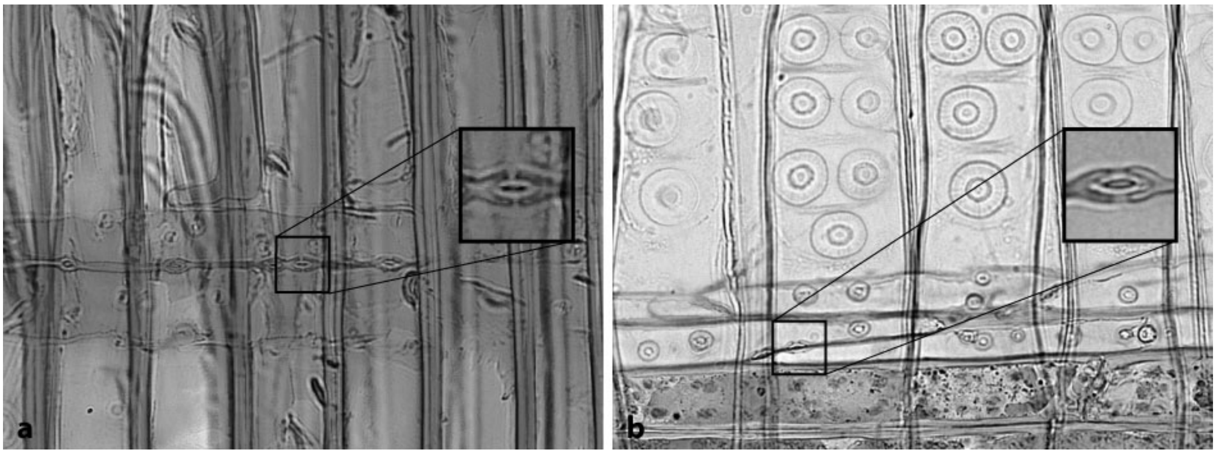


Figure 2: Distinctive anatomical feature for spruce and larch (radial cuts): a. Spruce contains angular bordered pits in its cross-sections. b. Larch comprises smooth-shaped bordered pits in its cross sections.

Our results emphasize the importance of thorough wood anatomical analyses and reveal a diverse species distribution among the driftwood sample, which reflects the circumpolar boreal species composition fairly well. Scots pine constitutes almost half of the material (37%), followed by larch and spruce (26% and 18%) (Fig. 3). Small branches represent local driftwood from surrounding areas, with willow accounting for 8% of the entire compilation. *Pinus sibirica*, *Abies sp.*, *Populus sp.*, and *Betula sp.* are less frequent and do not surpass 5% each.

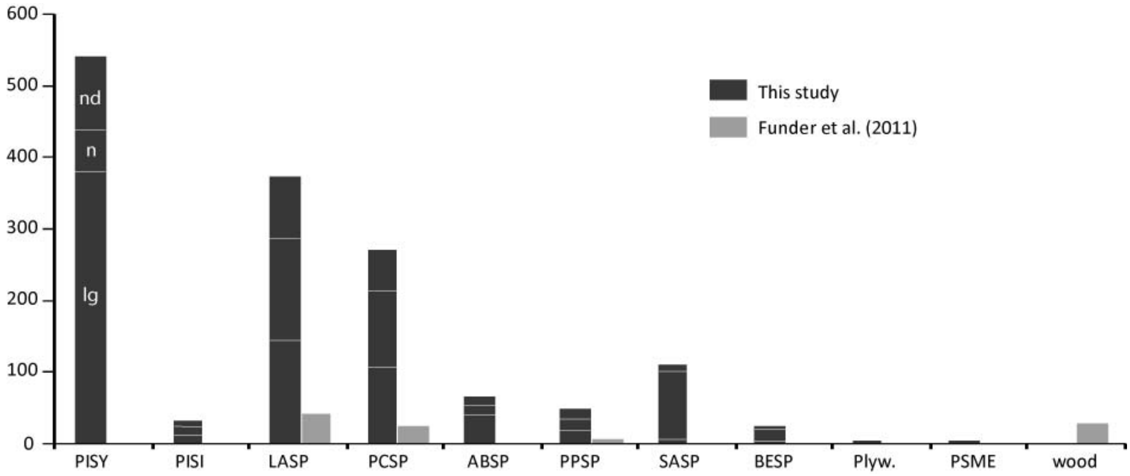


Figure 3: Species distribution of different driftwood studies, including material from northern Greenland (Funder et al. 2011), as well as eastern Greenland and Svalbard (this study), with species being abbreviated (PISY: Pinus sylvestris, PISI: Pinus sibirica, LASP: Larix sp., PCSP: Picea sp., ABSP: Abies sp., SASP: Salix sp., BESP: Betula sp., Plyw.: Plywood, wood: unidentified samples; nd: not declared if natural or logged wood, n: natural, l: logged).

This study highlights the importance of a precise anatomical assessment, and questions the results by Funder et al. (2011), who separated 80 samples from northeast Greenland into larch and spruce only. At the same time, our results stress the anatomical challenge of differentiating between spruce and larch species, and hence imply the impossibility of defining the precise origin of these two driftwood genera.

A combination of wood anatomical and dendrochronological techniques including crossdating against boreal master chronologies per catchment therefore appears particularly relevant for a precise driftwood provenancing.

Based on a fairly rough species distribution, Funder et al. (2011) considered spruce to originate exclusively from northern North America, and larch to derive only from eastern Siberia > ~85°E (east of the Yenisei River). However, the natural boreal species distribution is much more complex (Fig. 4), and all genera appear circumpolar on both continents. Moreover, larch is widely distributed in Siberia and its habitat reaches far more west than the Yenisei. According to the prevailing ocean currents, wood from western Siberia should be able to enter the main currents, which subsequently can transport the wood to its final deposition along the shallow coastlines of eastern Greenland (Fig. 4).

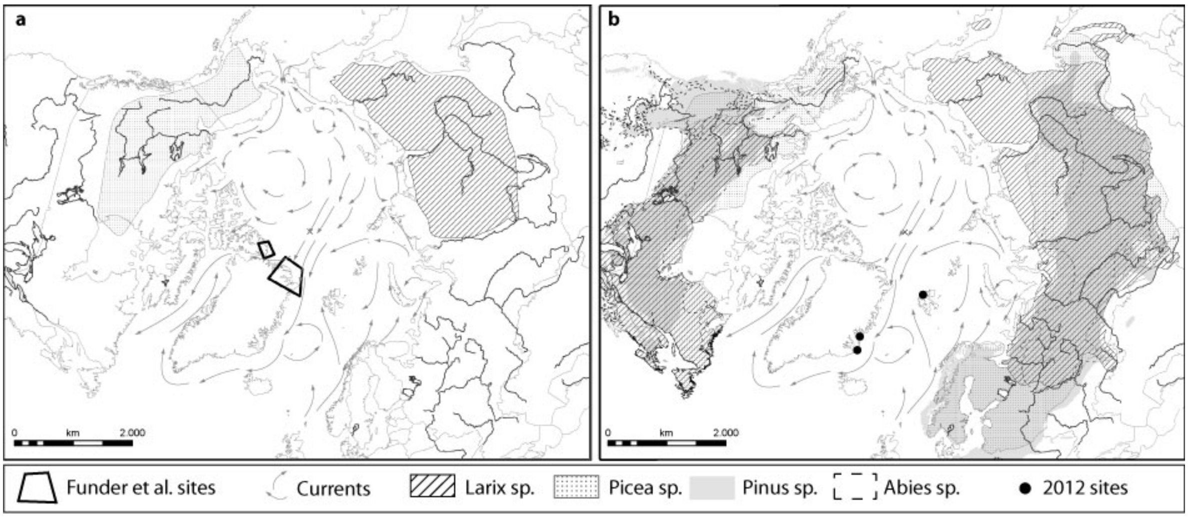


Figure 4: Spatial distribution of boreal forest species: a. Funder et al. (2011), b. Distribution considered in this study (EUFORGEN 2009, Little 1971, Malyshev 2008).

The proportion of logged and natural stems differs between the species. Almost two third (71%) of all Scots pines were logged. Within larch and spruce the amount of logged (39% and 40%) and natural (39% and 40%) wood is nearly the same. Our results therefore contradict the rather old material described by Funder et al. (2011). Pine is the dominating species in central Siberia and therefore prominent in the Russian wood industry, where timber rafting on the large rivers is the common way of transport. Intensive logging in combination with timber floating on the large Siberian rivers was started in the first half of the 20th century. Before better floating methods were established by the middle of the last century, many stems got lost on their way down the rivers. Henceforth, pine is more likely to be transported into and further through the Arctic Ocean.

Conclusions

Macro- and microscopic wood anatomical classification reveals different driftwood genera. A species-specific classification is exclusively possible for pine. Almost half of all samples were logged, and thus originate from rather recent wood industrial activities, e.g. timber rafting. Contradicting earlier results from the northeastern coastlines of Greenland, *Pinus sylvestris* accounts for the majority of our sample. This material is associated to a particularly large distribution area in Siberia, as well as to its predomination in the wood industry. Moreover, we identified *Larix sp.*, *Picea sp.*, *Abies sp.*, and *Pinus sibirica*, as well as deciduous wood of *Salix sp.*, *Populus sp.*, and *Betula sp.*. The herein analyzed driftwood collection proportionally reflects the natural species distribution of the circumpolar boreal forest zone, where the same genera appear with different intensity on both continents. Additional dendrochronological analyses including precise crossdating will guarantee the precise geographical and temporal originating of our driftwood collection. Further investigation on isotopes, fungi, ancient DNA or radiocarbon dating, also on material from different sites in the Arctic will help to fully detect the dendroecological potential of Arctic driftwood.

Acknowledgements

This study is part of an ongoing ‘driftwood project’ supported by the Eva Mayr-Stihl Foundation. B. Sittler, B. Frauenberger, C. Lachenmeier, I. Pike, and H. Linderson dynamically contributed to the sampling, and A. Verstege and D. Nievergelt supported lab work.

References

Agardh, J. (1869): Om den Spetsbergska Driftvedens ursprung. *Öfversigt af Kongl. Vetenskaps-Akademiens Förderhandlingar* 26: 97-119.

Alix, C. (2005): Deciphering the impact of change on the driftwood cycle: contribution to the study of human use of wood in the Arctic. *Global and Planetary Change* 47: 83-98.

Bartholin, T. (1979): The Picea-Larix-Problem. *IAWA Bulletin* 1: 7-9.

Berg, L. (1950): Natural regions of the U.S.S.R.. New York, The Macmillan Company. 436 pp.

Büntgen, U., Tegel, W., Nicolussi K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K-U., Wanner, H., Luterbacher J., Esper J. (2011): 2500 Years of European Climate Variability and Human Susceptibility. *Science* 331: 578-582.

Dyke, A., England, J., Reimnitz, E., Jetté, H. (1997): Changes in Driftwood Delivery to the Canadian Arctic Archipelage: The Hypothesis of Postglacial Oscillations of the Transpolar Drift. *Arctic* 50: 1-16.

Eggertsson, Ó. (1993): Origin of the driftwood on the coasts of Iceland; a dendrochronological study. *Jökull* 43: 15-32.

Eggertsson, Ó. (1994a): Driftwood as an indicator of relative changes in the influx of Arctic and Atlantic water into the coastal areas of Svalbard. *Polar Research* 13 (2): 209-218.

Eggertsson, Ó. (1994b): Mackenzie River Driftwood – A Dendrochronological Study. *Arctic* 47: 128-136.

Esper, J., Cook, E.R., Schweingruber, F.H. (2002): Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability. *Science* 22: 2250-2253.

EUFORGEN (2009) Distribution of European larch (Larix decidua), Distribution of Norway spruce (Picea abies), Distribution of Scots pine (Pinus sylvestris). In: http://www.euforgen.org/distribution_maps.html (21.04. 2012, 12.19h)

Eurola, S. (1971): The driftwoods of the Arctic Ocean. *Rep. Kevo Subarct. Res. Stat.* 7: 74-80.

Friedrich, M., Kromer, B., Spurk, M., Hofmann, J., Kaiser, K.F. (1999) Paleo-environment and radiocarbon calibration as derived from Lateglacial/Early Holocene tree-ring chronologies. *Quaternary International* 61: 27-39.

Fritts, H. (1976) Tree Rings and Climate. London New York San Francisco, Academic Press. 567 pp.

Funder, S., Goosse, H., Jepsen, H., Kaas, E., Kjaer, K., Korsgaard, N., Larsen, N., Lyså, A., Möller, P., Olsen, J., Willerslev, E. (2011): A 10,000-Year Record of Arctic Ocean Sea-Ice Variability – View from the Beach. *Science* 333: 747-750.

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

Johansen, S. (1998) The origin and age of driftwood on Jan Mayen. *Polar Research* 17 (2): 125-146.

Johansen, S. (1999) Origin of driftwood in north Norway and its relevance for transport routes of drift ice and pollution to the Barents Sea. The Science of the Total Environment 231: 201-225.

Kindle, E. (1921): Mackenzie River Driftwood. *Geogr. Review* 11: 50-53.

Little, E. Jr. (1979): Atlas of the United States trees, volume 1, conifers and important hardwoods: U.S. Department of Agriculture Miscellaneous Publication 1146, 9 p., 200 maps.

Malyshev, L. (2008): Range of Dahurian Larch (Larix dahurica), Range of Siberian Fir (Abies sibirica), Range of Siberian Larch (Larix sibirica), Range of Siberian Pine (Pinus sibirica). In: http://www.agroatlas.ru/en/content/related/ (21.04.2012, 12.21h)

Schweingruber, F. (1990): Mikroskopische Holzanatomie. 3. Aufl. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft. 226 pp.

SECTION 6

GEOMORPHOLOGY

Development of an island with a patchy structure in a gravel-bed river: Coupling of tree-ring and GIS methods

A. Rzepecka [1], B. Czajka [1], P. Mikuś [2], R.J. Kaczka [1], & B. Wyżga [2]

[1]Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
[2]Institute of Nature Conservation, Kraków, Poland
E-mail: aneta.rzepecka@gmail.com

Introduction

Under natural conditions, wooded islands are common features of braided mountain rivers (Gurnell, Petts, 2002). Islands develop if the rate of turnover of the river's active zone is lower than the rate at which trees can grow on emerged in-river surfaces (Gurnell et al., 2009). In turn, island development can be prevented: (i) by high flow and sediment dynamics of rivers resulting from rapid run-off from deforested catchments, (ii) by a frequent occurrence of high flood flows, and (iii) where natural (in gorges) or artificial (in channelized reaches) flow constrictions occur.

Early studies on the influence that vegetation exerts on the functioning of mountain rivers focused on the environmental significance of large woody debris in North American (e.g. Sedell et al., 1988) and European river systems (Gurnell et al., 1995). Studies concerning island development in mountain rivers were undertaken later (e.g. Kollmann et al., 1999), leading to recognition of the significance of vegetative regeneration of Salicaceae in island inception (Karrenberg et al., 2002) and a beneficial influence of islands on river biocomplexity (Gurnell et al., 2005; Mikuś et al., 2013). Trees developing from seeds or living driftwood can colonise gravel bars, changing them into relatively stable islands within a few years (Kaczka et al., 2008).

Studies of island development in Polish Carpathian rivers indicated that most islands in the rivers are relatively small and exhibit a simple pattern of tree age, with the oldest trees growing in the island centre (Kaczka et al., 2008; Mikuś et al., 2013). This study concerns an atypical island in the Czarny Dunajec River, that has relatively large area (1.78 ha) and exhibits a patchy structure of tree height. The Czarny Dunajec flows out of the high-mountain Tatra massif and constitutes the upper course of the Dunajec, the second largest river of the Polish Carpathians. The studied island is located in a 4-km-long, unmanaged reach of the river with an island-braided channel pattern (Fig. 1). The island is overgrown with willow-alder alluvial forest.

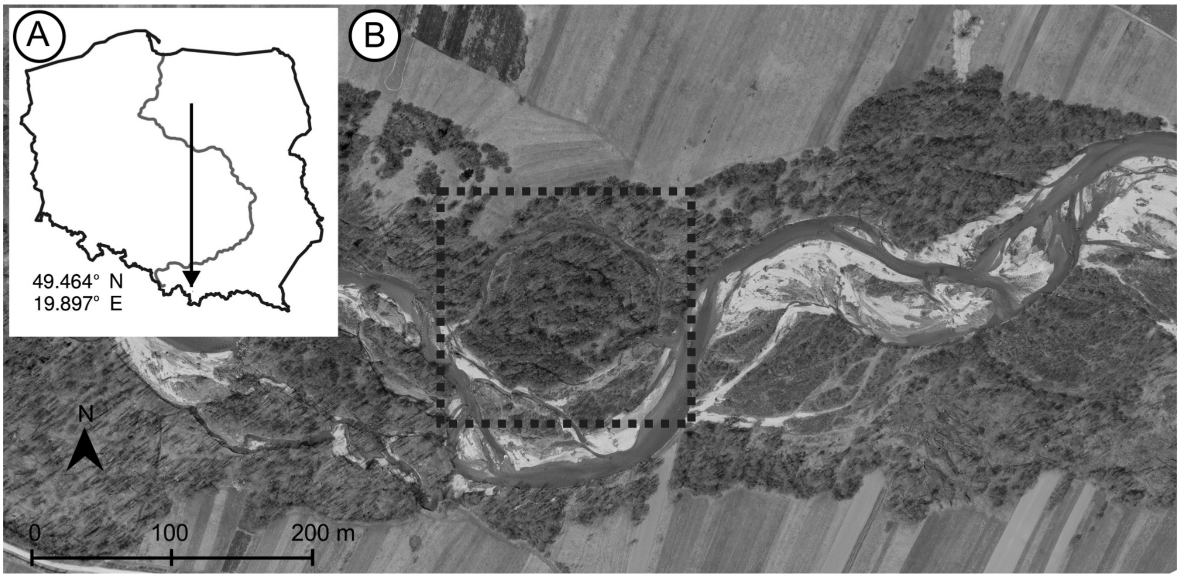


Figure 1: Location of the studied island.

The study aimed at a recognition of development stages of the large, complex island. To get a comprehensive view on the development of this form, two analytical methods (a dendrochronological study supported by GIS analysis and a photo-interpretation of fluvial forms) were applied.

Study methods

Development of the studied island was reconstructed by means of two independent methods. The first method utilized tree-ring dating of larger trees growing along four transects running across the island (Fig. 2A). In total, we dated 474 trees with a trunk diameter larger than 5 cm (measured on the height of 30 cm above the ground). We assumed that the diameter of a trunk is a good indicator of tree age as the former is directly proportional to the latter (Fig. 2B). Increment cores were taken at the lowest elevation still enabling the use of a tree corer to obtain as many rings as possible and to determine the year of tree establishment most precisely. The samples were subjected to standard dendrochronological processing. The number of rings was counted from pith to bark. The Duncan's method was employed in the case of missing pith (Duncan 1989, Rozas 2003). The location of each sampled tree was established using "Trimble GeoXT" GPS receiver with average accuracy of 0.45 m.

Data about tree age are discrete and represent points on the island surface. In order to obtain continuous information about the time of tree establishment on the island, interpolation of the data by means of the Inverse Distance Weighted method (IDW) was performed. In this method, the extreme (minimum and maximum) values are not generated outside the preset points and the critical value is the distance from the starting point. Summary results were visualized using the ArcMap software.

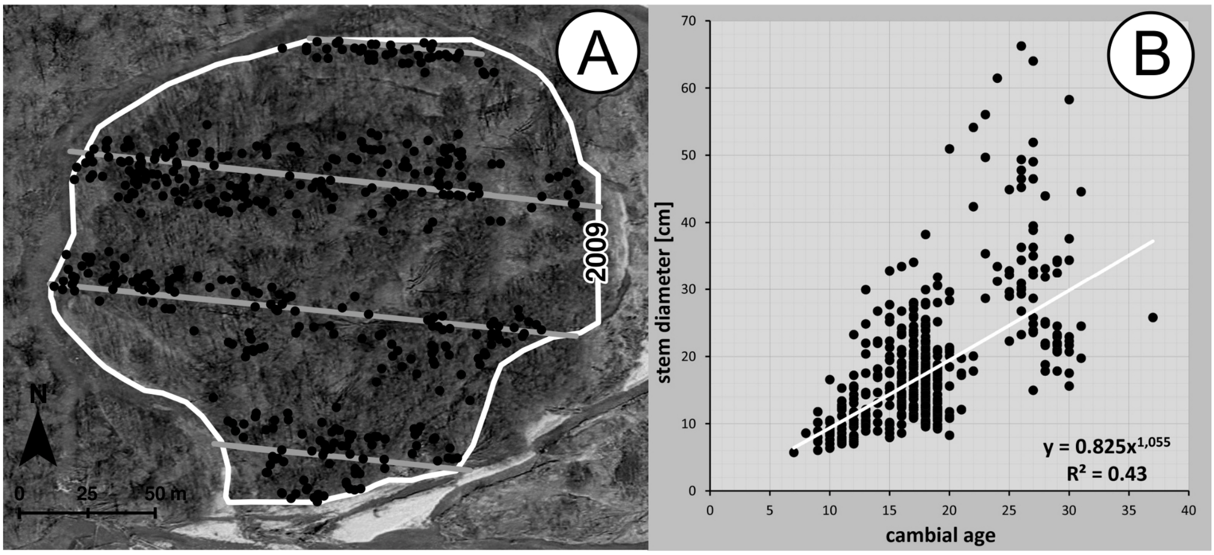


Figure 2: (A) Location of sampled trees along four transects running across the island and (B) the relationship between stem diameter and the cambial age of the trees estimated using Duncan's method (Duncan 1989, Rozas 2003).

Another method used in the reconstruction of the island development was photo-interpretation of orthophotos taken in 1977, 1983, 1994, 2002 and 2009, with a pixel size varying between 0.5 and 0.75 m. Based on the analysis of spectral reflectance signature (brightness, colour and contrast between pixels) (Smirnow 1970), each element of the study area was classified into one of the four fluvial forms: low-flow channel, floodplain, river island and gravel bar.

Results

Results of the tree-ring dating interpolated over the whole studied island, together with the spatial pattern of fluvial forms shown on the orthophotos from 5 dates, allowed to get a model of island development (Fig. 3). The analyses indicate that over the past 35 years the studied reach of the Czarny Dunajec was significantly transformed by erosion and accumulation processes. In 1977 the location of the present island was occupied by a floodplain overgrown by a well-developed riparian forest (NW part of the present island), a lateral bar (central part) and a low-flow channel (SE part). A tree that started growing on the lateral bar in 1974 was found on Transect 2. The left bank of the river, that 35 years ago occurred within the area of the present island, later gradually retreated, leaving the space for the island development since the late 1980s.

With the deposition of material within the river, new depositional forms originate, first as gravel bars that subsequently can be colonised and strengthened by vegetation. Patches of woody vegetation on gravel bars form the nuclei of island development and stimulate the deposition of fines, allowing the depositional processes to prevail over erosion in a given part of the channel.

In 2002 the studied island was almost fully developed and its further growth in the years 2002-2009 was limited to its marginal parts (Fig. 3). The island originated as a result of the coalescence of a few smaller gravel bars that were stabilised by encroaching woody vegetation. Islands in the braided rivers of the Polish Carpathians develop in the upstream direction (Kaczka et al., 2008: Mikuś et al., 2013) and usually are considerably smaller than the studied island. The latter initially exhibited the same pattern of longitudinal growth, with the oldest central part, but about 10 years after the island inception its width started to rapidly increase.

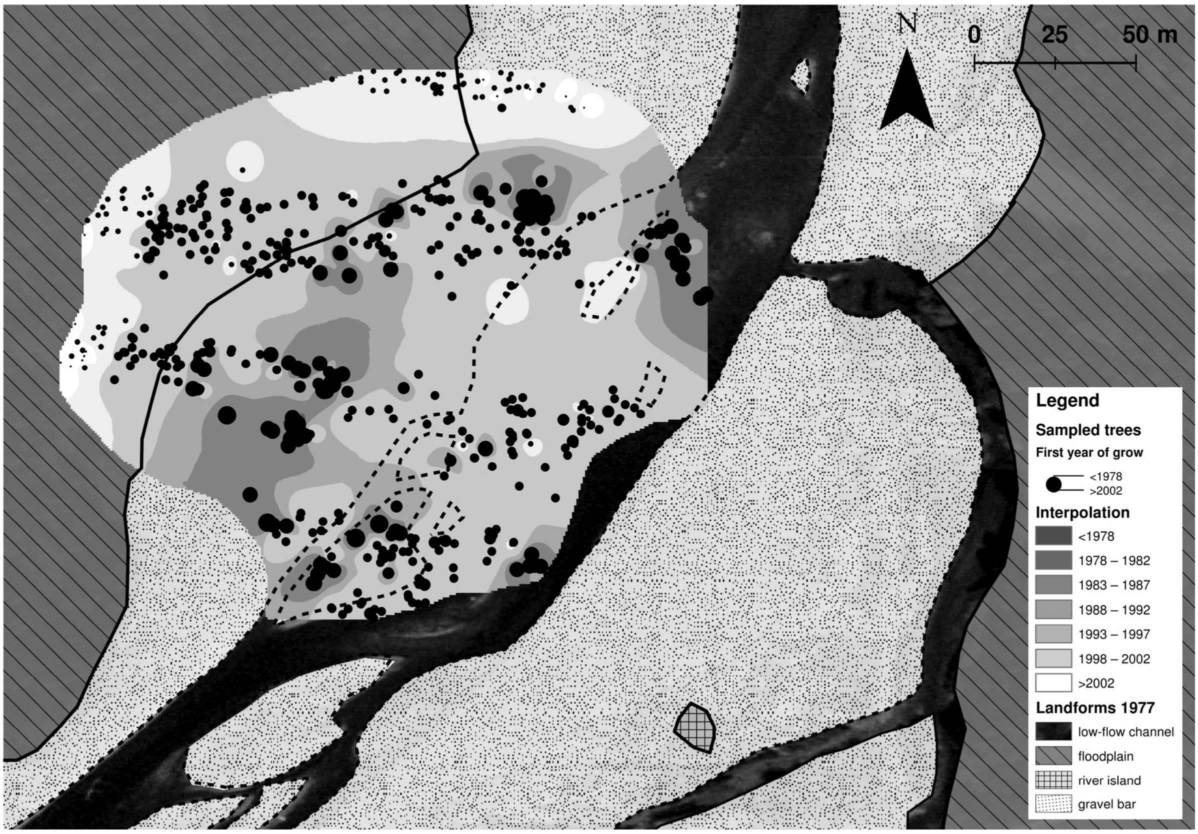


Figure 3: Location and extent of the studied island in 2009 shown on the background of fluvial forms presented on the orthophoto from 1977, and the model of the island development between 1977and 2009 based on the results of dendrochronological sampling (black circles).

Conclusions

The studied island originated as a result of the long operation of depositional and erosional processes in the river. The development of the form was supported by vegetation establishment that has led to the stabilisation and coalescence of gravel bars. During more than 30 years (1977-2009) the studied form evolved from a set of small gravel bars to the large wooded island, with the associated seventeen-fold increase in its area.

A comparison of the results of both methods (the photo-interpretation of fluvial forms and the dendrochronological dating of trees on the island) shows that a more comprehensive reconstruction of the island development could be obtained by the use of the dendrochronological method supported by a modern cartographic technique (GIS). Not only did it reveal the spatial extent of woody vegetation encroachment on emerged surfaces in the river but also, due to the nature of the record in tree rings, allowed a more detailed reconstruction of its temporal progress. The photo-interpretation method is faster but its results are less precise and discontinuous in time.

The interpolation of point data about the age of trees, performed with the use of GIS, enabled to create a model presenting the successive stages of island development. The use of GIS also enabled combination of the results of both methods, which yielded a more comprehensive reconstruction of the development of the studied element of the multi-thread river.

Acknowledgements

This study was performed within the scope of the Research Project N N305 097239 financed by the Polish Ministry of Science and Higher Education.

References

Duncan R.P. 1989. An evaluation of errors in tree age estimates based on increment cores in Kahikatea (Dacrycarpus Dacrydiodes). *New Zealand Natural Science* 16: 31-37.

Gurnell, A.M., Gregory, K.J., Petts, G.E. (1995): The role of coarse woody debris in forest aquatic habitats: implications for management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5: 143-166.

Gurnell, A.M., Petts, G.E. (2002): Island-dominated landscapes of large floodplain rivers, a European perspective. *Freshwater Biology* 47: 581-600.

Gurnell, A.M., Surian, N., Zanoni, L. (2009): Multi-thread river channels: A perspective on changing European alpine river systems. *Aquatic Sciences* 71: 253-265.

Gurnell, A.M., Tockner, K., Edwards, P.J, Petts, G.E. (2005): Effects of deposited wood on biocomplexity of river corridors. *Frontiers in Ecology and the Environment* 3: 377–382.

Kaczka, R.J., Wyżga, B., Zawiejska, J. (2008): Tree-ring study of the island formation and riparian forest along a gravel-bed river in the Polish Carpathians. In: Elferts, D., Brumelis, G., Gärtner, H., Helle, G., Schleser, G. (Eds.), *TRACE – Tree Rings in Archaeology, Climatology and Ecology 6. Proceedings of the Dendrosymposium 2007, 3-6 May 2007*, *Riga, Latvia. Association for Tree Ring Research, Potsdam*, pp. 106-110.

Karrenberg, S., Edwards, P.J., Kollmann, J. (2002): The life history of Salicaceae living in the active zone of floodplains. *Freshwater Biology* 47: 733-748.

Kollmann, J., Vieli, M., Edwards, P.J., Tockner, K., Ward, J.V. (1999): Interactions between vegetation development and island formation in the Alpine river Tagliamento. *Applied Vegetation Science* 2: 25–36.

Mikuś, P., Wyżga, B., Kaczka, R.J., Walusiak, E., Zawiejska, J. (2013): Islands in a European mountain river: linkages with large wood deposition, flood flows and plant diversity. *Geomorphology*. DOI:10.1016/j.geomorph.2012.09.016

Rozas V. 2003. Tree age estimates in Fagus sylvatica and Quercus robur: testing previous and improved methods. *Plant Ecology* 167: 193-212.

Sedell, P.A., Bisson, P.A., Swanson, F.J., Gregory, S.V. (1988): What we know about large trees that fall into streams and rivers. In: Maser, G., Tarrent, R.F., Franklin, J.F. (Eds.), *From the Forest to the Seas: a Story of Fallen Trees, USDA Forest Service, Pacific Northwest* Station, Portland, pp. 47–81.

Smirnow, J. (1970): Teoretyczne podstawy fotointerpretacji. PWN, Warszawa, 240 pp.

Dendrological reconstruction of the avalanches occurring on the eastern slope of the Piatra Craiului Mts. (Carpathians, Romania), preliminary results

A. Munteanu[1] **& O. Pop**[2]

[1]Faculty of Geography, University of Bucharest, Romania
[2]Faculty of Food and Tourism, Transilvania University of Braşov, Romania
E-mail: munteanca@yahoo.com

Introduction

The Romanian Carpathians represent a geographical space where dendrogeomorphological analyses are still at the beginning, as the laboratories that specialize in such analyses have emerged only during the last years. Consequently, the dendrogeomorphological analyses undertaken along the avalanche chutes in the Romanian Carpathians are relatively recent. In 2005, many such catastrophic events occurred, which created the opportunity to run such kind of tests. In Piatra Craiului Mts., for instance, the specialists were able to accomplish a dendrogeomorphological reconstruction of the respective events based on the analyses undertaken along the avalanche tracks, which scar the mountain slopes (Motoiu & Munteanu 2006). Thus, the investigations focused both on the local conditions that encourage avalanche formation and on the impact they have on forest vegetation. The present study shows in detail what happened in the Vlăduşca area in 2005.

Study area

The investigated area lies on the eastern slope of the Piatra Craiului massif, a mountain unit developing on the eastern façade of the Southern Carpathians (the central part of Romania). The massif is essentially a calcareous ridge trending northeast-southwest, which reaches the maximum altitude of 2238 m in Piscul Baciului peak (Fig. 1). The ridge is influenced by the geological structure, as it is nothing else but the western flank of the Piatra Craiului synclinorium, which has taken the appearance of a hogback. Therefore, it has two slopes that differ from the morphological point of view: the eastern one is less inclined, with limestones in its upper part and conglomerates in its middle and lower sections, while the western one is calcareous and steeper. Both slopes are dissected by a temporary hydrographic network, which encourages the formation of avalanche chutes that destroy the adjacent forest. Consequently, avalanches and torrential erosion are the most important present-day geomorphological processes (Constantinescu 2006, 2009, Munteanu 2009, Munteanu et. al. 2011). The eastern slope displays a number of structural cliffs lying on the upper calcareous part or at the contact between the limestones and conglomerates. In the middle part of the slope, one can see the avalanche tracks in the Vlăduşca area (Fig. 2), one beginning beneath the highest peak in the massif and the other immediately north of it. The two longitudinal tracks are separated by an interfluve, which in 2005 was transcended by the sliding snow. Both corridors belong to the headwaters area of the northeastern catchment of the massif, which goes by the name of Prăpăstiile Zărneştiului.

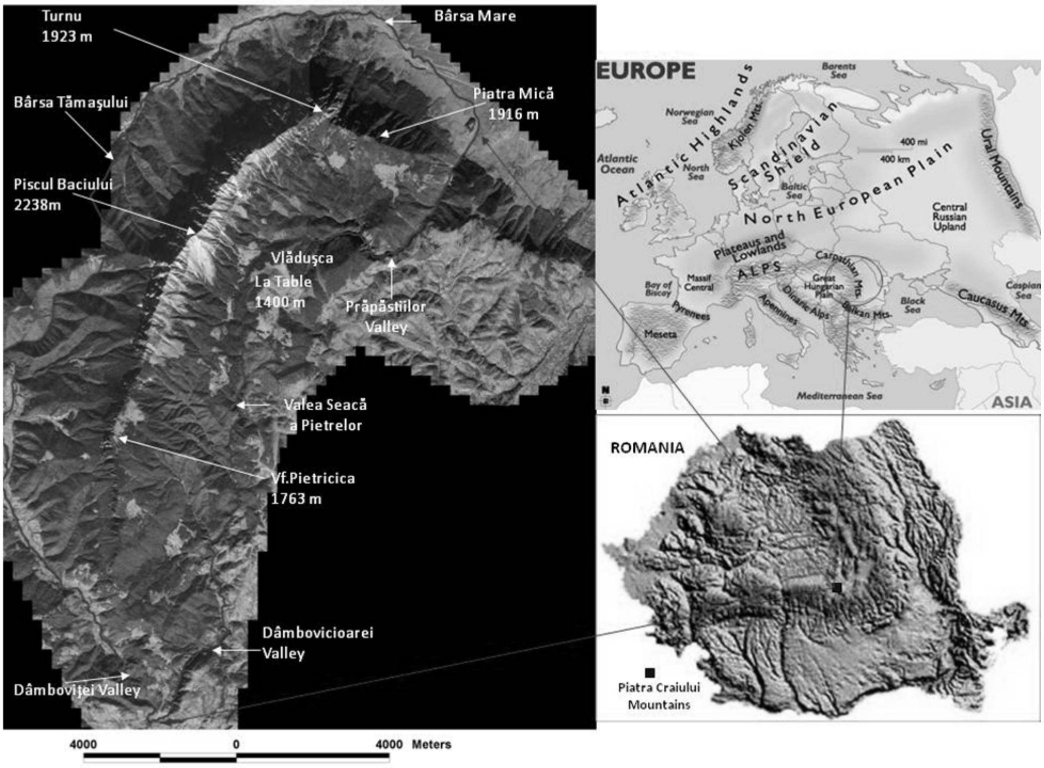


Figure 1: The location of study area

Methods

Dendrological analyses have relied on the existing data, which are found in a number of specialty works (Deline et al.2011, Decaulne & Saemundsson 2006, Malik & Owczarek 2007, Viglietti et al. 2010, Stoffel & Bollschweiler 2008).

The dendrogeomorphological reconstruction of the avalanche tracks was accomplished based on the traces left on vegetation (namely on forest and on the isolated trees). Beside the mappings in the field, accomplished by using GPS receivers, measure tapes, clinometers and compasses, we also used topographic and tourist maps, satellite imagery, ortophotoplans and aerial photographs of various scales and editions, in order to assess the initial situation and the changes that occurred in the aftermath of the avalanche event. At the same time, we analyzed the vegetation along the avalanche chute, as well as the one lying at its extremities, trying to get a clear picture of the avalanche effects. By studying the fallen trees and by taking samples of their trunks we were able to establish their age and the moment of their compression.

Fig. 2 The avalanche tracks in the Vlăduşca area, identified on the Ikonos 2004 satellite image and the location of the corridors in the Vlăduşca area, lying on the eastern slope of the Piatra Craiului Mts.

Results and discussion

On March 2005, the Piatra Craiului Mts. witnessed three large avalanches, which occurred in three areas, i.e. Vlăduşca, Grind and Padinile Frumoase (Munteanu & Motoiu, 2006; Motoiu & Munteanu, 2006). Here, the local morphological conditions encourage avalanche formation, because the upper part of the ridge lies above 2000 m altitude. Consequently, the snow piles up easily and wind slabs and snow cornices come into existence. When they collapse, they often trigger natural avalanches. The general morphology is given by the divergent temporary river network, which scars the calcareous slope and deepens into the conglomerates underlying the forest vegetation (Fig.3). The resulting channels shelter along their thalwegs loose deposits alternating with scree formations found in various stages of stabilization. The prevailingly eastern aspect encourages avalanche formation throughout the entire cold season. The slope gradients exceed 60^0 on the structural cliffs, while in the upper calcareous area they range between 35^0 and 45^0. In the middle section, however, the values drop to 20^0-35^0, but at the base of the cliff they get even lower (Munteanu & Motoiu 2006, Munteanu et. al. 2011). At the same time, one must also take into account the favorable climatic conditions of the winter 2004-2005, when successive snowfalls were recorded starting with November, alternating with periods of stability and warm spells, which brought about naturally triggered avalanches (Motoiu & Munteanu 2006).

The avalanche of March 2005 occurred on the southern corridor, which originates in the catchment area lying beneath the Piscul Baciului peak (Fig. 4). Its general direction was west southwest-east northeast. Initially, the avalanche followed the main channel, went over the contact between the limestones and conglomerates, and after approximately 200 m crossed the lower northern interfluve, passing into the northern corridor. The avalanche continued simultaneously on both tracks, thus indicating a diffluence phenomenon. With the decreasing of gradient, the avalanche lost energy and finally stopped at the base of the slope. The deposits aligned themselves according to the initial morphology: divergent to the south and along the valley, to the north (Fig. 4) (Munteanu & Motoiu 2006). Parallel to this avalanche, on the southeastern slope of the peak, another snow-sliding phenomenon occurred, which borrowed the corridor of the Grind Valley (Motoiu & Munteanu 2006).

The morphology of the functional zones is well emphasized by the local features of each of them (Fig. 3). Thus, the starting zone is represented by two nival depressionary areas, developed on limestones, lying at elevations between 2238 and 1950 m. The mean values of the slope gradients exceed 40^0, the mean length is 400 m and the mean width is 660 m. In the northern microdepression, the substratum is represented by limestones, rocks and screes, while in the southern one, it is prevailingly herbaceous, the sedimentary deposits being distributed more sparsely, especially on the lower section. The depressionary area situated on the northern corridor, upstream the calcareous rocks, is divided into four small thalwegs. Here, the vegetation is represented by East Carpathian sesleria-evergreen sedge grasslands; alpine and subalpine calcareous grassland (*Sesleria rigida ssp. Haynaldiana, Carex sempervirens)*; Carpathian Kotschy's alpenrose heaths (Bushes with *Pinus mugo* and *Rhododendron myrtifolium*)*;* East Carpathian xerophile poppy screes; calcareous and calchist screes of the mountain to alpine levels (*Thlaspietea rotundifolii*) - *Papaver corona-sancti-stephani, Cerastium lerchenfeldianum* and *Cerastium transsilvanicum*.

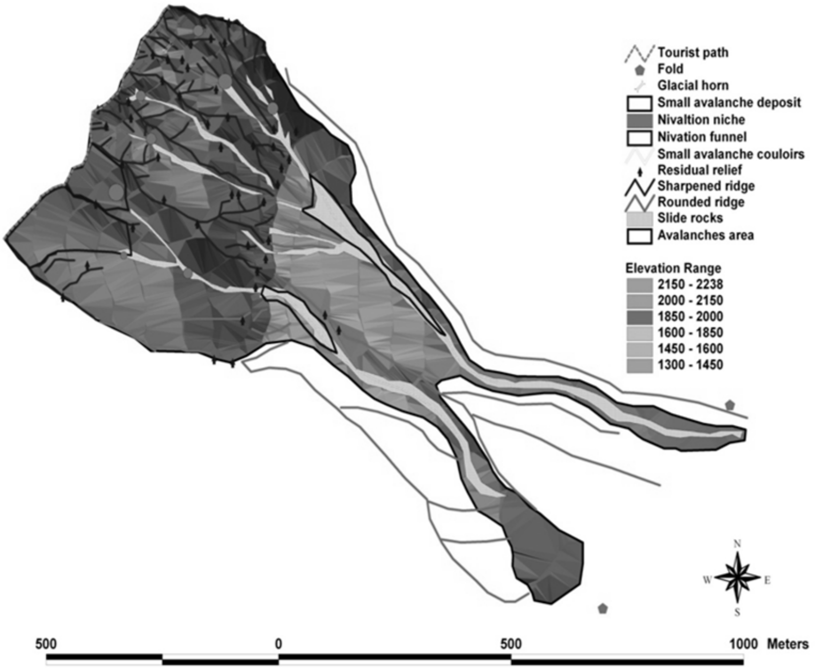


Figure 3: Map of the avalanche corridors in the Vlăduşca area

The avalanche path is made up of two distinct channels, which fall in steps. When large avalanches occur, at elevations between 1950 and 1500 m these corridors can merge with each other. The gradient ranges here from 85^0 to 10^0, the mean slope is 36^0, the mean length is 700 m, and the mean width is 250 m. At the contact between the limestones and conglomerates, the avalanches jump over the calcareous cliff, which is more than 60 m high. On the northern slope, the substratum is made up of mobile and semi-mobile scree, while on the southern one, it mainly consists of semi-mobile talus slopes. The vegetation growing in this area is represented by Eastern Carpathian yellow oatgrass meadows (*Agrostis capillaris* and *Festuca rubra*); Eastern Carpathian mat-grass swards Species-rich *Nardus* grasslands, in siliceous substrates in mountain areas (and submontane areas, in Continental Europe) - *Nardus stricta* and *Viola declinata*; East Carpathian xerophilous poppy screes. To the base of the slopes, begins to appear the Carpathian *Oxalis* spruce forest *(Picea abies and Oxalis acetosella*).

The deposition zone runs from 1500 to 1345 m altitude and shows distinct features for each corridor. Thus, the northern one is elongated and deep, while the southern one is wider. The first is 510 m long, while the second is only 345 m. As far as the width is concerned, it is 45 m and 80 m respectively. The deposit's maximum computed area is approximately 7 hectares, including the adjacent pastures. The substratum mainly consists of semi-mobile scree and grassy vegetation, Eastern Carpathian yellow oatgrass meadows; and Carpathian *Oxalis* spruce forest *(Picea abies and Oxalis acetosella)*. Between the two nival-torrential catchments there is a rounded interfluve covered by the Carpathian *Oxalis* spruce forest *(Picea abies and Oxalis acetosella)* (Pop & Vezeanu 2006). The forest vegetation suffered the most damage, as the felled trees deposits lying only 200 m away from the Vlăduşca sheepfold suggest. This means the avalanches that occurred on the southern and northern corridors leveled to the ground the trees that stood in their way, no matter if they were along their tracks or on the middle and lower sections of the divide. In the aftermath of these events, twelve hectares of forest were destroyed. The erosion exerted on the substratum is significant, especially if we consider the starting zones and the avalanche paths. The materials removed from above were later deposited in the lower areas, in the so-called runout zone. At the base of the two avalanche tracks, there are two important tourist trails, which are very busy even in winter. This means the avalanches also pose a serious threat to the tourist activities carried out in this area. Although it is very important to know the avalanche recurrence interval, the efforts in this respect are still at the beginning. Generally, the small-size avalanches that occur every year begin in the alpine level and end up before reaching the forest zone. The analyses of the compressed wood suggest that the largest events of this kind took place about 30-34 years ago (Tab. 1) (Motoiu & Munteanu 2006). This is the reason why the vegetation is so sparse, being represented only by dwarf shrubs and grass, which stabilize the scree deposits.

Table 1: Age of trees and of compression wood found on spruce in Vladusca Valley

Valley	Age of trees (years)	Percent of trees	Age of compression wood
Vladusca	>15	3%	
	16-25	5%	
	26-30	10%	2-3 years
	31-40	24%	2-3; 26; 30 years
	41-50	55%	2-3; 17; 26; 30-31; 39-40 years
	>50	3%	3; 6; 26; 30-31; 40 years

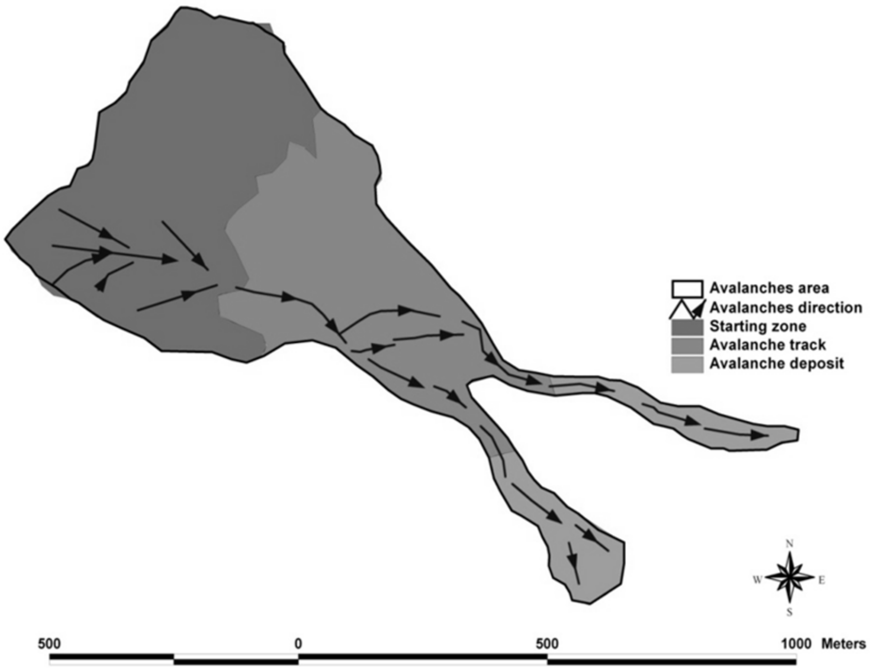


Figure 4: The functional zones and the itinerary of the avalanche of 2005, reconstructed on a dendrogeomorphological basis

Conclusions

The winter 2004-2005 was very special from the point of view of avalanche occurrence in the Romanian Carpathians. Specialists were able to reconstruct some of these avalanche events based on the traces they found on the vegetation affected by the respective tracks. Generally, the most obvious impact was suffered by the wooden vegetation. However, the periodical devastation of the forests gives the vegetation along the avalanche tracks a chance to survive. Under different conditions, this would be doomed to extinction, which would be unbeneficial for the Piatra Craiului National Park. For the moment, the study of avalanche recurrence is at the beginning, but it is beyond any doubt that the future dendrochronological analyses boosted by this study will bring additional information on this topic.

Acknowledgements

This geographical and geomorphological investigations was supported by the strategic grant POSDRU/89/1.5/S/58852, Project Program for postdoctoral researchers in science education, co-financed by the European Social Fund within the „Sectoral Operational Program Human Resources' Development 2007 – 2013". The researches on vegetation and habitats dynamics included in this paper are supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/89/1.5/S/59323.

To our late colleague, Maria Dana Motoiu, together with whom we began these studies.

References

Constantinescu, T. (2006): Torentiality and avalanches, the main present day geomorphological processes in Piatra Craiului Ridge, *Reserch in Piatra Craiului National Park*, Ed. Universității Transilvania, Braşov 2: 38-46.

Constantinescu, T. (2009): Piatra Craiului – Geomorphological study, Ed. Universitara, Bucharest, 163.

Deline, P., Alberto, W., Broccolato, M., Hungr, O., Noetzli, J., Ravanel, L., Tamburini, A. (2011): The December 2008 Crammont rock avalanche, Mont Blanc massif area, Italy, Nat. *Hazards Earth Syst. Sci.* 11: 3307–3318.

Decaulne, A., Saemundsson, T. (2006): Geomorphic evidence for present-day snow-avalanche and debris-flow impact in the Icelandic Westfjords, *Geomorphology* 80: 80–93.

Malik, I., Owczarek, P., (2007): Dendrochronological records of erosion and sedimentation in a mid-mountain stream (Jeseniki Mountains – Czech Republic), Haneca K, Verheyden A, Beekmann H, Gärtner H, Helle G, Schleser G (eds.) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 5: Proceedings of the DENDROSYMPOSIUM 2006, April 20th – 22nd 2006, Tervuren, Belgium. Schriften des Forschungszentrums Jülich, Reihe Umwelt 74: 240 - 247.

Moțoiu, M.D. (2008): Avalanches and their impact on the environment. Case studies in the Carpathians, Ed. Proxima, Bucharest, 280.

Moțoiu, M., Munteanu, A. (2006): Large Avalanches On The Eastern Slope Of The Piatra Craiului Massif In March 2005, *Reserch in Piatra Craiului National Park*, Ed. Universității Transilvania, Braşov, 3: 44-66.

Munteanu, A., Moțoiu, M., D. (2006): The avalanchses' impact into the antrophic activities on the Piatra Craiului Easten Slope, *Analele Universități de Vest din Timişoara*, Geografie 16: 113-126.

Munteanu, A., Nedelea, A., Comănescu L., Gheorghe C. (2011): The dynamics of slopes affected by avalanches in Piatra Craiului Massif – Southern Carpathians, *International Journal of the Physical Sciences*, 6 (7): 1720-1731.

Pop, O., Vezeanu, C. (2006): Mapping of the main habitas in the Piatra Craiului National Park, *Reserch in Piatra Craiului National Park*, Ed. Universității Transilvania, Braşov 2: 144-151.

Viglietti, D., Letey, S., Motta, R., Maggioni, M., Freppaz, M. (2010): Snow avalanche release in forest ecosystems: A case study in the Aosta Valley Region (NW-Italy), Cold *Regions Science and Technology* 64: 167–173.

Stoffel, M., Bollschweiler, M. (2008): Tree-ring analysis in natural hazards research – an overview. *Nat. Hazards Earth Syst. Sci*. 8: 187–202.

Gerhard Helle

Dr. Gerhard Helle is senior scientist and head of dendrochronology laboratory of Section 5.2 at the German Centre for Geosciences GFZ in Potsdam. He is specialist for stable isotope dendroclimatology. His current interest is the invention and optimization of techniques for ultra high-resolution intra-annual isotope studies in tree-rings. These techniques shall help studying the climate and isotope signal transfer from atmosphere into tree-rings. Another objective of his reasearch is the natural climate variability since the last Late Glacial as reflected in tree-ring stable isotopes. Dr. Helle is teaching Dendrochronology at the FU Berlin.

Ingo Heinrich

Dr. Ingo Heinrich is postdoc researcher in the Dendrochronology Group at the Helmholtz Centre Potsdam, GFZ German Centre for Geosciences. He graduated with a PhD in Resource Management and Environmental Science from the Australian National University in 2004. His research focuses on tropical dendrochronology, dendrogeomorphology, wood anatomy and stable isotopes in tree rings. In the last 3 years, he has developed a new technology for better histometric cell measurements in quantitative wood anatomy by means of confocal laser scanning microscopy technology. He has achieved 25 publications in the last 5 years (23 papers and 2 book chapters). He is teaching climatology and palaeoclimatology at Humboldt-University Berlin.

Wolfgang Beck

Dr. Wolfgang Beck is a senior scientist at the Thünen Institute of Forest Ecosystems. His fields of interest are growth patterns of forest trees and the stand dynamics of forest stands influenced by enduring deposition of airborne pollutants and changing climate conditions. Dendroecological and dendroclimatological methods are applied in this institute as part of a complex forest ecological research framework.

Tanja Sanders

Tanja Sanders is a scientist at the Thünen Institute of Forest Ecosystems in Eberswalde, Germany. Currently she is working on the integrative analysis of the intensive forest monitoring data (ICP Forests) combining tree performance parameters with soil and climate measurements. Her main interest is the detection of predisposing factors for tree growth and their modification of climate-growth reactions.

Karl-Uwe Heußner

Dr. Karl-Uwe Heußner hat von 1977 bis 1982 Ur-und Frühgeschichte an der Humboldt-Universität zu Berlin studiert. Seit 1988 ist er in der Dendrochronologie in Berlin tätig und seit 1991 Referent für Dendrochronologie am Deutschen Archäologischen Institut (DAI). Dr. Heußner wird seit 2009 von seinem technischen Mitarbeiter Alexander Müller unterstützt. Der Arbeitsschwerpunkt liegt in der Datierung von Holzfunden und der Erschließung von Jahrringen/Hölzern als Informationsträger für archäologische Forschungen. Historisch gewachsen ist dabei ein Schwerpunkt im Bereich des östlichen Deutschland, wo die fast flächendeckende und weitgehend vollständige Untersuchung relevanter Hölzer eingeführt wurde. Neben Eichenholz wurden auch lange Reihen mit mehr als 1000 Jahren für alle anderen wichtigen Holzarten wie Kiefer, Tanne, Fichte, Buche, Erle und Esche aufgebaut. Weitere Arbeiten betreffen Chronologieaufbauten in Zentralasien, Italien und anderen Gebieten.

Holger Gärtner

Dr. Holger Gärtner (1965) 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 research scientist responsible for the laboratory of wood anatomy at the Swiss Federal Research Institute WSL, Birmensdorf, Switzerland. He currently is the vize president of the Association of Tree-Ring Research.

ISSN 1610-0956