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TRACE

Tree Rings in Archaeology, Climatology and Ecology

Volume 7

Proceedings of the DENDROSYMPOSIUM 2008

April 27th – 30th, 2008 in
Zakopane, Poland

Edited by:
Ryszard J. Kaczka, Ireneusz Malik,
Piotr Owczarek, Holger Gärtner, Ingo Heinrich,
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Preface

This volume contains 30 short papers which summarise the main subjects of talks and posters presented at the seventh TRACE (Tree Rings in Archaeology, Climatology and Ecology) conference organized by Ireneusz Malik, Ryszard J. Kaczka and Piotr Owczarek and held in Zakopane, Poland on April 27th – 30th, 2008. The annual TRACE conference supports networking and scientific exchange between scientists and students involved in the study of tree rings from different regions of Europe and from other continents. This annual dendro-meeting is an initiative of the 'Association for Tree-Ring Research' (ATR). A high scientific level was maintained at the conference as at previous TRACE conferences, but an informal forum was simultaneously provided for young scientists and students to discuss concepts and ongoing or completed projects.

The conference was organised by the University of Silesia and University of Wroclaw with support from the Tatrzanski National Park and the Association of Polish Geomorphologists. There were more than 100 participants at the conference from four continents including representatives from Australia, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Latvia, Lithuania, Netherlands, Poland, Slovak Republic, Slovenia, Spain, Switzerland, Turkey, United Kingdom and USA. The oral and poster presentations were given by participants representing a wide spectrum of tree-ring research. In total, 39 talks were presented covering the fields of archaeology (2), climatology (12), ecology (5), geomorphology (2), isotopes (7), methods (4), and wood anatomy (7). During the conference 36 posters covering these fields of study were put on display for the audience.

Two talks were given by invited speakers. Dr. Rob Wilson (School of Geography & Geosciences, University of St Andrews, UK) presented a paper on recent developments and challenges in dendroclimatology based on examples from Great Britain. Dr. Jozica Gricar (Slovenian Forestry Institute, Department of Yield and Silviculture, Ljubljana, Slovenia) presented very recent findings on oak xylogenesis based on results from 2007. Although both lectures focused on very specific topics, they also included more general backgrounds which helped the understanding of links between different tree-ring studies.
During TRACE 2008 a podium discussion was introduced as a new element of the conference. Four experts on dendroclimatology and climatology presented different points of view on the intriguing topic of divergence.

The editors of the TRACE Proceedings 2008 are delighted to present 30 short papers on tree-ring studies. We would like to thank the reviewers for their valuable comments on the first versions of these manuscripts. The organisers of the conference would like to thank the sponsors (Grube sp. z o.o., Regent Instruments Inc.), whose contribution helped support the conference. Appreciation is also given to all participants for their valuable work, discussions, and exchange of ideas.

Ryszard J. Kaczka
Ireneusz Malik
Piotr Owczarek
Holger Gärtner
Ingo Heinrich
Gerd Helle
Gerhard Schleser

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PODIUM DISCUSSION TRACE 2008

TRACE 2008 Conference, April 27th – 30th 2008, Zakopane, Poland

Organized by:

Department of Quaternary Paleogeography and Paleoecology, University of Silesia
&
Institute of Geography and Regional Development, University of Wroclaw

INVITED TALKS

Bringing the “climate” back to British tree-rings

Wilson, R.

School of Geography & Geosciences, University of St Andrews, Scotland, U.K.
Email: rjsw@st-andrews.ac.uk

Introduction

Large scale, annually resolved reconstructions of past temperatures for the last 1000 years (Mann et al. 1999, Briffa 2000, Esper et al. 2002, D’Arrigo et al. 2006) are important to not only provide information on past climatic variability (IPCC 2007), but also to constrain climate model scenarios for the 21st century and aid attribution studies (Hegerl et al. 2007). Such large scale reconstructions however, are derived from relatively few proxy series which are sparsely located and are unable to provide detailed spatial climatic information. There is therefore a need to produce new, long temperature reconstructions for regions where currently little or no proxy data exist.

With a general bias towards studying large scale temperature trends for the last 1000 years (IPCC 2007), the importance of understanding past precipitation variability is often overlooked, despite its likely greater influence on economic stability than temperature changes. This is especially true in Europe, where drought has less of an impact than in the United States. Despite the successful development of almost spatially complete millennial long tree-ring (TR) based estimates of precipitation and drought indices for much of North America (Cook et al. 2004), similar spatial analyses are not yet possible for Europe. This is mainly due to the sparse nature of long (> 500 years) precipitation sensitive TR records (Brázdil et al 2002, Wilson et al. 2005), although recent work by Nicault et al. (2008) has produced 500-year long spatial drought reconstructions for the Mediterranean region. However, the record breaking central European floods in 2002, the widespread European drought in 2003 and the recent wet summers in the United Kingdom, not only demonstrate the need for a better understanding of past precipitation variability, but also highlight the importance of developing new long precipitation sensitive proxy records to place the recent period into a longer term context.

Palaeoclimatology in the United Kingdom

There are surprisingly few continuous millennial-scale proxy records for the United Kingdom. Quantified millennia long reconstructions have been developed from speleothems (NW Scotland - Proctor et al. 2000, 2002) and water table estimates using testate amoebae (Multiple regions in the UK - Charman et al. 2006), but these proxy records are difficult to interpret due to conflicting influences of both temperature and precipitation. Qualitative climatic information has also been developed using historical documents (Lamb 1995).

TR records have been utilised from several locations around the Northern Hemisphere to successfully produce annually resolved millennial or longer local/regional reconstructions of temperature (Esper et al. 2003, Luckman & Wilson 2005, Linderholm & Gunnarson 2005, Buntgen et al. 2005, 2006, Wilson et al. 2007, Grudd 2008) and precipitation related indices (Stahle & Cleaveland 1992, Grissino-Mayer 1996, Ni et al. 2002, Salzer & Kipfmueller 2005). However, in the United Kingdom, dendroclimatology is problematic due to either weak or mixed climatic signals, as noted in long (> 1000 years) English oak records (Kelly et al. 2002), or the inability of extending temperature sensitive living Scots pine (*Pinus sylvestris* L.) records in the Highlands of Scotland which only go back ~200-300 years (Hughes et al. 1984, Fish 2007).

This extended abstract describes ongoing dendrochronological research at the University of St. Andrews that aims to rectify the current paucity of long TR based proxy records in the United

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Kingdom which should allow the reconstruction of both temperature (from Scots pine) and precipitation (from Oak) for the last millennium.

Scots Pine

Schweingruber et al. (1978, 1979) showed in their seminal studies that the maximum density of annual conifer rings, measured using x-ray microdensitometry, yields a strong and consistent proxy of past summer temperatures. Using data obtained from ring-width (RW) and maximum latewood density (MXD) from several pine sites throughout the Highlands of Scotland, Hughes et al. (1984) showed it was possible to reconstruct summer temperatures from AD 1721- AD 1975. Figure 1a highlights the strong calibration using the original Hughes et al. (1984) data (locations shown in figure 1b) where the linear combination of both RW and MXD parameters explains 65% of the temperature variance.

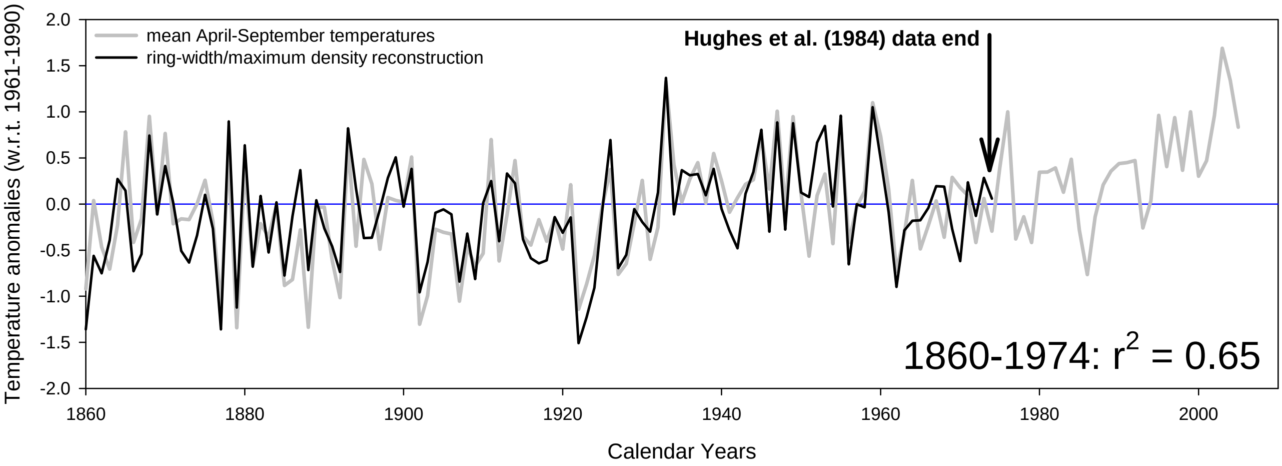

Figure 1a: Calibration (1860-1974) results between the combined (using linear multiple regression) RW and MXD derived from Scotland and April-September mean temperatures (Brohan et al. 2006).

Despite the clear potential of using Scots pine for dendroclimatic reconstruction, one of the elusive aims for working with pine in Scotland is extending the living pine chronologies back in time, as has been done with oak (Crone & Mills 2002). ^{14}C dating of sub-fossil pine material found preserved in peat bogs has, however, been used to provide information on the spatial and temporal distribution of pine in Scotland over the last ~ 8000 years (Ward et al. 1987, Bridge et al. 1990, Gear & Huntley, 1991). However, dendrochronological techniques could not be applied to the samples in these studies due to the relatively short length (due to decay) of the samples (~100 years) and the fact that many of the samples were taken from the root stock of the trees (the stems being rotted away) where the tree rings are highly distorted.

The key to extending the Scottish living pine chronologies therefore lies NOT in using incomplete, distorted pine samples from peat bogs, but finding sources of complete stems where clearly-defined, long TR sequences can be found. In Scandinavia, very long (> 5000 years) pine RW chronologies have been developed using sub-fossil wood preserved in the sediments of small lakes (Eronen et al. 2002, Gunnarson & Linderholm 2002, Grudd et al. 2002, Linderholm & Gunnarson 2005, Grudd 2008). To date, no equivalent attempt has been made in Scotland to find pine material in small lochans.

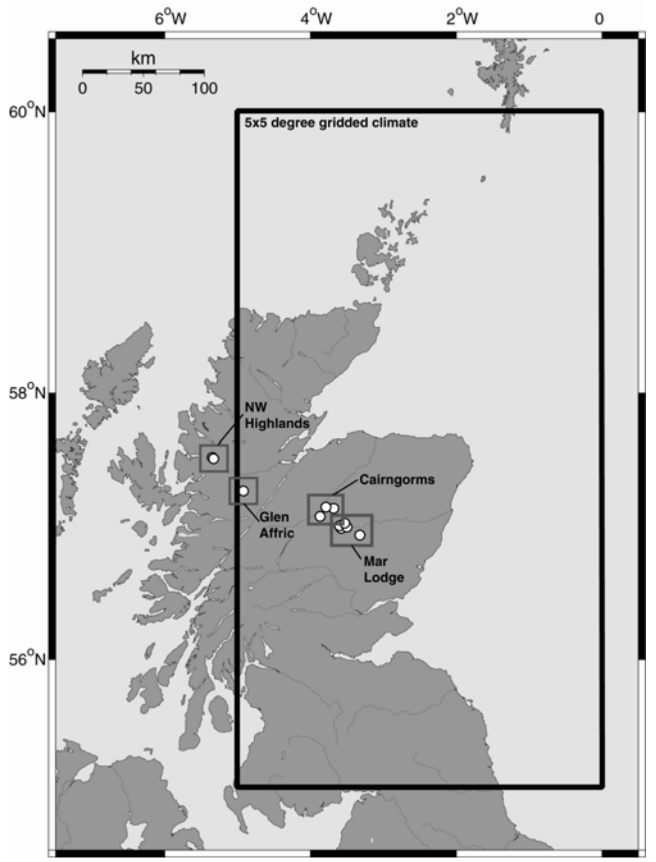

Figure 1b: Location map of existing living pine network. The Hughes et al. (1984) study used samples taken from the NW Highlands, Glen Affric and Mar Lodge regions. The Cairngorm samples are recent additions (Fish 2007). Green box denotes the gridded temperature data (Brohan et al. 2006) utilised for the calibration in Figure 1a.

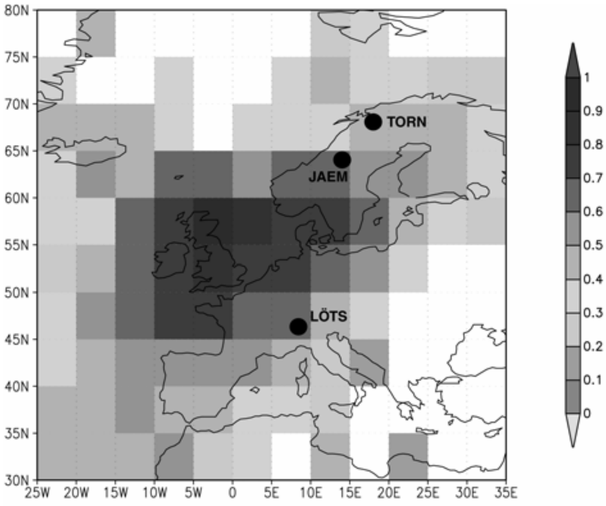

Figure 1c: Spatial correlations (1860-1974 for April-September) between the relevant grid over Scotland (Figure 1a) with gridded (5x5 degrees) temperatures over Europe (Brohan et al. 2006). The dots show the locations of the only millennial long TR based reconstructions in Europe: TORN = Torneträsk (Grudd 2008); JAEM = Jaemtland (Gunnarson & Linderholm 2002; Linderholm & Gunnarson 2005); LÖTS = Lötschental (Büntgen et al. 2005, 2006).

Scots pine has existed in some areas of Scotland for about 8000 years (Bennett 1995, Shaw & Tipping 2006). The present distribution of pine is much reduced compared to its maximum extent around 5700 years ago and the remaining pine woodlands are protected by government policy and non intervention management so that they are theoretically self-sustaining in perpetuity (Colin Edwards, Forest Research, pers. comm). Palynological analysis in the Scottish Highlands has shown that pine has grown continuously for the last ~ 8000 years in the Glen Affric and Cairngorm regions (Shaw & Tipping 2006, Fig. 1b). These regions are therefore important critical areas for locating sub-fossil pine remains.

Climatologically, Scotland is distinct from Europe due to its proximity to the North Atlantic. The influence of the North Atlantic Oscillation (NAO) is especially strong upon Scottish climate (Cook et al. 2002, Folland et al. in press). Figure 1c shows a spatial correlation map between gridded temperatures relevant to Scotland (Fig. 1b) and gridded temperatures across Europe for April-September mean temperatures (the reconstructed season in figure 1a). Also shown are the locations of the existing 1000+ year long TR based reconstructions of past summer temperatures in Europe. Acquiring a similar TR based palaeoclimate reconstruction from Scotland would not only fill an important spatial gap within the European region, but will also provide important information on the past behaviour of the NAO.

The Scottish Pine Project: Current Status

Current work is focussing on identifying appropriate locations where sub-fossil pine material exists. Initial surveys are being undertaken in regions where it is known that pine has grown continuously for many thousands of years (e.g. The Cairngorms and Glen Affric; Fig. 1b). In June 2008, a survey of lochs was made through the North-West Cairngorms. A few sub-fossil pine stems were found in many small lochans (even ones above the present tree-line). However, a particularly abundant amount of material was noted in two lochs in the Rothiemurchus Estate (OS coordinates: NH8907). A preliminary reconnaissance sampling field trip was undertaken in September 2008 to acquire samples for carbon dating to ascertain the rough time frame that the material represents. In total, 25 samples have been collected, many of which contain over 150 rings (Fig. 2). One noteworthy observation is the green colour that some of the samples (especially those from Loch an Eilein) developed after contact with the air. Discussions with colleagues in Scandinavia (Håkan Grudd of Stockholm University and Risto Jalkanen of the Finnish Forest Research Institute, pers. comm.) suggest that these samples could well be over 1000 years old.

Figure 2: Preliminary sub-fossil pine test samples taken from Loch an Eilein and Loch Gamhna in September 2008.

English Oak

Compared to Scots pine, there is no shortage of historical material (e.g. beams etc) that enable the development of millennial long Oak TR chronologies in the United Kingdom (Baillie 1995, Crone & Mills, 2002). During the late 1970s, several labs throughout the United Kingdom produced long oak chronologies for different regions around Britain. While dating of oak samples had been established, the question arose as to whether the RW data could be used to derive information on past climate. To that end, Pilcher & Baillie (1980) developed eight oak chronologies, three from Scotland and five from England, with which to perform dendroclimatic analyses. Despite the success of identifying strong climatic signals in TR chronologies for the American southwest (Fritts, 1976), the identification of such signals in British oak remained elusive (Pilcher & Baillie, 1980). Hughes et al. (1978), however, found that oak could sometimes show a definite climate response and such data could be used to look at temporal and spatial climatic changes. In the 1980s, this work was extended by Dr. Keith Briffa, of the University of East Anglia, who showed that reasonable calibrations of both moisture stress and sea level pressure could be developed from Oak RW data. A recent study conducted by Kelly et al. (2002) expanded on these results but highlighted the mixed nature of the climatic signal in extreme (i.e. wide and narrow) ring-width years.

The English Oak Project: Current Status

In collaboration with Dr. Dan Miles of the Oxford Tree-Ring Laboratory, and building upon the work by Briffa (1984), we are focussing entirely on living and historic Oak RW data from south-central England where oak RW data from this region was noted to show the strongest moisture stress signal (Briffa 1984). To date we have compiled a data-base of 235 living RW series and 990 historical RW series (Fig. 3).

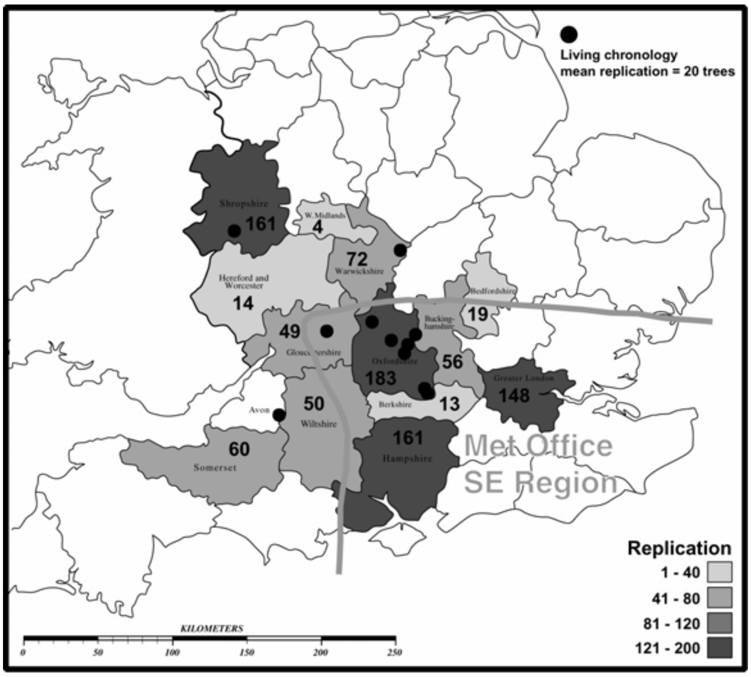

Figure 3: Map showing location of living Oak chronologies use, and the current spatial density of historical Oak RW data.

Data collation is an ongoing process and using the Expressed Population Statistic (Wigley et al., 1984) about 30 series are needed to acquire a robust mean composite series. However, as the longer term goal is to capture more secular scale variability, the data will be processed using the relatively noisy Regional Curve Standardisation (RCS) method (Cook et al. 1995, Briffa et al. 1996), and we therefore feel that for any particular period, a minimum of 50 series would be ideal. Although, the EPS value is currently above the often cited ideal of 0.85 (Figure 4D), the current data-set falls below this 50 series threshold in the 11th and 17th centuries and during the period of overlap around 1800 (Figure 4A). The period of overlap between the living and historic data (Figure 4E) is a crucial validation period to (1) ensure that the historic data show the same signal as the living data, but also (2) when the RCS method is applied, this period ensures that the relative level between the living and historic data is correct (i.e. no biases due to differing populations in the RW data-set).

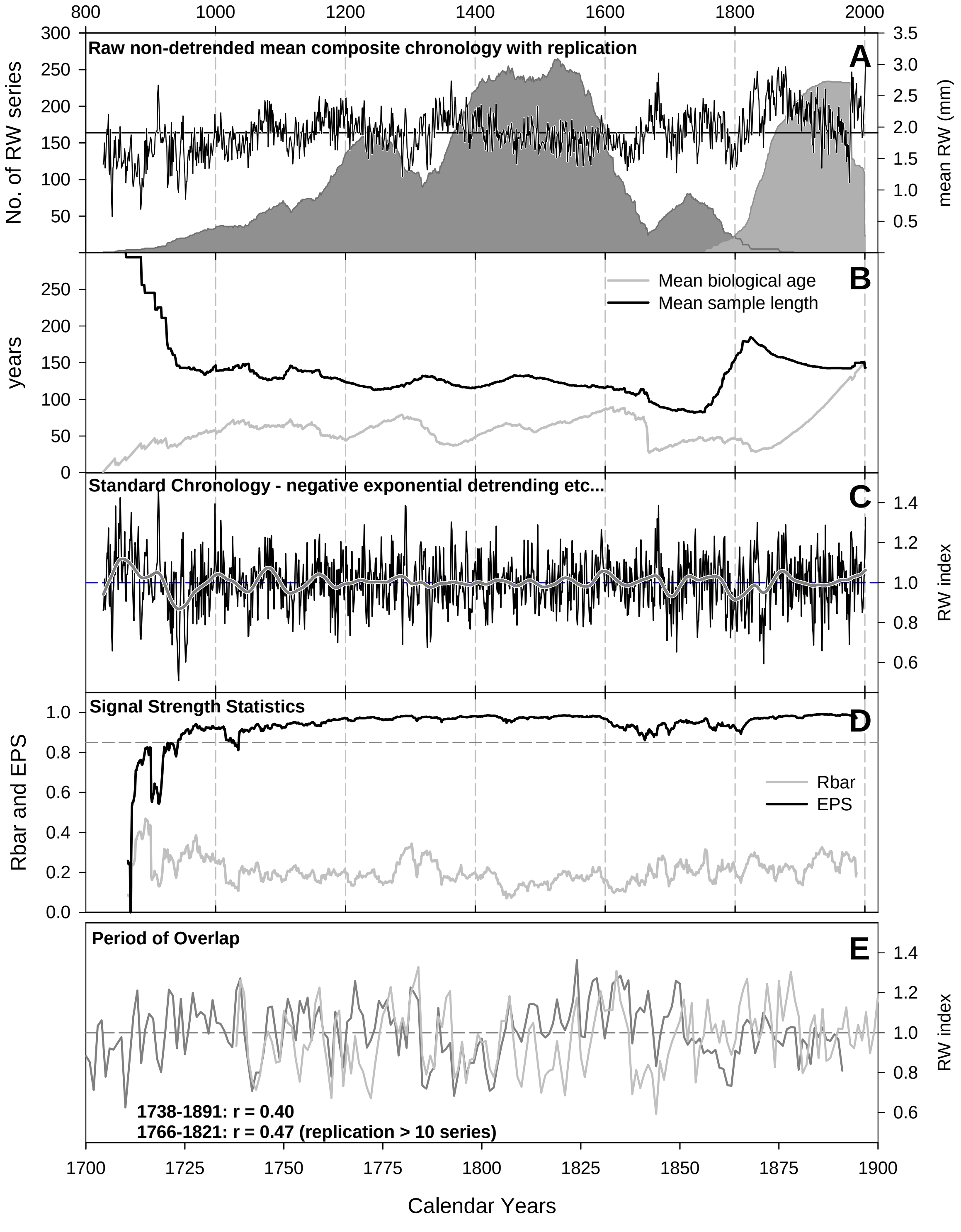

Figure 4: South-central England Oak composite chronology: A: Raw non-detrended chronology with replication histogram; B: Mean biological age and sample length; C: Standard chronology after individual series have been detrended using negative exponential or regression (negative or zero slope) function functions; D: RBAR and EPS statistics; E: Period of overlap between standard living and historic chronologies.

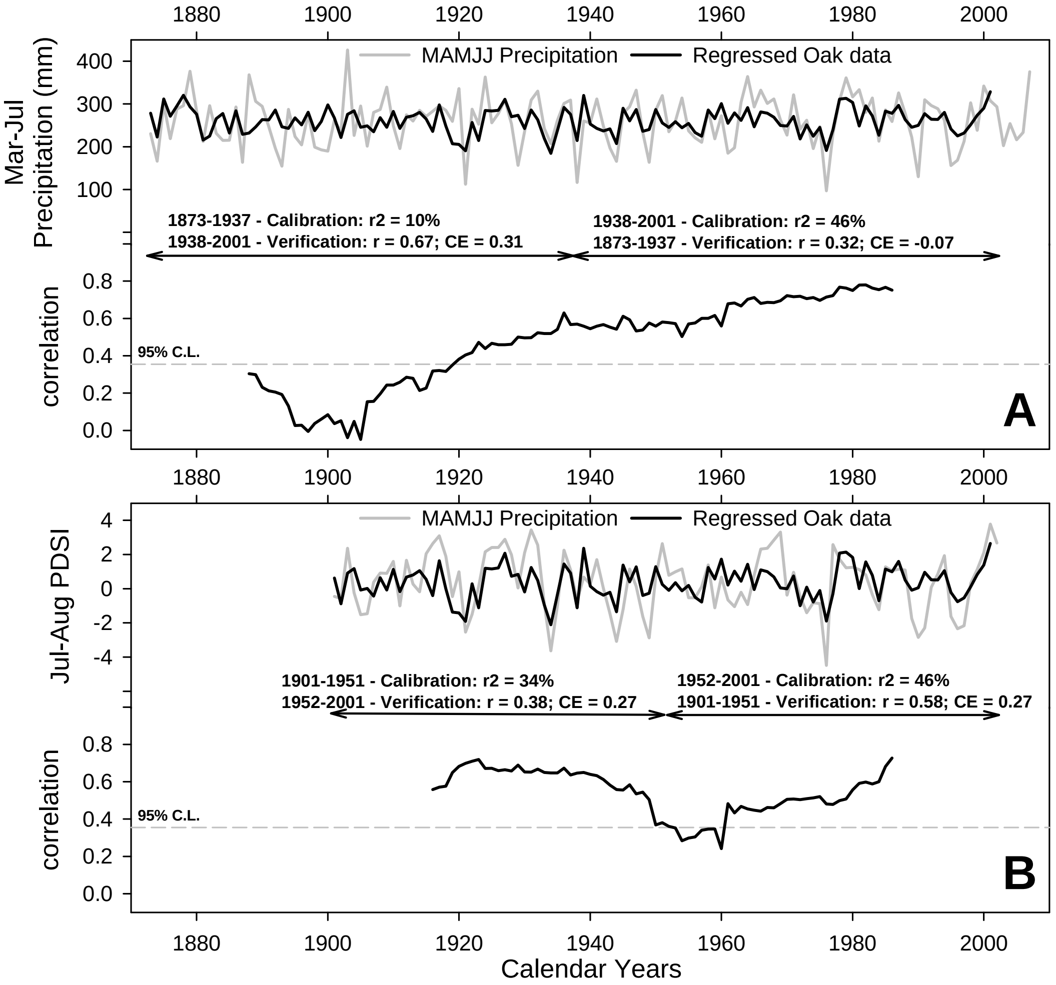

Figure 5A: Preliminary calibration and verification against the Met Office SE regional precipitation series (Alexander & Jones 2001) for the March-July season. The lower panel is a running 31-year correlation between the two time-series; 5B: but for July-August Palmer Drought Severity Index *(PDSI) (van der Schrier et al. 2006).*

Calibration and verification experiments against both precipitation (Figure 5a) and the Palmer Drought Severity Index (PDSI - Figure 5b) show a more time stable relationships with PDSI using the Oak RW composite record. It is not yet clear why the Oak RW response with precipitation is non-significant during the late 19th and early 20th centuries although it may simply reflect the quality of early instrumental precipitation records. This is the focus of ongoing studies. However, the preliminary results with the PDSI data (Figure 5b) are encouraging and agree with similar results obtained by Briffa (1984).

Conclusion

This extended abstract has detailed ongoing dendrochronological research at the University of St. Andrews that aims to develop millennial length climate sensitive TR proxy records for Scotland (temperature from pine) and central-southern England (precipitation/drought from oak). We must stress, however, that much work remains.

Of the two projects, the English Oak project is the most advanced, but further work must (1) address calibration issues against precipitation, (2) sample more living sites outside Oxfordshire (Figure 3), as well as (3) infill periods where replication is relatively low. Future research also aims to explore the potential of measuring stable isotopes (Loader et al. 2008) and early wood vessel area (Fonti & Garcia Gonzalez 2008) to add to the climatic information that can be currently gleaned from the RW data. Extending the Scottish pine chronologies is a huge challenge as the between tree common signal is not particularly strong using RW data alone and even if sub-fossil material could be found covering the last 1000 years, it may not be easy to identify a probabilistically strong cross match with current pine chronologies. Through collaboration with Drs. Coralie Mills and Anne Crone of AOC Archaeology we hope to partly improve the 'signal' and extend reference chronologies by sampling historic structures from the Scottish Highlands. Lastly, we are also experimenting with measurements of blue reflectance, a proxy for MXD measurements (McCarroll et al. 2002, Campbell et al. 2007), which appear to have a stronger signal strength than the RW data and may aid the crossdating of the sub-fossil samples.

This is an exciting time for British dendroclimatology. The preliminary results presented in this extended abstract highlight the potential of developing 1000-year long TR based temperature and drought reconstructions for Scotland and southern-central England. These records would fill in an important gap in the European and global proxy networks and, after a ~25 year wait, will finally bring the "climate" back to British tree-rings.

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Significance of intra-annual studies of radial growth in trees

Gričar, J.

Slovenian Forestry Institute, Department of Yield and Silviculture, Večna pot 2, Si-1000 Ljubljana, Slovenia
Email: jozica.gricar@gozdis.si

Introduction

Numerous studies are currently being carried out on the seasonal dynamics of xylogenesis (wood formation), but similar studies on secondary phloem are rare. Extensive investigations have mainly been performed on conifers, principally because of their simple anatomical structure, great commercial importance, and because they occupy a large proportion of European forests. Although the first pioneer studies were done many decades ago (for review see Larson 1994), the tendency today is towards an analysis of wood formation dynamics of certain tree species at a selected research plot over several years. The influence of certain climatic factors on the mechanism of xylem and phloem ring growth formation can be studied on trees that are growing in their natural environment or under experimentally controlled conditions.

This paper gives a brief overview of the studies of radial growth of trees and intra-annual wood formation currently being carried out in Europe, the potential of phloem formation research, the most frequently used methods and the importance of such studies.

Radial growth of trees

The activity of the secondary meristem is expressed as radial growth, which allows an increase of the volume of the conducting system and the formation of mechanical and protective tissues. The radial growth of trees is a result of the activity of two lateral meristems: the vascular cambium and cork cambium (phellogen). The vascular cambium (in short, cambium) produces the cells of the secondary phloem in a centrifugal direction and wood cells (secondary xylem) in a centripetal direction. The phellogen forms the tissues of the secondary protective tissue (periderm). Under favourable growing conditions, the xylem increment is normally the most extensive and represents the major part of the tree's radial growth (Panshin & de Zeeuw 1980, Larson 1994). Moreover, of all the secondary tissues, xylem and its formation are by far the most investigated, particularly due to its great economic and ecological importance.

Cambial activity

A characteristic of tree species in the temperate climatic zone is a seasonal alternation of cambial activity and dormant (resting) periods, which is generally related to alternations of cold and hot or rainy and dry seasons (Lachaud et al. 1999, Kozlowski & Pallardy 1997, Larcher 2003). Cambial activity usually starts in spring with cell division and ends in late summer with the completed development of the latest newly formed cells. At the beginning of cambial activity, the number of cambial cells increases, they start to divide, which is followed by differentiation of derivatives into the adult elements of xylem or phloem. In the process of differentiation, which includes post-cambial cell growth, deposition of the secondary cell wall and – in wood tracheids, fibers and vessels – also lignification and programmed cell death, the cells specialize in order to perform their functions (Plomion et al. 2001).

Xylo- and phloemogenesis

Xylo- and phloemogenesis lead to specialization of cells in terms of their chemical composition, morphological characteristics and function (Plomion et al. 2001). Cell divisions in cambium and postcambial growth determine the width of the annual xylem and phloem increment, and the deposition of the secondary cell wall (and lignification) determines the accumulation of biomass in the walls of the xylem and phloem cells (annual biomass increment).

The widths of the xylem and phloem increments are determined by the length of the period of cambial activity and the rate of cambial cell division. Under normal growing conditions, cambial cell production is more intensive on the xylem than on the phloem side. However, under physiologically very demanding conditions, the phloem increment can exceed the xylem one, which, in exceptional cases, may not appear at all. The widths of phloem and xylem growth rings, and thus also the proportion between the phloem and xylem increment, vary around the circumference of an individual tree (Panshin & de Zeeuw 1980, Kozlowski & Pallardy 1997).

The environment determines the physical conditions and the energy that are necessary for xylo- and phloemogenesis. The signals that determine the beginning, cessation and rate of individual processes of xylo- and phloemogenesis derive from the environment. The rate and duration of individual developmental processes determine the morphology of cells (Sundberg et al. 2000, Wodzicki 2001). Environmental factors that affect xylo- and phloemogenesis, and thus the structure of wood and phloem, can be divided into basic (temperature, water, nutrients, i.e. the fertility of the soil, gravitation, photoperiod, etc.) and occasional factors (wind, fires, frost, floods, defoliation, forestry, air pollution, etc.) (Wodzicki, 2001).

The effects of selected environmental factors on individual processes of xylo- and phloemogenesis in adult trees are mostly explained indirectly through studies of the influences of occasional factors or seasonal climatic change. Environmental factors interact under normal conditions, which makes the study of the effects of selected factors on xylo- and phloemogenesis processes difficult. This information is usually gathered from research into xylo- and phloemogenesis and the structure of xylem and phloem in trees that are growing in forests, with combined external influences of climate, soil humidity, availability of nutrients, forest management and air pollution (Wodzicki, 2001). In addition, the effect of individual factors on xylo- and phloemogenesis changes during the growth season. The effect of certain climatic factors on the radial growth of trees is most expressed in less favourable growing sites, where a limiting factor affects the beginning, the end and the dynamics of cell production. The influence of specific climatic factors on the mechanism of xylem and phloem growth ring formation can be studied on trees that are growing in their natural environment or under experimentally controlled conditions (e.g., Antonova & Stasova 1993, Oribe et al. 2001, Deslauriers et al. 2003, Gričar et al. 2006, Rossi et al. 2007, 2008, Seo et al. 2008).

Controlled experiments on cambial activity and cell differenatiation

The effect of individual factors on wood and phloem formation has been successfully demonstrated in experiments with shoots, stem cuttings or intact stem portions growing under controlled conditions. By exposing young stems, saplings or parts of trees to controlled conditions during the period of cambial activity or dormancy, additional information on factors that influence cambial activity and cell differentiation can be obtained (e.g., Denne & Dodd 1981, Mellerowicz et al. 1992, Barnett & Miller 1994, Oribe & Kubo 1997, Oribe et al. 2001, Gričar et al. 2006, 2007, Begum et al. 2007). Studies have revealed that the application of temperature can cause alterations in regular cambial activity; however the application of heat revealed differences in the response of dormant cambium to treatments among different species of evergreen and deciduous habit.

Cambial cells of evergreen conifers in the quiescent stage of dormancy can re-initiate cell division independently of the growth of new shoots and the development of buds in spring. The response of the cambium to experimentally elevated temperatures gradually increased as the dormant season passed from winter to spring, suggesting that heating directly triggers the breaking of cambial dormancy in evergreen conifers. The application of heat stimulated divisions in the dormant cambium, first on the phloem side and then on the xylem side (Oribe & Kubo 1997 Oribe et al. 2001, Gričar et al. 2006, 2007). In the stem of adult *Picea abies*, cambial reactivation was restricted to the heated region, which suggests that temperature is not transmitted along the stem from the site of its application (Gričar et al. 2006, 2007). The absence of cambial response to heat treatment in the deciduous *Larix leptolepis* indicated that cambial reactivation is limited by several factors associated with bud break in this species (Oribe and Kubo 1997). In the deciduous diffuse-porous hardwood *Populus sieboldii x Populus grandidentata* the temperature in the stem is a limiting factor for reactivation of phloem and cambium. An increase in temperature might induce the conversion of storage starch to sucrose for the activation of cambial cell division and secondary xylem (Begum et al. 2007).

Cooling of the stem portion of *Picea abies* at the height of cambial activity caused earlier formation of late wood and premature cessation of cambial activity. Temperature treatments did not cause alterations in the pattern of secondary wall formation and lignification nor in lignin content (Gričar et al. 2006). The application of a constant increased or decreased temperature continually over the entire vegetation period showed that the influence of temperature varies over the course of the vegetation period. It seems that temperature is crucial for cambial activity and cell development at the beginning of the growing season, while other factors prevail in the second part of the growing season. Phloem production is less dependent on temperature (Gričar et al. 2007).

External factors are very important for cambial activity and cell differentiation, but the influence of internal factors (phytohormones, sugars, etc.) is also certainly not negligible (e.g., Mellerowicz et al. 1992, Aloni et al. 2000, Krabel 2000, Uggla et al. 2001).

Seasonal dynamics of xylem formation

In Europe, investigations of the seasonal dynamics of xylem formation in various tree species are being currently in full swing; e.g., in Finland (Mäkinen et al. 2003, Schmitt et al. 2004, Seo et al. 2008), Italy (Rossi et al. 2006b, 2007, 2008), Slovenia (Gričar 2007, Čufar et al. 2008, Levanič et al. 2008), Switzerland (Eilmann et al. 2006), The Netherands (van der Werf et al. 2007), Germany, (Schmit el al. 2000), Spain (Camarero et al. 1998, De Luís et al. 2007), France (Bréda & Granier 1996) and others.

Many researchers collaborate nowadays, exchange ideas, experience and combine their data into large databases in order to improve knowledge about the radial growth of trees and its relationship to environmental factors. Intra-annual studies of wood formation provide information about the timing, rate and duration of individual phases of cell development, which determine xylem structure, and thus wood properties and the end-use of wood. Extensive databases containing data covering several years enable detailed studies of tree response to various site conditions on a global scale. It is thus possible to develop models for wood formation that can be used to estimate forest productivity and wood properties under different climate scenarios.

Seasonal dynamics of phloem formation

Studies of the seasonal dynamics of phloem growth rings are fewer (e.g., Alfieri & Evert 1968, Golinowski 1971, Antonova & Stasova 2006, Gričar & Čufar 2008), which can be partly explained by lower interest in the commercial use of bark in comparison to the use of timber. In addition, the phloem increment is exposed to relatively fast secondary changes of the tissue, e.g., collapse, sclerification and inflation of axial parenchyma, so only the structure of one or two of the most recent phloem growth rings can be seen clearly (Alfieri & Evert 1968, Golinowski 1971). Older non-conducting tissue eventually collapses in a radial direction, deforms and later often also falls off and is thus not suitable for dendrocronological and dendroecological studies.

Nevertheless, the seasonal dynamics of phloem formation is very important in studies of trees' radial growth, because cambium is a bi-facial meristem, so studies of cambial activity and wood formation reveal only part of the information on cambium cell productivity during the growth season. In the case of narrow xylem growth rings, when the ratio between the xylem and phloem can be in favour of phloem, an important share of the width increment is thus neglected. Unlike in the case of xylem growth rings, the width of phloem growth rings is tightly related to their anatomy (Holdheide 1951, Golinovski 1971). Moreover, the processes of wood and phloem formation differ in terms of time and space, and internal and external influences affect the mechanisms of their formation differently. Comprehensive studies are therefore vital for investigating the influence of specific climate factors on the radial growth of trees.

Methods of investigating the seasonal dynamics of radial growth

Numerous methods are used for research into the seasonal dynamics of cambial activity and the formation of xylem growth rings in various tree species, e.g., measurements with dendrometers, micro-sampling, pinning, nailing, measuring the electrical conductivity of the cambium, radiological methods, the tilting method, etc. (Wolter 1968). Today the most frequently used methods are micro-sampling, pinning and dendrometer measurements.

Micro-sampling

Studies of the radial growth of trees during a single growth season are mostly based on repeated small samples (so-called micro-sampling) of cambium and xylem and phloem tissue around the circumference of an individual tree. Non-specific tools such as a surgical bone needle, the Trapsystem® needle, a hammer and a sharp chisel can be used to collect samples. Specific tools, such as an increment hammer, an increment puncher, and a Trephor, have also been designed and are used for to harvest samples for this purpose (Forster et al. 2000, Rossi et al. 2006a, Gričar 2007). Micro-sampling is most important at the beginning of the vegetation period when the cambium area is wide and cells of early wood, with thin cell walls and large radial dimensions, are created. The quality of the sample depends on the sharpness of the cutting edge of the tool. If jagged tools are used, the samples are cracked, crushed or crumbled (Forster et al. 2000, Rossi et al. 2006a). Taking small blocks of samples instead micro-cores is recommended when samples are destined for electron microscopy, in which a high quality of the samples is required. However, because of the relatively large samples, sampling a tree for several years can affect the tree's long-term growth and development. The size of samples determines the distance between neighbouring samples, due to the response of cambium to mechanical damage.

The micro-sampling method is very suitable for studying individual phases of xylogenesis, since cells are better preserved than with the pinning method. This method allows changes in the number of cambial cells during the growth season to be followed, as well as the seasonal dynamics of cell production on the phloem side.

Pinning method

The pinning method is based on a very small injury to the cambium with a needle with a diameter of 1-2 mm and its response to the injury, by which the xylem increment that has formed until the moment of wounding is marked (Wolter 1968). The method has been successfully used for studies of the seasonal dynamics of wood formation in coniferous and deciduous trees (e.g., Wolter 1968, Yoshimura et al. 1981, Kuroda & Shimaji 1984, Schmitt et al. 2004, Eilmann et al. 2006, Levanič et al. 2008).

The mechanical damage to the cambium causes the formation of callus, wound-wood and traumatic resin canals (Yoshimura et al. 1981, Kuroda & Shimaji 1984). The boundary between cambial cells and cells in post-cambial growth that were in the callus defines the xylem increment until the moment of pinning. Callus is permanently preserved in the xylem growth ring and can be recognized even after several years. This is an essential advantage of this method in comparison to others. The injury with the needle is limited to a very narrow area of tissue and does not influence the vitality of the whole tree. The traumatic resin canals that form as a consequence of needle injury did not reliably indicate xylem growth during the vegetation period in Norway spruce (Gričar 2007). Needle injury might have restimulated cambial activity at the end of growth season (Kuroda & Kiyono 1997, Gričar 2007), thus hindering the completion of regular cambial division activity. This phenomenon was probably a result of hormonal imbalance caused by the needle injury. The pinning method does not allow the individual phases of xylogenesis, variability in the number of cambial cells during the growth season and the formation of the phloem growth ring to be examined.

Dendrometers

Dendrometers are non-destructive instruments that continuously monitor radial variations of tree stem or, occasionally, roots (e.g. Bréda & Granier 1996, Deslauriers et al. 2003). The properties of different types of dendrometer differ in regard to accuracy, precision, resolution, costs and simplicity of use. A distinction is generally made between contact (point and band) and optical dendrometers (Clark et al. 2000). Dimensional changes of stems include radial growth of trees (wood and bark), changes in hydration, seasonal variations in cambial width and secondary changes in bark (collapse of sieve elements, inflation of parenchyma, formation of sclereids etc.). Dendrometer measurements are shown as a continuous time-series of stem radius variation that can be divided in reversible shrinking and swelling of the stem because of water conductivity and irreversible stem growth during growing season. Radial growth includes post-cambial growth of xylem and phloem developing cells. Dendrometer analysis can be presented on different time scales (daily, weekly etc.). Dendrometer records have mainly been done during the growing season, rarely in the dormant period.

Which method to use?

Each method has advantages and drawbacks; however, the application of a particular method depends on the purpose of the planned research. In studies in which the main interest lies in the variation in the number of cambial cells, individual phases of xylogenesis and phloem formation, the micro-sampling method is recommended. The pinning method is very useful in studying the response of cambium to wounding or in tropical trees for marking xylem increment. In addition, performing pinning experiments is much easier and faster, because no fixative solution for samples in the field is needed, as in the case of micro-coring, in which the quality of the sample taken is also important. The pinning method is therefore very suitable when students or local foresters do the sampling. Dendrometers continuously measure stem variations, but correct interpretation of the data is very important. Not all radial growth recorded by dendrometers should be ascribed to an increase in wood increment, because the phloem part is in that case entirely neglected. In cases in which xylem increments are very narrow, inaccuracy of the data is quite high. The activity of the cambium is very difficult to follow solely with dendrometer measurements. However, by applying this method and micro-sampling (or pinning) on the same tree, it is possible to combine continuous measurements of radial growth with repeated instantaneous observations of developing xylem and phloem tissue at a cellular level in order to get a more integral idea of radial annual growth.

Conclusions

Despite numerous studies, the mechanism of wood formation processes is still not fully explained. The vascular system in trees is very complex, composed of various types of cells that are differently orientated. Xylo- and phloemogenesis are periodic processes driven by a variety of internal and external factors, the influence of which changes during the growing season. The huge variability of the structure of xylem and phloem in a single tree, among trees at the same or different sites complicate the research. However, a detailed knowledge of all these processes will improve our understanding of the relationship among wood structure, properties and end-use of wood.

Intra-annual information on wood formation dynamics would help dendroclimatologists better to use climate proxies that are stored in ring features and interpret them properly. In addition, knowledge about xylem and phloem formation is fundamental for an assessment of the adaptability and flexibility of trees species and, consequently, the composition and biodiversity of forests under changing climate conditions in the future.

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SECTION 1

CLIMATOLOGY

North Atlantic Oscillation signal in tree-rings of oak in Poland

Bijak, Sz.

Department of Dendrometry and Forest Productivity, Faculty of Forestry, Warsaw University of Life Sciences-SGGW
Email: Szymon.Bijak@wl.sggw.pl

Introduction

Climate influences the tree growth process in great measure. Pace and intensity of tree-ring formation is shaped locally by different weather elements such as temperature, precipitation and moisture availability, sunshine duration or even snow abundance (Fritts 1976, Schweingruber 1996). However these meteorological driving forces are very often of hemispherical or global origin. Large-scale interactions between oceans, atmosphere and land are transferred into both marine and terrestrial ecological systems affecting various processes occurring within them (Ottersen et al. 2001). Moreover, widely used climate descriptors i.e. temperature and precipitation do not explain the whole variability observed in tree-ring width series. This may suggest that some part of the tree-ring formation causes be under the influence of more general factor.

North Atlantic Oscillation (NAO) is a pattern of atmospheric pressure between the Arctic represented by Iceland Low and the subtropical Atlantic indicated by the Azores High. Swinging from one phase to another, NAO produces large-scale variation not only in heat and moisture transport between the Atlantic and European continent, but also in the intensity and number of extreme weather phenomena. NAO shapes the weather conditions over Central Europe prominently in cold seasons (Hurrel et al. 2003).

The influence of circulation expressed especially with NAO on tree-rings has gained widespread interest in the dendroclimatology and dendroecology over recent years. Authors discuss the role of NAO in tree-ring formation and attempt to reconstruct the past NAO patterns basing on the tree-ring proxies (Cullen et al. 2001 and references herein, Cedro 2007, Schultz et al. 2008). However, such analyses concerning Poland are very limited and sparse.

The objective of the study was to analyse the influence of the NAO on radial growth of oaks growing in Poland. Special interest was paid to the correspondence of circulation conditions and the abundance of extremely wide and narrow tree-rings (pointer years).

Data

To obtain the possibly widest spatial coverage of dendrochronological data for Poland, common oak (*Quercus robur*) was selected. Tree-ring width database utilised for this study consists of 13 series representing different environmental conditions regarding altitude, exposition, forest community, and habitat type. The data was collected and described by Ważny (1986, 1990). Later on, raw measurements as well as elaborated standard chronologies were contributed to the International Tree-Ring Data Bank (ITRDB, www.ngdc.noaa.gov/paleo/treering.html). Tree-ring series taken from that source were applied in this analysis.

Number of trees in series from an individual site varies from 17 (Poznań) to 45 (Gdańsk). The time span covers in general the period from 1750s to mid-1980s. The longest series represents 23 oaks from Wolin and covers the period of 1554-1986. The shortest data comes from Gołdap and ranges from 1871 to 1986. More detailed information about used tree-ring series is presented in table 1.

Commonly, the NAO is represented by an index that describes its phases. The index is based on the difference of the normalised sea-level atmospheric pressure (SLP) in two meteorological stations that represent the Azores High and Iceland Low. Several variants of the NAO index have already been developed regarding various stations (Cullen et al. 2001, Hurrel et al. 2003). For the purposes of this study, index developed by Jones et al. (1997) was used. It defines the NAO as the difference in normalised SLP between Gibraltar (the Iberian Peninsula) and Reykjavik (south-west

Iceland). Monthly values of this index ranging from 1821 were downloaded from Climate Research Unit web page devoted to NAO (www.cru.uea.ac.uk/cru/data/nao.htm).

Table 1: Tree-ring series of oak in Poland

site	coordinates		period	# of series
	N	E		
Gdańsk	54°18’	18°33’	1762-1985	45
Gołdap	54°21’	22°23’	1871-1986	22
Hajnówka	52°42’	23°39’	1720-1984	19
Koszalin	54°06’	16°09’	1782-1986	22
Kraków	50°03’	20°22’	1792-1985	29
Poznań	52°16’	16°48’	1836-1986	17
Roztocze	50°39’	23°03’	1782-1988	22
Suwałki	54°05’	23°01’	1861-1986	19
Toruń	53°05’	18°33’	1713-1986	21
Warszawa	52°18’	20°59’	1690-1984	19
Wolin	53°57’	14°30’	1554-1986	23
Wrocław	51°15’	17°10’	1727-1986	22
Zielona Góra	51°52’	15°34’	1774-1986	19

Methods

The NAO index values were obtained in monthly resolution. In order to produce seasonal data a three-month average was calculated for spring (March-May), summer (June-August), autumn (September-November) and winter (December-next year February). The annual value of the NAO index was calculated as an average of all twelve monthly values in a year of ring formation.

As the dendrochronological data in the International Tree-Ring Data Bank consisted of already built standard chronologies no other manipulation was performed on the series in terms of investigation the growth-circulation relationships. The response function concept (Fritts 1976, Briffa & Cook 1990) was applied in order to detect the NAO signal in the whole tree-ring width series. Monthly as well as seasonal and annual values of the index were used to describe the circulation pattern in each of the analysed oak series. Elaboration of the correlation and response function equation parameters and tests of their statistical significance were performed with DendroClim2002 software (Biondi & Waikul 2004). Significance threshold was accepted at 0,05 level.

Pointer year determination was carried out on raw measurement series transformed according to Cropper (1979). Five years window was used for that calculation. These transformed indices were then normalised and checked against arbitrary threshold for positive and negative event values detection. The threshold value was set at +1 and –1 for positive and negative event values respectively. An individual year was considered as a pointer year when more than 50% of trees at the site show the same kind of an extreme increment reaction described by an event value (Boryczka et al. 2007). In order to check if there is a coincidence between the character of the year when oaks in Poland formed extremely wide or narrow rings and the North Atlantic Oscillation pattern, contingency tables consisting of these two traits were built. For each either positive or negative oak pointer year, the character of the NAO annual index in that given year was noted. So-described features were then compared. The statistical significance of this relationship was tested with chi-square test at 0,05 significance level.

Results

NAO signal in tree-rings

Multivariate correlation coefficients between tree-ring width and the NAO indices are presented in table 2 (monthly resolution) and in figures 1 and 2 (annual and seasonal resolution respectively).

Significant values are rather rare and spatially dispersed. However the general pattern can be recognised when analysing the sign of the correlation coefficients.

Table 2: Relationship between monthly NAO index and tree-ring width of oaks from different sites in Poland. Bold values are significant at 0,05 level. "p" indicates months of year prior to tree-ring formation.

	pJ	**pJ**	**pA**	**pS**	**pO**	**pN**	**pD**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Gdańsk	-0,08	-0,03	-0,08	-0,09	0,06	-0,01	-0,06	-0,03	0,11	0,09	-0,11	**-0,21**	**-0,13**	-0,14	-0,04	-0,02
Gołdap	0,05	-0,08	-0,01	-0,02	**0,17**	0,00	0,12	0,01	-0,02	0,12	0,05	0,14	0,03	0,05	0,00	0,03
Hajnówka	-0,03	-0,13	-0,09	0,05	-0,02	0,00	0,09	-0,04	-0,05	-0,07	-0,01	0,01	-0,08	-0,06	-0,06	0,14
Koszalin	0,03	0,02	0,10	-0,10	**0,15**	0,11	-0,09	0,07	0,14	0,00	-0,03	-0,13	-0,10	-0,05	0,01	-0,02
Kraków	0,07	-0,06	0,01	-0,02	0,11	0,00	-0,03	0,08	0,02	0,02	0,04	**-0,18**	-0,02	-0,02	0,13	**0,17**
Poznań	0,00	-0,03	-0,07	-0,09	0,03	-0,08	-0,08	**0,17**	0,13	0,05	0,01	-0,11	-0,09	-0,06	-0,03	0,01
Roztocze	-0,05	-0,06	-0,09	0,06	0,04	0,05	0,06	0,05	0,02	-0,05	0,02	**-0,20**	-0,08	-0,04	-0,04	**0,15**
Suwałki	0,01	-0,04	-0,10	0,08	-0,04	0,04	0,14	0,02	**0,20**	0,02	0,11	-0,11	0,12	-0,12	0,02	0,07
Toruń	-0,03	0,03	0,00	-0,14	**0,16**	-0,04	-0,12	0,02	**0,22**	0,03	-0,09	-0,13	-0,02	0,08	-0,11	**-0,15**
Warszawa	-0,09	-0,09	-0,13	0,14	0,08	-0,03	-0,09	0,00	-0,05	-0,03	**0,15**	-0,06	-0,08	**-0,14**	0,09	**0,19**
Wolin	-0,05	-0,11	-0,05	-0,03	0,06	0,02	0,01	0,05	0,01	0,10	-0,14	**-0,14**	-0,06	0,02	-0,05	0,07
Wrocław	**-0,18**	-0,10	-0,01	0,11	0,13	0,00	-0,13	0,07	-0,01	0,06	0,03	-0,13	-0,09	-0,05	-0,01	0,07
Zielona Góra	-0,05	-0,12	-0,08	-0,03	0,05	-0,10	0,03	-0,04	-0,01	0,00	-0,01	-0,01	-0,02	-0,17	**-0,17**	0,02

Negative correlation with the early summer NAO can be observed almost all over the country both at monthly and seasonal level. Individual coefficients for May, June and July in the year of ring formation are in majority (85%) of sites negative. For Gdańsk, Kraków, Roztocze and Wolin sites this relationship is statistically significant in May. Similarly high frequency of negative coefficients occurs for July and August of the year prior to the growth. Considering the seasons, oaks in Poland show a negative response for the NAO conditions in the warm half of the year (spring and summer). Frequency of the negative coefficients in these seasons equals 77% and 85% respectively.

In turn, prevailing positive correlation between the NAO and tree-ring width indices can be observed in cold half of the year. 70% of sites showed positive coefficients for winter, even higher ratio (85%) occurs in autumn. As far as monthly resolution is concerned, October of the year prior to the ring formation characterises the highest (85%) frequency of positive coefficients. For Gołdap, Koszalin and Toruń this relationship is statistically significant. March and September of the year of ring formation also show quite high (77%) accordance in reaction of oaks. In addition, three sites (Kraków, Roztocze, Warszawa) reveal significant coefficients in the latter of these months. Noteworthy is significant negative response of Toruń site (Tab. 2).

As far as relationships in annual time-scale are concerned, slight predominance of positive response can be observed. However it is only significant at one site (Fig. 1).

Pointer years

In total for the time span common for NAO and dendrochronological data, there were 144 positive and 141 negative pointer years determined for all of the oak series in Poland (Tab. 3). The greatest total number of pointer years was obtained for Roztocze (30), the smallest – for Gdańsk (11). Determined pointer years constitute from about 7% (Gdańsk) to 18% (Gołdap, Kraków, Roztocze) of analysed tree-ring series. Number of positive and negative pointer years in an individual series is similar in most of the cases and constitutes, on average, 7,2% and 7,1% for positive and negative years respectively (apart from Gdańsk, where the frequency is distinguishably lower).

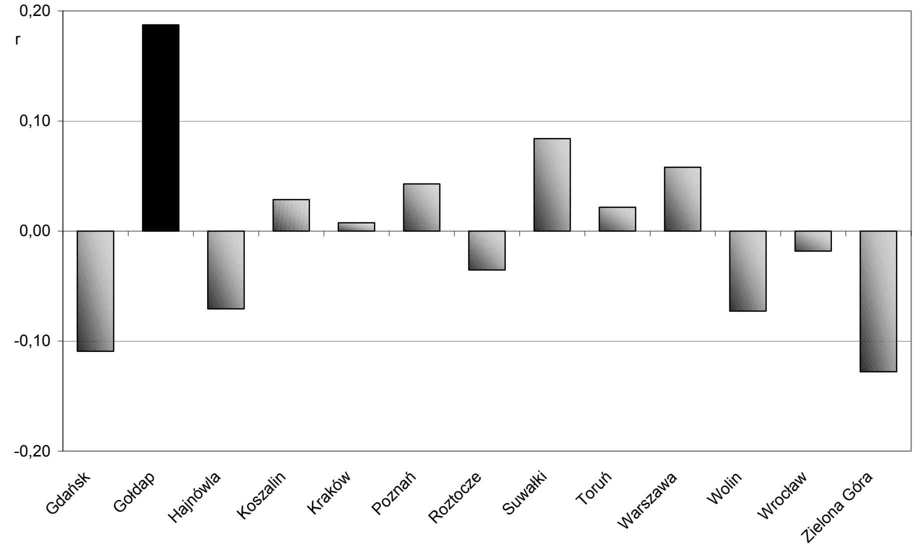

Figure 1: Coefficient of correlation (r) between annual NAO index and tree-ring width of oaks from different sites in Poland. Black bar represents value significant at 0,05 level.

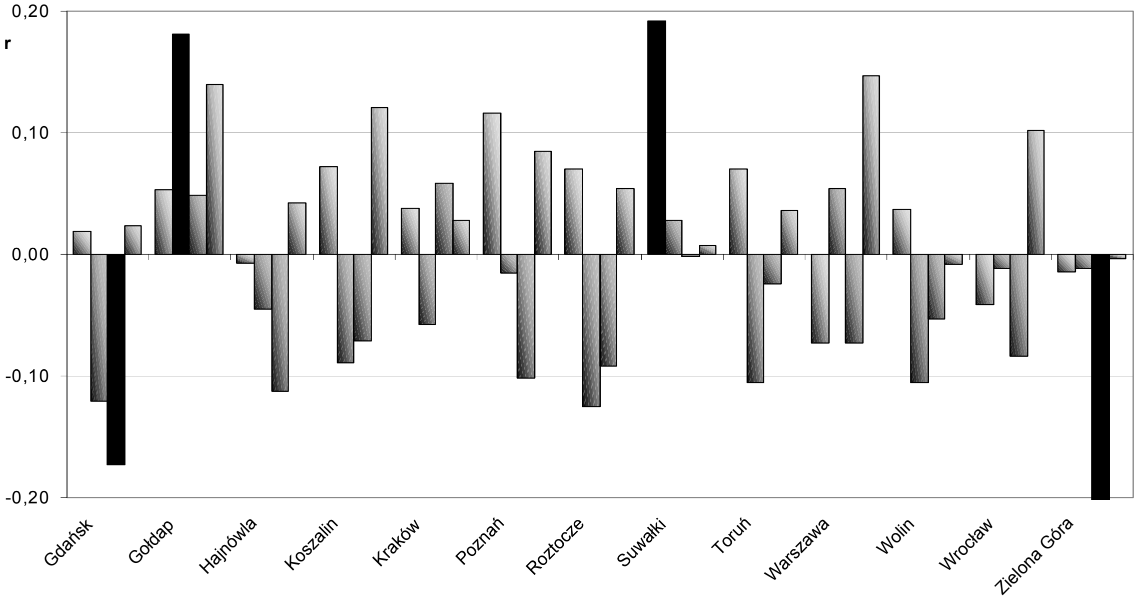

Figure 2: Coefficient of correlation (r) between seasonal NAO index and tree-ring width of oaks from different sites in Poland. Bars presented for individual site indicate, from left to right, winter, spring, summer, and autumn. Black bars represent values significant at 0,05 level.

The extremely narrower or wider tree-rings were more frequent in the 1800s than in the 1900s. However, there are only a few pointer years of larger spatial abundance and most of them occurred in the 19th century. Positive pointer years that were determined for more than 40% of sites include 1834, 1837 and 1890. Especially narrow tree-rings of wider spatial abundance can be observed in 1827, 1840, 1841, 1882, 1937 and 1940. Of great interest is the sequence of three consecutive negative pointer years at the beginning of the 19th century (1819-1821). Up to 55% of sites spread out all over Poland showed these years as the pointer ones, however only in Roztocze series all of them had this character at the same time. There are only seven cases when all trees from an individual site formed extremely narrow or wide ring.

Table 3: Pointer years of oak in Poland

site	positive		negative		total
	n	%	n	%	
Gdańsk	4	2,48	7	4,35	11
Gołdap	10	8,62	11	9,48	21
Hajnówka	15	9,38	11	6,88	26
Koszalin	13	8,02	10	6,17	23
Kraków	11	6,83	18	11,18	29
Poznań	12	7,95	10	6,62	22
Roztocze	14	8,54	16	9,76	30
Suwałki	6	4,76	10	7,94	16
Toruń	13	8,02	10	6,17	23
Warszawa	9	5,63	10	6,25	19
Wolin	15	9,26	6	3,70	21
Wrocław	13	8,02	13	8,02	26
Zielona Góra	9	5,56	9	5,56	18

NAO signal in pointer years

Figure 3 present frequency of positive and negative annual NAO index values during specific types of pointer years determined for the individual data-sets. In total number of 144 positive pointer years 47% represents positive NAO phase. Ratio of similar NAO phase and pointer year character equals for negative pointer years in general 48%. However, as far as the individual series are concerned, much more variability can be observed. Analysis of the coincidence between pointer years and the NAO annual index characters reveals that the hypothesis about the lack of dependence of the pointer year type on the phase of the circulation pattern cannot be rejected. Significance test resulted in chi-square value equal 0,784, which is not significant at 0,05 level.

In addition, the coincidence between ‘extreme’ values of the NAO annual index and character of pointer years was analysed. The previous was elaborated on the basis similar to the pointer year determination, however no Cropper transformation was performed. The values greater or smaller than 1 standard deviation from the data-set mean were considered in the analysis. The number of pointer years of a given character was almost identical for both types of the extreme NAO index values (Fig. 4). So neither in this case, any statistically based reasons for recognition of the relationship between character of the circulation pattern and the type of the pointer years of oaks in Poland were found.

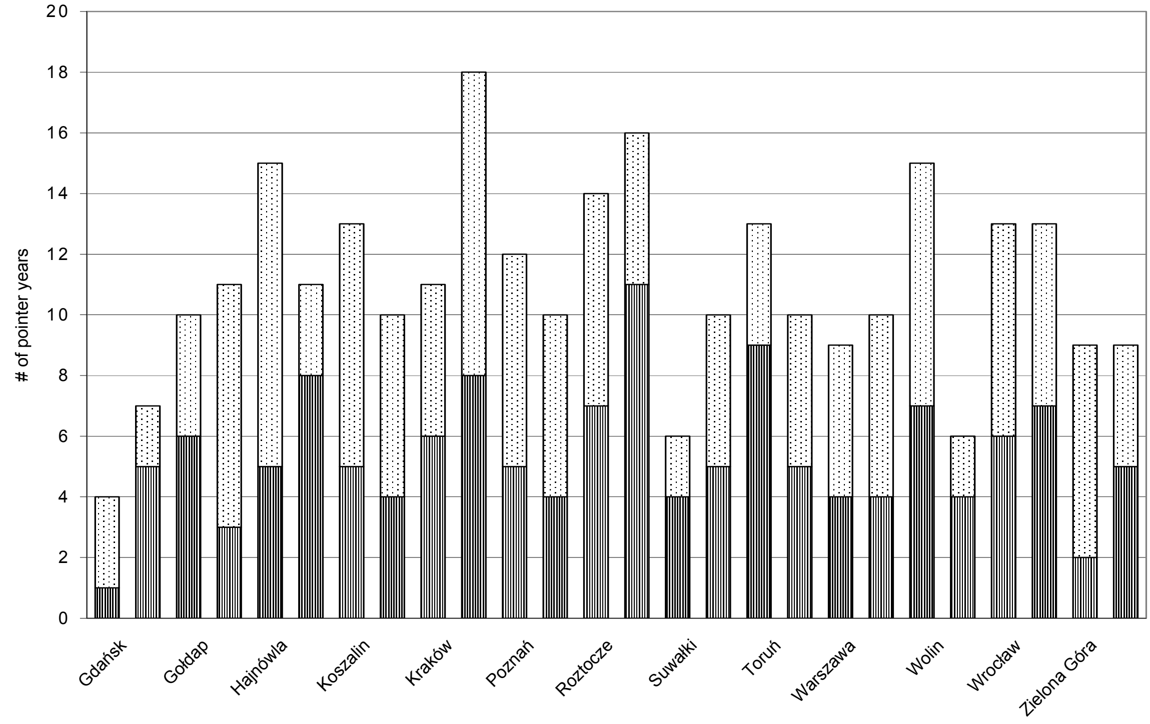

Figure 3: Frequency of positive (hatched) and negative (dotted) values of annual NAO index during positive (left bar) and negative (right bar) pointer years of oak at different sites in Poland

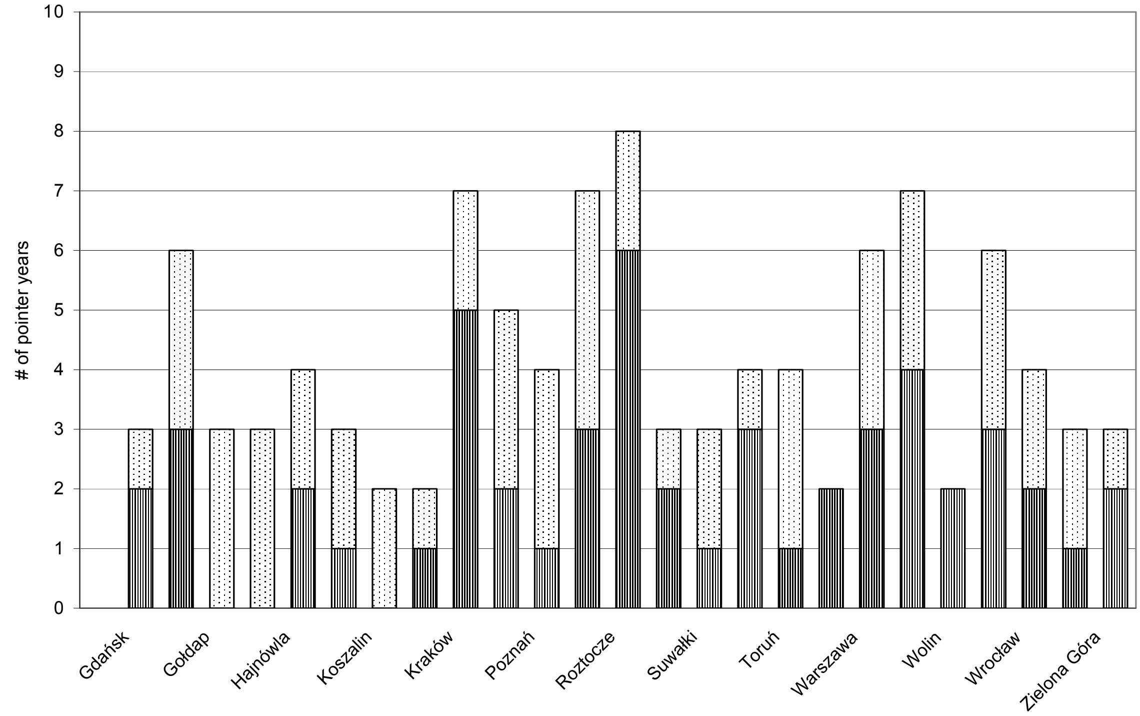

Figure 4: Frequency of positive (hatched) and negative (dotted) 'extreme' values of annual NAO index during positive (left bar) and negative (right bar) pointer years of oak at different sites in Poland

Discussion

Growth of oaks in Poland does not show significant influence of the North Atlantic Oscillation pattern either in monthly or seasonal scale. Schultz et al. (2008) obtained similar results while analysing circulation signal in tree-rings of various species (including oak) in Central Europe. Moreover, tree-ring formation of oak in Poland is correlated rather with climate conditions in summer (Cedro 2004) and the transfer of NAO influence on weather conditions in that region is the most profound in cold season (Boryczka & Stopa-Boryczka 2007a, b). This discrepancy is probably the main reason of observed pattern, for in case of Scots pine temperature/precipitation-tree growth dependence translates directly into NAO-tree-ring width relationship (Cedro 2007). Another factor that may influence significance of the relationships between oak growth and NAO influence is the way of the index calculation. Schultz et al. (2008) found different direction of this relation regarding various forms of NAO index. On the other hand, NAO pattern may be too general characteristic and local, site-dependent conditions shape the tree growth in greater measure as in case of maritime pine in Spain (Bogino & Bravo 2008). Although well-documented relations between climate conditions (mostly temperature and precipitation) and NAO index, no particular and significant relationship between circulation and tree-ring width was found in Iberian Peninsula. Perhaps investigation of the influence of the circulation patterns based on locally variations of pressure field is more appropriate solution, especially for regions distant from the main source of NAO character.

Pointer years indicate extreme conditions that caused formation of extraordinarily narrow or wide tree-rings. Assuming leading role of the climate in driving the ring formation process we may expect that circulation, especially its extreme indications, should also have some influence on this phenomenon. However pointer years of oaks in Poland show no coincidence with the extreme values of NAO index as, in general the share of positive and negative NAO phase in specific type of the pointer year equals about 50%. Piovesan & Schirone (2000) found agreement between pointer years and NAO sign only in non-standardised series. Also, results presented by Cedro (2007) show that relationship between these features is very variable and no clear pattern can be observed. Again, hemispheric (i.e. more general) character of NAO may be the reason as the wood formation process can be supported or, which is more often, limited by single extreme event of very small spatial impact.

Conclusions

Performed analysis was the first attempt to investigate the influence of circulation pattern on growth of oaks in Poland.

The North Atlantic Oscillation signal in the tree-ring widths of oaks is, in annual, seasonal and monthly scales, rather small and not significant with the correlation coefficient below 0.2. This result is caused by greater dependence of oak response to the climate on weather conditions in warm season, while the NAO influence is more profound rather in cold half of the year. Either, no circulation signal can be observed in pointer years determined for analysed data-set, which suggests that extreme relation of trees to climate is rather driven by local factors than those of global or hemispheric origin.

Analysed circulation pattern seems to be too general and it is advisable to investigate rather regionally developed indices that depict variation specific for climate conditions in smaller scale.

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Improving Alpine summer temperature reconstructions by increasing sample size

Büntgen, U.[1], Frank, D.[1], Carrer, M.[2], Urbinati, C.[3] & J. Esper[1]

[1]*Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland*
[2]*Università degli Studi di Padova, Treeline Ecology Research Unit, Agripolis, 35020 Legnaro (PD), Italy*
[3]*Università Politecnica delle Marche, SAPROV, Forest Ecology and Management, 60131 Ancona, Italy*
Email: buentgen@wsl.ch

Introduction

Annually resolved reconstructions of multi-centennial to millennial-long temperature variations are commonly derived from tree-ring data (IPCC 2007). A detailed understanding of this proxy archive including growth trends, climate response patterns, eco-physiological disturbances and methodological biases is, however, crucial before robust estimates of past climate variability can be drawn (Esper et al. 2005).

Among potential disturbance factors in millennial-length larch (*Larix decidua* Mill.) chronologies from the European Alps (Büntgen et al. 2005, 2006), effects from periodic oscillations in abundance of the larch budmoth (LBM; *Zeiraphera diniana* Gn.) are of both concern and interest. LBM is one of the most regular systems of animal population dynamics with a high degree of periodicity in outbreaks every 8-9 years (Baltensweiler & Rubli 1999), and an exceptional persistence over the past millennium (Esper et al. 2007). It is a foliage-feeding *Lepidoptera* widespread throughout sub-alpine larch forests in the European Alps, and shows considerable variability in temporal population densities ranging from 1 to 30,000 larvae per host tree (Baltensweiler et al. 1977). When such epidemics occur over larger areas, defoliation affects ecosystem processes, but rarely triggers tree mortality. Fingerprints of cyclic LBM outbreaks include significantly reduced larch ring width and density values, that allow long-term LBM dynamics to be estimated, but simultaneously hinder the reconstruction of past climate variations. Since defoliation is not perfectly synchronized over the Alpine arc and along altitudinal gradients (Baltensweiler et al. 2008, Bjørnstad et al. 2002, Johnson et al. 2004, 2006), i.e., there is typically a time-lag of 1-3 years between mass outbreaks, averaging TRW data from different locations could help diminishing the otherwise simultaneous occurrence of severe growth depressions. Scientific importance for such an approach is given, as the retained temperature signal in unaffected larch trees from higher elevations is known to be very pronounced (Frank & Esper 2005), and the longevity of larch timberline trees and the persistence of dry-dead and construction wood has resulted in well replicated composite datasets that are spatially defined and extend back into medieval times (Büntgen et al. 2006a).

Here we present a reconstruction of millennium-long summer temperature variability based on a massive compilation of larch TRW chronologies distributed across the Alpine arc. Calibration/verification trials demonstrate the strength of this unique record to capture the full range of natural temperature fluctuations from inter-annual extremes to lower frequency trends. Wavelet and spectral analyses suggest that increased sample size from a geographically heterogeneous network adequately compensates for non-climatic growth depressions caused by insect defoliation. Effects of changing sample size on the climatic signal strength are discussed in the light of comparison between the new reconstruction and pervious studies based on smaller compilations.

Data and Methods

A compilation of 2610 TRW series from 40 temperature sensitive larch sites located at higher elevations in the European Alps was used for reconstruction purposes (see Büntgen et al. 2008 for details). The Regional Curve Standardization (RCS; Esper et al. 2003) was applied to remove tree

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age related growth trends from the raw measurements allowing lower frequency information to be preserved. Chronologies were calculated using a bi-weight robust mean, and the number of samples per year and the cross-correlation coefficient between all measurements considered for variance stabilization (Frank et al. 2007b). For validation of the overall long-term course of the RCS chronologies, data were split into living (outermost ring >1950), historic (outermost ring <1950), young (<250 years), mature (>150 years), and old (>250 years) trees, according to principles outlined in Büntgen et al. (2005). The six resulting chronologies and their simple mean were compared with instrumental 'target' data (Auer et al. 2007). Ordinary linear regression was applied to transfer the dimensionless TRW indices into temperature anomalies with respect to the 20th century mean. The Pearson's correlation coefficient (*r*), explained variance (*R2*), reduction of error (*RE*), coefficient of efficiency (*CE*), and Durbin-Watson statistic (*DW*) were employed to estimate the reconstruction's skill (Cook et al. 1994). Spectral (Mann & Lees 1996) and wavelet (Torrence & Compo 1998) analyses were applied to perceive similarities and differences in the power spectra of the reconstructed (proxy) and measured (target) time-series.

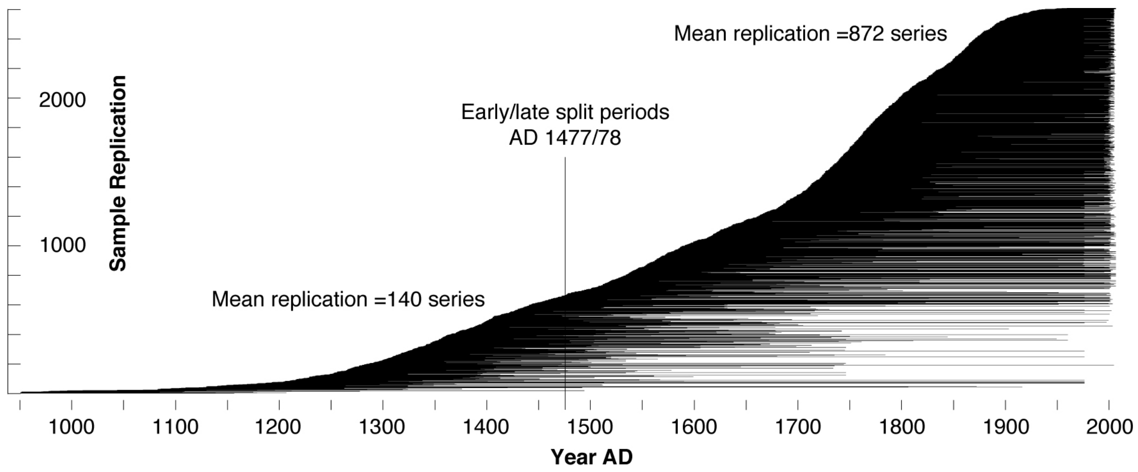


Figure 1: Temporal distribution of the 2610 living and relict Alpine larch sample used for temperature reconstruction.

Results and Discussion

The Alpine larch TRW dataset is characterized by evenly distributed series start dates from the mid 10th century until the early 20th century (Fig. 1). Mean sample replication during the 951-2004 period is 506 series and ranges from 10-1490. Mean sample replication during the split 951-1477 and 1478-2004 periods are 140 and 872 series, respectively. Minimum and maximum replication during early and late portions are 10 and 391 series, and 44 and 1490 series, respectively.

Six RCS chronologies based on the full dataset (2610 series) and subsets of living (1479 series), historic (1131 series), young (1874 series), mature (1593 series) and old (736 series) trees, as well as their arithmetic mean portray common variability on inter-annual to multi-centennial time-scales (Fig. 2). While all records are quite similar back to AD ~1300, increasing offset during the records' first 350 years most likely originates from constantly decreasing sample sizes back in time. Moving inter-chronology correlations (*Rbar*) between the six time-series start to slightly decrease before ~1300, whereas moving standard deviations increase during that period (Fig. 2B). A pronounced depression in *Rbar* values is found around the first half of the 12th century when offset between the individual chronologies is most evident. Nonetheless, one must note that the obtained statistics range on a high level of consistency throughout time. Correlations (common 1122-2003 period) between the six chronologies (after truncation <10 series) range from 0.69-0.97. Values decrease to 0.46-0.96 after 60-year low-pass filtering. Note that correlation between the fully independent chronologies based on trees younger and older than 250 years is 0.69 (1122-2003). A similar high correlation of 0.63 (1363-1945) derives from the two independent chronologies that either use living or relict wood.

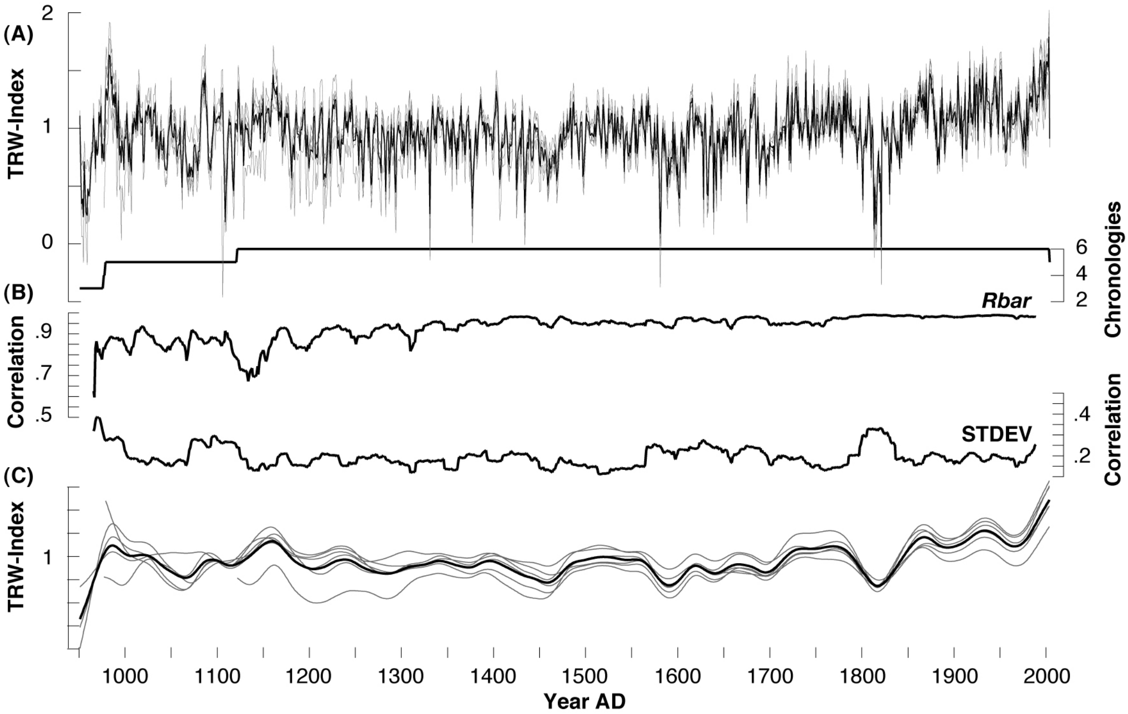
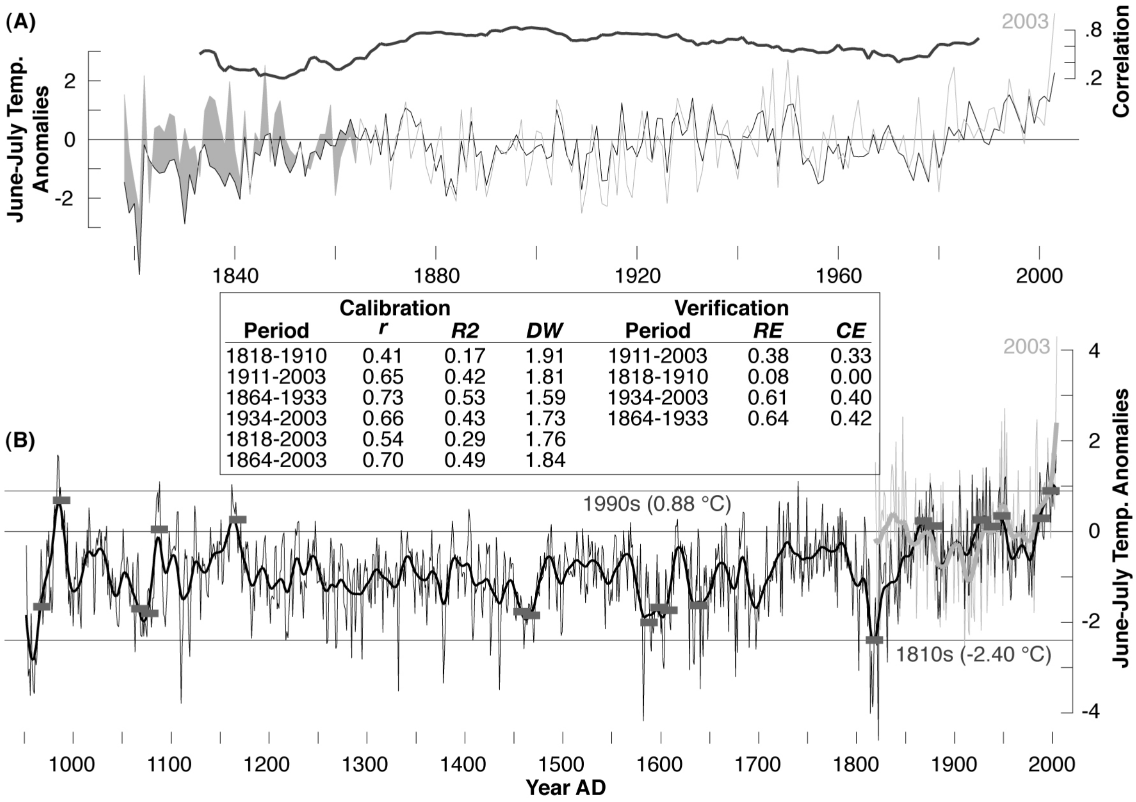


Figure 2: (A) Six chronologies (grey) after various detrendings and their mean (black). The black solid line shows chronology replication ranging from 2-6. (B) Moving 31-year inter-chronologies correlation (Rbar) and standard deviation (STDEV) of the six unfiltered chronologies. (C) Chronologies after 60-year low-pass filtering.

Correlation analysis (1864-2003) between temperatures of an 18-month window from May of the year prior to tree growth until October of the growing season along with various seasonal means and the six RCS chronologies plus their mean reveals a distinct response maximum (*r* =0.70) to June-July (not sown). Monthly correlations are non-significant from January to May, while correlations with June and July are both significant at *p* =0.001. Monthly correlations with August to October are again non-significant. After 30-year low-pass filtering, correlations increase to 0.82.

Interestingly, correlation coefficients of 0.68 and 0.70 gained from two RCS chronologies using young (<250 years) and old (>250 years) trees, respectively, denote fairly robust growth/climate relationships amongst different age classes. Such age independent signal strength, also demonstrated by Esper et al. (2008), most likely results from the fact that high sample size adequately compensates for juvenile growth ‘disturbances’. In contrast, a more local-scale analysis based on less data, found a maximum climate response in larch trees >200 years (Carrer & Urbinati 2004).



Calibration				Verification		
Period	*r*	*R2*	*DW*	Period	*RE*	*CE*
1818-1910	0.41	0.17	1.91	1911-2003	0.38	0.33
1911-2003	0.65	0.42	1.81	1818-1910	0.08	0.00
1864-1933	0.73	0.53	1.59	1934-2003	0.61	0.40
1934-2003	0.66	0.43	1.73	1864-1933	0.64	0.42
1818-2003	0.54	0.29	1.76			
1864-2003	0.70	0.49	1.84			

Figure 3: (A) Overlap between the instrumental (grey) and reconstructed (black) temperatures, with the solid line indicating 31-year moving correlations between both records. Temperatures are expressed as anomalies with respect to the 20th century. The grey shading indicates offset between warmer instrumental measurements and cooler proxy estimates. (B) The June-July temperature reconstruction after regressing the mean chronology over the 1864-2003 period. Inset denotes calibration and verification statistics. Series are 20-year low-pass filtered, and grey boxes show the 10 warmest and coldest calendar decades.

After linear regression (1864-2003) of the mean RCS chronology against June-July temperatures (l*ag-1* autocorrelation of the proxy and target time-series are 0.44 and 0.17, respectively), the reconstruction provides evidence for warmth around the 990s, 1090s and 1170s, a prolonged cooling from the 13th-19th century and exceptionally warm summers since the 1980s (Fig. 3). The warmest and coldest reconstructed calendar decades are the 1990s (+0.88 °C; wrt. 1901-2000) and the 1810s (-2.40 °C), respectively. Warmest summer temperatures back to AD 952 are estimated for 2003 (+2.27 °C) and 983 (+1.69 °C). Seven of the ten warmest summers occurred from 1986 onwards. Positive *RE* and *CE* values – estimates of shared variance between actual and reconstructed data – suggest temporal robustness of the model. A *DW* value of 1.84 (1864-2003) indicates low 1st order autocorrelation in the proxy/target residuals. Temporal stability of the reconstruction is further demonstrated by 31-year moving correlations that describe highest coherency between ~1870-1940 (Fig. 3A). Note that low calibration and verification statistics are obtained during the 1818-1910 period. A similar offset between warmer early instrumental and cooler proxy data is reported from previous Alpine studies and reviewed by Frank et al. (2007a).

Comparisons of this reconstruction with two related previous versions of millennium-long summer temperature history from the Alps (Büntgen et al. 2005, 2006b), hereinafter B05 and B06, indicate in-phase variability on all frequency domains (not shown). These reconstructions are, however, not completely independent in terms of the data utilized and methods applied. Correlation (952-2002) between this study and B05 (based on TRW) and B06 (based on MXD) is 0.67 and 0.45, respectively. After 20 (80) year low-pass filtering, correlations with B05 decrease from 0.61 (0.54), whereas correlations with B06 increase to 0.57 (0.57). When splitting the time-series into early (952-1476) and late (1477-2002) portions, correlations with B05 and B06 are 0.61 and 0.29 for the early period and 0.64 and 0.76 for the late period, respectively. After 20 (80) year low-pass filtering, correlations for the early period decrease to 0.40 (0.15) (B05) and 0.29 (0.17) (B06), whereas correlations for the late period increase to 0.80 (0.83) (B05) and 0.85 (0.90) (B06). Increasing coherency between this study and B05 during the records' first portion reflects escalating data overlap back in time. High correlations between all time-series during the late period indicate their common signal strength.

We consider the reconstruction back to ~1300 to be an improvement of B05. This is because sample size increased from 1110 larch (and 417 pine) TRW series to now 2610 larch series (it remains debatable if the removal of pine data offsets the augment of larch data) The enhancement is most evident during the records last seven centuries and subsequently helps diminishing LBM-indiced 'noise' from ~1300-present. Successful compensation for otherwise cyclic growth depressions in TRW results from the heterogeneous dispersal of the 40 site chronologies covering locations from the southern French Pre-Alps to Austria and an altitudinal range from 1400-2200 m asl. This network is characterized by temporal offset in the occurrence of insect outbreaks at different locations.

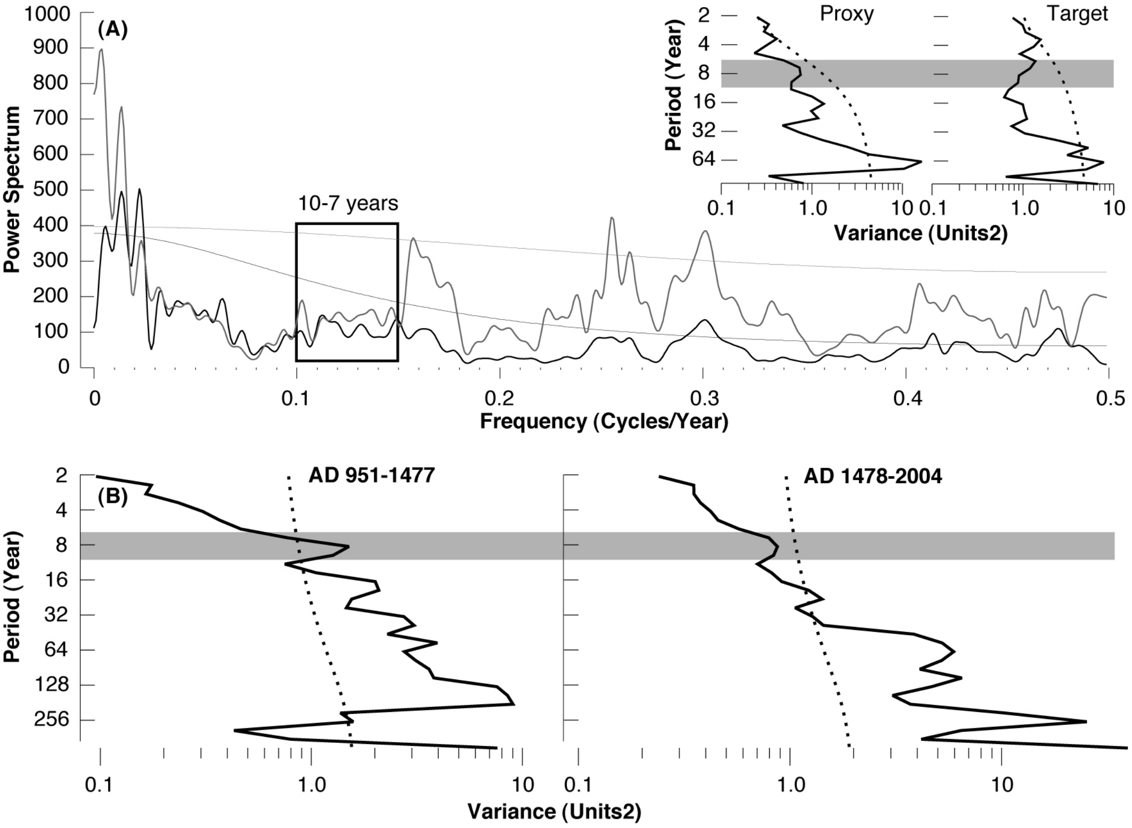


Figure 4: MTM power spectra of the (A) reconstructed (black) and measured (grey) June-July temperatures (1864-2003) using 3 tapers and a resolution of two years with robust background noise estimation. Smoothed lines are 95% confidence limits. The upper right inset denotes the corresponding global wavelet power spectra, with the dashed lines being 90% significance levels. (B) Global wavelet power spectra of the TRW-based reconstruction computed over two early/late split periods. Dashed lines are 90% significance levels using a white noise background.

Both, spectral and wavelet analysis applied to the TRW chronology shows non-significant power at ~8-9 years (Fig. 4), thus not revealing obvious indications of systematic growth periodicities commonly expected at this frequency domain if larch forests are regularly defoliated by LBM outbreaks. Comparison of the power spectra obtained from the proxy and target time-series shows remarkable similarity at all time-scales (Fig. 4A). Significant lower frequency variability of both time-series is indicated at approximately 128, 73 and 44 years. Moreover appears power to be significant at the inter-annual time-scale. Artificial power inflation as obtained from the target time-series towards lowest frequencies most likely reflects the overall long-term warming from the mid-19th century until 2003, rather than really fluctuations. Negligible power between 7-10 years, caused by the geographically random merging of TRW data from numerous larch sites, contrasts results obtained from the site-level (see Esper et al. 2007 for details). At the local-scale, TRW chronologies have in fact demonstrated the detection of LBM defoliation-induced growth reductions near Italian/French border (Nola et al. 2006), across two sub-alpine valleys in Switzerland (Weber 1997), and within the French Alps (Rolland et al. 2001). These recent studies conducted at the local-scale, nicely confirmed the regular recurrence of outbreaks with little evidence for changes in cycle period and amplitude over the last few centuries prior to the widespread collection of forest inventories data. Outstanding in this regard appears the 1200-year long history of insect epidemics developed on the basis of a sub-alpine TRW/MXD hybrid from living trees and historic timbers (Esper et al. 2007).

For a better understanding of the fidelity to diminish cyclic growth depressions at ~8-9 years back into medieval times when series sample size and spatial heterogeneity of the sites constantly decreases – most of the site chronologies that stretch well into the records first half are located in the western Swiss Alps, wavelet analysis was applied over two split periods (951-1477 and 1478-2004) of equal length (Fig. 4B). To pinpoint inter-annual to decadal-scale power peaks, the wavelet significance levels are based on a white noise background spectrum (Torrence & Compo 1998). While significant power associated with LBM outbreaks is found during the first interval, no such evidence derives from the second interval. This difference in the reconstructed strength of cyclic growth depressions during the early and late portion of the record is related to *(i)* the enormous difference in sample size, and *(ii)* the spatial network change from the regional- to larger-scale, as long-term consistency in LBM system itself has been proofed (Esper et al. 2007). While a mean replication of 140 series versus 872 series before and after AD 1477 already obscures compensating defoliation-induced growth depressions by high sample size alone, most of the site chronologies that extend back into medieval times derive from the same region in the western Swiss Alps.

Conclusion

A compilation of 2610 TRW series from 40 sites covers the Alpine arc and the 951-2004 period. Application of the RCS method resulted in a chronology that preserves inter-annual to multi-decadal scale variability. Since sample size and diversity in sample compensates for spatiotemporally asynchronous insect-induced ‘noise’, reconstructed summer temperatures show, for example, the cold and hot extremes of 1816 and 2003, respectively, as well as episodic warming during medieval times and towards present with prolonged Little Ice Age cooling in between.

This reconstruction validates earlier work and also improves our understanding of past climate variability across the Greater Alpine Region and back in time. This study exhibits that larch TRW measurements can robustly model summer temperature variations if enough data (i.e. evenly distributed and well replicated site chronologies) are carefully selected (i.e. based on their individual temperature response) and age-related composite detrending properly applied (i.e. tests of the RCS method using various data subsets).

Conversely, this study supports the ‘epicenter’ hypothesis of traveling waves in population dynamics (Johnson et al. 2004), and the ‘altitude’ hypothesis, which postulates that most severe LBM epidemics are concentrated at ~1800 m asl (Weber 1997). While the first hypothesis is affected by the complex landscape geometry of the Alpine arc that dampens the direction and speed of traveling waves (Bjørnstad et al. 2002, Johnson et al. 2006), the later is affected by local weather conditions that shift outbreak foci to lower or higher elevations, and modulate populations at different slope exposures (Baltensweiler et al. 2008).

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Climatic response of spruce trees growing at southern coast of the Baltic Sea (beyond the natural range of spruce)

Cedro, A.[1] **& B. Cedro**[2]

[1] University of Szczecin, Laboratory of Climatology and Marine Meteorology, Institute of Marine Science, Wąska 13, 71-415 Szczecin, Poland
[2] University of Szczecin, Laboratory of Geology and Paleogeography, Institute of Marine Science, Mickiewicza 18, 70-383 Szczecin, Poland
Email: Anna.Cedro@univ.szczecin.pl

Introduction

The Norway spruce (*Picea abies* L.) is attaining in Poland the north-western border of its natural extent (Modrzyński 1998), so the studied area - Western Pomerania - is lying outside the range of natural appearance of this tree species. The spruce was introduced there by German foresters at the turn of the 18th and 19th centuries (Modrzyński 1998), and its cultivation and seeding have been being continued until today. In spite of a considerable distance of this area from the border of clenched appearance of spruce, this tree species seems to attain in NW Poland its physiological optimum, characterized by dynamic growth, exuberation, as well as high resistance to diseases. For these reasons numerous single-species plantations have been being established, and spruce is also common as an additive and/or undergrowth species. In forests of the Western Pomerania region the common spruce occupies 3.4% of the forest surface, being one of more important tree species (Szymański 1998).

This study is aimed at construction of a chronology for *Picea abies* from NW Poland, determination of the relations growth-climate, as well as comparison of the results obtained with dendroclimatological analyses of spruce trees growing within their natural range.

Study area

The research plots are localised in NW Poland on moraine heights covered with beech forests (Fig. 1, Tab. 1). In the Wolin Island, small areas covered with spruce trees of the age of about 100 and 120 years (the plots W2 and W6) are situated about 2-5 km from the Baltic Sea shore, on strongly disturbed postglacial settlements. The next chain of moraine heights stretches in the vicinities of Szczecin, about 60 km S from the coastline. This area is a habitat for, among others, old experimental plots, once established for introduction of new species of trees (the plots W4 and W8).

Table 1. Specification and basic information about the investigated plots.

Laboratory Code	**Region**	**Forestry**	**Division**	**Geographic coordinates**		**No of sampels**
				φ (N)	λ (E)	
W2	Wolin Island	Międzyzdroje	37dx	$53^0\,57'$	$14^0\,28'$	23
W4	Bukowe Hills	Klęskowo	166a	$53^0\,18'$	$14^0\,44'$	17
W6	Wolin Island	Wicko	89c,f	$53^0\,55'$	$14^0\,32'$	20
W8	Bukowe Hills	Smerdnica	123e	$53^0\,19'$	$14^0\,45'$	19

Figure 1: Position of the study area and geographical ranges of Norway spruce in Europe.

Methods

Field studies were carried out in summer 2004. A total of 79 trees were sampled by coring with Pressler borers. The cores were taken at the height of 130 cm. The tree-ring widths were measured using special equipment coupled with the DendroMeter software (Mindur 2000). All measurements were made with 0.01 mm accuracy. The chronology was assembled using the classical dendrochronological technique and tested with the COFECHA software (DPL program package, Holmes 1983, 1994). This chronology served as a basis for the analyses of the signature years and the response function. The signature-year analysis was carried out using the TCS software (Walanus 2002); signature years were identified from at least 10 trees, and the minimum convergence threshold was set at 90%. In addition, relationships between climate and tree-ring width were explored using the response function analysis (Fritts 1976, Fritts & Xiangding 1986, Blasing et al. 1984, Cook & Kairiukstis 1990, Zielski & Krąpiec 2004). The response functions were calculated with the aid of the DPL program package (RESPO module, Holmes 1983, 1994).

Climatic data

The dendroclimatological analyses were based on data from the IMGW meteorological stations in Szczecin and in Świnoujście, situated not far from the examined tree stands. There were analysed average monthly temperatures and total monthly rainfall from the period 1948-2003 (56 years). As NW Poland is strongly affected by the Atlantic Ocean and the Baltic Sea, the weather conditions depend above all on inflow of the polar-sea air masses, occurring with a frequency of up to 70%. The average annual temperature is between 8.2°C (in Świnoujście) and 8.5°C (in Szczecin); the coolest month is January with the average temperature a little below zero (-0.6°C), extremely dropping to -8.8°C, and the warmest one is July (ca. 17°C). The average annual rainfall is from 532 mm for Szczecin to 551 mm for Świnoujście. In the driest years the rainfall is below 400 mm, in the most humid ones – above 700 mm. The most humid month is July is (60-70 mm), and the driest are February and March (about 30 mm of precipitation). The snow cover occurs during less than 30 days, moreover, due to frequent inflows of polar-sea air masses, it proves to be highly fragile; e.g. in winter 1988/89 it appeared only one day.

Dendrochronological and dendroclimatological analysis

For each of the sites analysed a local chronology was constructed; two for the Wolin Island (W2 and W6) and two for the vicinities of Szczecin (W4 and W8). The longest average pattern, W4, spans 112 years (1892-2003); the next one, W2 - 111 years; the sequence W6 - 87 years; and the shortest sequence W8 contains only 66 growth rings (1939-2003) (Tab. 2). Every chronology is based on 12 to 18 individual sequences measured, 15 in average.

Table 2. Statistical data for measured and indexed chronologies of spruce.

Lab. code	*No of years*	*Time span*	*No of samples*	*Mean ring width (mm)*	*Std deviation*	*Mean sensitivity*	*Autocorrelation order 1*	*RESIDUAL CHRONOLOGY*			
								Median	*Mean sensitivity*	*Std deviation*	*Autocorrelation order 1*
W2	111	1893-2003	18	1.36	0.66	0.32	0.63	1.01	0.32	0.27	-0.04
W4	112	1892-2003	13	1.9	0.92	0.30	0.74	1.00	0.25	0.20	-0.07
W6	87	1917-2003	12	1.69	0.97	0.36	0.72	0.97	0.34	0.28	-0.02
W8	66	1939-2003	16	1.85	0.84	0.34	0.62	1.01	0.33	0.27	-0.06

The mean width of annual growth is not related to the length of the sequence; the longest sequence W4 contains the widest growth rings (1.9mm in average), whereas the narrowest average increments (1.36 mm) occur in the W2 sequence. High similarity between the growth patterns (Tab. 3) points out to similar growth-climate reactions.

Similar relations were obtained at analyses of the signature years and the response function. The main factors affecting the annual growth width are rainfall in the summer and temperatures of the winter and the beginning of the spring (Figs. 2, 3). High precipitations in the vegetation season (particularly in June and July) have a positive effect on the cambium activity. Similarly, mild temperatures of winter months, particularly February and March, positively affect growth in the forthcoming vegetation season. Meteorological conditions of the previous growth season also proved to be significant. High rainfall combined with not too high temperatures at the end of the previous vegetation season result in higher stores of assimilates and, in turn, better adaptation of trees for the approaching period of the rest and the next growth season.

Table 3: Convergence of spruce chronologies measured with „GI" and "t" value.

t/GI	**W2**	**W4**	**W6**	**W8**
W2	X	8.53	12.81	10.9
W4	71.4	X	6.58	3.8
W6	84.3	67.4	X	10.25
W8	83.1	61.5	84.6	X

Table 4: Signature years determined from sequences of spruce chronologies (positive years marked light grey; negative years marked dark grey).

YEAR	W2	W4	W6	W8	YEAR	W2	W4	W6	W8	YEAR	W2	W4	W6	W8
1910	+				1945	+				1975			-	
1911	-				1946				-	1976	-	-	-	-
1915	-				1947		-			1977	+		+	
1916	+				1948			-		1979			+	+
1917	-				1950	-		-	-	1980				+
1918	+				1951		-			1981		+	+	
1919	+				1953			-	-	1982		-		
1921	-				1954	-	-	-		1983		-	-	-
1923	+				1955	+		+	+	1984	-		+	+
1925	-				1957			+		1985			+	
1926	+	+			1958		-	-		1986				-
1927		-			1959				-	1987	+		+	+
1930	-				1960	+		+	+	1989				-
1932		+			1961				-	1990			-	
1934		-	-		1962			+		1991				+
1935	+				1963	-		-	-	1992	-		-	-
1936			+		1964			-		1993				+
1937			-		1965	+	+	+	+	1994				-
1938		-			1968			-	-	1995			+	
1939			+		1969			-		1997	+		+	+
1940			-		1970		+			2000	-	-	-	-
1943			-		1971			-		2001		+		
1944			+		1972	+		+		2003	-	-	-	-

Table 5: Results of response function analysis for spruce chronologies. Pearson correlation coefficients and multiple regression coefficients for air temperature and rainfall. Significant values for α = 0.05: (+) positive, (-) negative. Coefficient of determination for W2: r^2 = 50%, for W4: r^2 = 46%, for W6: r^2 = 52% and for W8: r^2 = 66%.

TEMPERATURE

	CORRELATION COEF.															
Lab. code	pVI	pVII	pVIII	pIX	pX	pXI	pXII	I	II	III	IV	V	VI	VII	VIII	IX
W2	+															
W4									+							
W6	+															
W8	+			-												

	REGRESSION COEF.															
Lab. code	pVI	pVII	pVIII	pIX	pX	pXI	pXII	I	II	III	IV	V	VI	VII	VIII	IX
W2	+	-							+					-		
W4				-					+	+						
W6		-		-					+	+		-	-	-		
W8	+	-	+	-					+							

PRECIPITATION

	CORRELATION COEF.															
Lab. code	pVI	pVII	pVIII	pIX	pX	pXI	pXII	I	II	III	IV	V	VI	VII	VIII	IX
W2									+				+			
W4			+					-	+					+		
W6			+						+							
W8									+			+	+	+		

	REGRESSION COEF.															
Lab. code	pVI	pVII	pVIII	pIX	pX	pXI	pXII	I	II	III	IV	V	VI	VII	VIII	IX
W2	+			+						+	+	+	+			
W4	+	+	+					-						+	-	
W6	+		+						+		+	+	+			
W8									+		+	+	+	+		

Discussion and summary of the results

The examined Norway spruce trees are characterized by high annual growth, mostly affected by the climatic conditions. The main factors are rainfall in the summer and thermal conditions of the winter. A deficiency of rainfall between April and July negatively affects the cambium activity, alike low temperatures in February and March.

Spruce trees growing in NE and S Poland (within their natural range) display similar relations growth-climate (Koprowski 2003, Koprowski & Zielski 2006). There, the factors determining the annual growth widths are rainfall in the period May-August and the temperature of March. The impact of the rainfall is increasing to the south, whereas the thermal conditions of the end of the winter and the beginning of the spring are crucial in the N and NE parts of the country (Koprowski 2003, Koprowski & Zielski 2006). Similar growth reactions to varying climate conditions are noticed on the Baltic Coast - in Lithuania (Vitas 2004) and in Germany (Eckstein et al. 1989). High air temperatures may be there an additional factor limiting growth.

Other coniferous tree species (Scots pine, Douglas fir, and common yew) growing in NW Poland slightly differ in growth reactions. The cambium activity of these tree species mostly depends on thermal conditions of the winter and the beginning of the spring, whereas high rainfall in the summer period is only an additional factor positively affecting the annual growth widths (Cedro 2004).

Both, current climatic conditions and the forest management support the proliferation of the Norway spruce in the European Lowland. Great adaptation possibilities, health and natural renovating may cause this tree species to occupy broader surface and be of higher economic importance in lowland terrains of Poland.

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Growth-climate relationships of high-elevation conifers in the central Hengduan Mountains, China

Fan, Z. & A. Bräuning

Institute of Geography, University of Erlangen-Nuremberg, Kochstr. 4/4, D-91054 Erlangen, Germany
Email: abraeuning@geographie.uni-erlangen.de

Introduction

The physiological mechanisms whereby climatic parameters are translated into radial growth variations are complex, because radial tree growth in any given year integrates the effects of climate conditions in prior years, site conditions and tree species (Fritts 1976). High elevation forests are particularly sensitive to climatic variability (Körner 1998). Predicting the impacts of global change on mountainous forests requires a more complete accounting of tree growth-climate interactions (Tessier et al. 1997). With an average elevation of above 4000 m a.s.l., the Tibetan Plateau is one of the most sensitive regions to climate change (Zheng 1996). The north-south oriented Hengduan Mountains form the southern rim of the Tibetan Plateau, and have a widespread forest cover and high potential for dendroclimatic studies. Dendroclimatological techniques were used to assess the effects of climatic variability on radial growth (ring width and density) of high-elevation conifers in the central Hengduan Mountains, southern, China.

Material and Methods

Study area and climate

The study area is located in the central Hengduan Mountain region, northwestern Yunnan Province, China (Fig. 1). The region’s climate is temperate, and it is influenced by the South Asian summer monsoon during June to September.

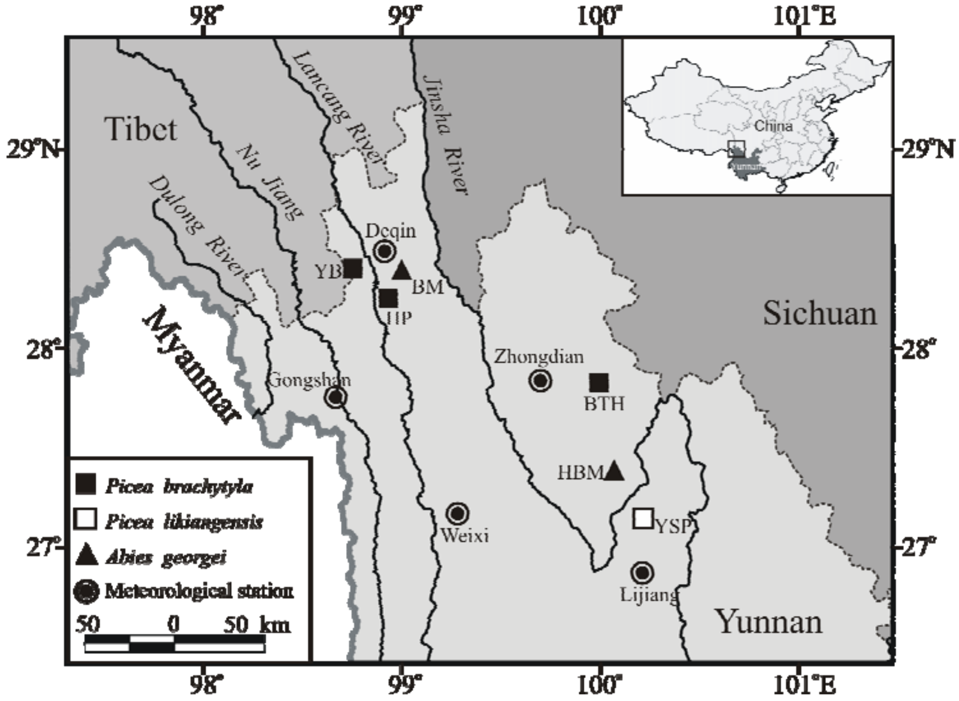

Figure 1: Map of tree-ring sites and meteorological stations in the central Hengduan Mountains.

According to the meteorological records from Zhongdian station (27.83°N, 98.76°E, 3 276 m a.s.l.), the annual total precipitation is 644 mm. Precipitation in the summer monsoon season (June to September) accounts for 73% of the annual total precipitation. Mean annual temperature is 5.8°C and the coldest and warmest months are January (-3.2°C) and July (13.5°C), respectively.

Tree-ring sampling and chronology development

Increment cores from living fir (*Abies georgei*) and spruce (*Picea brachytyla* and *P. likiangensis*) trees were collected from six high-elevation sites in the central Hengduan Mountains (Fig. 1). At each site, a minimum of fourteen trees were cored at breast height. In total, 244 cores from 166 trees were sampled (Tab. 1).

The cores were mounted on sample holders and the surface was prepared with sharp razor blades. Total ring-widths (TRW) were registered with a LINTAB II measuring system with a resolution of 0.01 mm, and all cores were cross-dated visually and statistical tests (sign-test and t-test) (Stokes & Smiley 1968, Rinn 1996). For the HP and BTH sites, maximum latewood density (MLD) measurements were further processed for cores with good wood quality (31cores/29trees for each site) by using the Lignostation densitometry system (Rinntech, Germany, Schinker et al. 2003). Relative density variations were measured along smoothed wood surfaces using a high-frequency dielectric scanner with a spatial resolution of 10 m.

Residual chronologies were calculated using program ARSTAN (Cook 1985). Prior to standardization, the variance was stabilized with a data-adaptive power transformation (Cook & Peters 1997). The tree-ring series were detrended by first adjusting a negative exponential or a linear regression function to the raw data, and then the resulting sequences were detrended with a cubic smoothing spline with a 50% frequency-response cut-off equal to 2/3 of the series length. Autoregressive modeling was used to remove persistence from TRW series since they contain high auto-correlations (Tab. 1), producing pre-whitened “residual” indices (Cook 1985). All detrended series were averaged to chronologies by computing the biweight robust mean in order to reduce the influence of outliers (Cook & Kairiukstis 1990). Variance stabilization (Osborn et al. 1997) was applied to adjust for changes in variance associated with declining sample size (number of trees) over time.

Table 1 Statistical characteristic of six tree-ring width and two maximum latewood density (bold) standard chronologies. ABGE, Abies georgei; PCBR, Picea brachytyla; PCLI, Picea likiangensis. AGR, average growth rate; SD, standard deviation; MS, mean sensitivity; AC1, first-order autocorrelation; R_{bt}, mean inter-series correlation; EPS, expressed population signal.

Site	Species	Elevation (m)	Cores (Trees)	Period	AGR (mm)	SD	MS	AC1	R_{bt}	EPS
BM	ABGE	4100	49 (24)	1651–1999	0.57	0.26	0.15	0.79	0.47	0.87
HBM	ABGE	3600	18 (14)	1760–2007	1.06	0.26	0.18	0.70	0.37	0.64
YB	PCBR	3280	15 (15)	1696–2003	1.25	0.24	0.17	0.71	0.39	0.66
HP	PCBR	3500	80 (51)	1688–2007	1.40	0.28	0.20	0.70	0.59	0.91
			31 (29)	**1724–2005**	**–**	**0.13**	**0.11**	**0.41**	**0.41**	**0.83**
BTH	PCBR	3580	50 (40)	1623–2007	0.81	0.23	0.15	0.65	0.48	0.87
			31 (29)	**1623–2006**	**–**	**0.14**	**0.11**	**0.49**	**0.46**	**0.85**
YSP	PCLI	3200	32 (22)	1641–2006	1.07	0.28	0.25	0.72	0.50	0.87

Climate-growth relationship

The meteorological stations in this region are sparse and generally located along the valleys. A regional meteorological data series was developed from monthly records of three meteorological high elevation stations (> 2400 m a.s.l.), named Deqin, Zhongdian and Lijiang (Fig. 1), by applying the techniques outlined by Jones & Hulme (1996). The meteorological records include monthly mean temperature (TEM) and precipitation sums (PRE), as well as minimum (T_{min}) and maximum temperature (T_{max}), and cover the period 1958-2004. Correlation analyses between individual chronologies (residual for TRW and standard for MLD) and regional climate variables were undertaken over the 1958–2004 period, using a 16-month window from July of the year prior to tree growth until the current-year October.

Correlation functions provide information about the average climate-tree growth relationship, however, the climatic forcing of single extreme years is not revealed (Schweingruber et al. 1990). The determination of pointer years and the climatic factors triggering extreme growth events can overcome this weakness of the correlation analysis. If the tree-ring width index in a given year is 1 standard deviation lower or higher than the mean, we consider that year as a negative (NPY) or positive (PPY) pointer year. Mean deviations of regional temperature (TEM, T_{max}, T_{min}) from their respective means were used to identify triggers for the NPYs and PPYs.

Results

Tree-ring Chronology statistics

The chronologies generally covered the last 200–350 years (Fig. 2). Most chronologies show a low mean sensitivity (MS) and high first-order autocorrelation (AC1), which is typical for conifers growing in humid environments (Tab. 1). Compared with the TRW chronologies, the MLD chronologies of *Picea brachytyla* at HP and BTH site usually display lower MS, standard deviations (SD) and AC1. The mean inter-series correlations (R_{bt}) range from 0.37 to 0.59, and expressed population signals (EPS) range from 0.64 to 0.91. The chronologies of HBM and YB contain less replications and show less common signals among trees; however the EPS statistics excess the commonly accepted 0.85 threshold (Wigley et al. 1984) after A.D. 1880 for HBM and A.D. 1780 for YB chronologies.

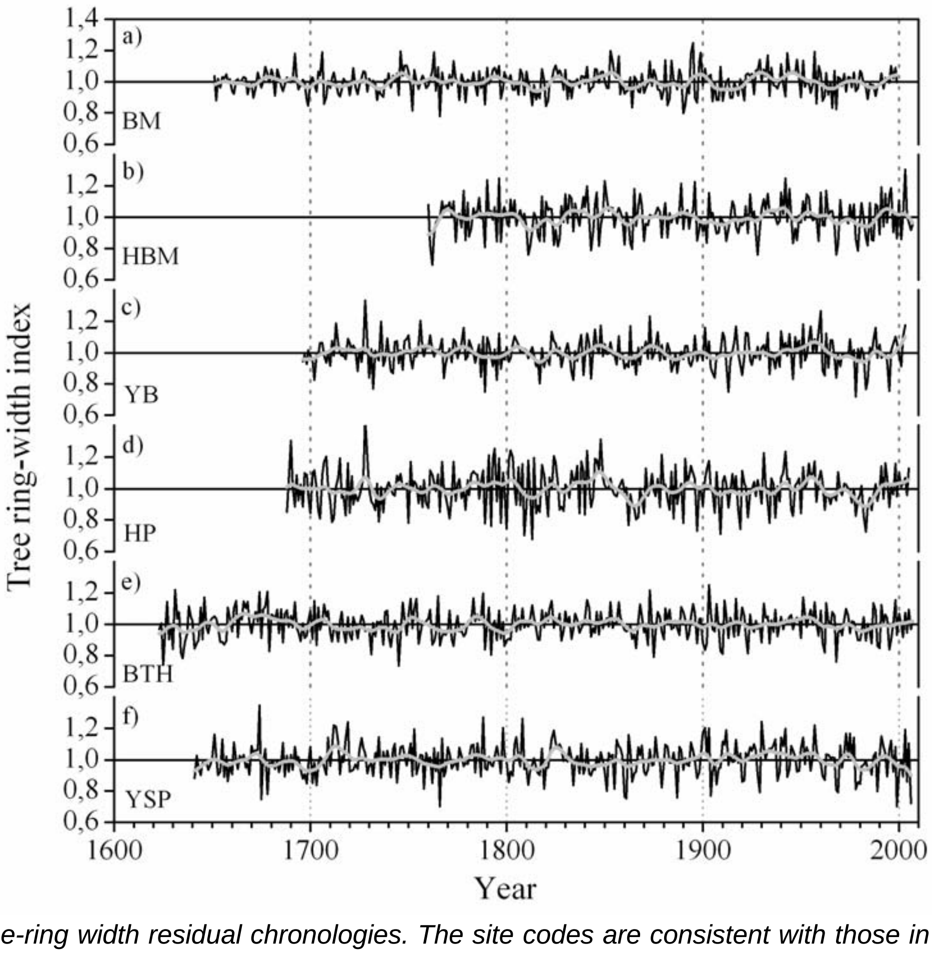

Figure 2 Six tree-ring width residual chronologies. The site codes are consistent with those in table 1. Tree-ring series are smoothed with a 15-year cubic spline (grey lines).

The six TRW chronologies correlate with each other significantly over their common period 1850–1999, with correlation coefficients ranging from 0.21 to 0.42 ($p < 0.05$). The principal component analysis for six TRW chronologies revealed that only the first principal component (PC#1) was significant (eigenvalue > 1) and account 40% of the total variance in the period 1850-1999. The factor loadings on PC#1 of the individual chronologies are similar and range from 0.51 for BM to 0.70 to BTH site. The common signals embodied in PC#1 are most likely reflecting regional climatic variability. Other growth components represented by PCs of higher order may reflect the species-specific growth reactions and growth responses to local site conditions.

Growth/climate response

Correlation analyses with regional climate data indicate that the radial growth rates are mainly influenced by temperature conditions, especially in the winter season (Fig.3). The influence of winter temperature on growth is more pronounced in the higher elevation site BM, but less significant at the lower site YSP. Warm summers generally stimulate growth. However, the growth responses to daily maximum (T_{max}) and minimum temperatures (T_{min}) are less consistent in the summer season than that during winter. High daily maximum temperature in August may increase the water deficit at some sites (i.e. HBM, HP, BTH), and rainfall in this season becomes more important (Fig. 3).

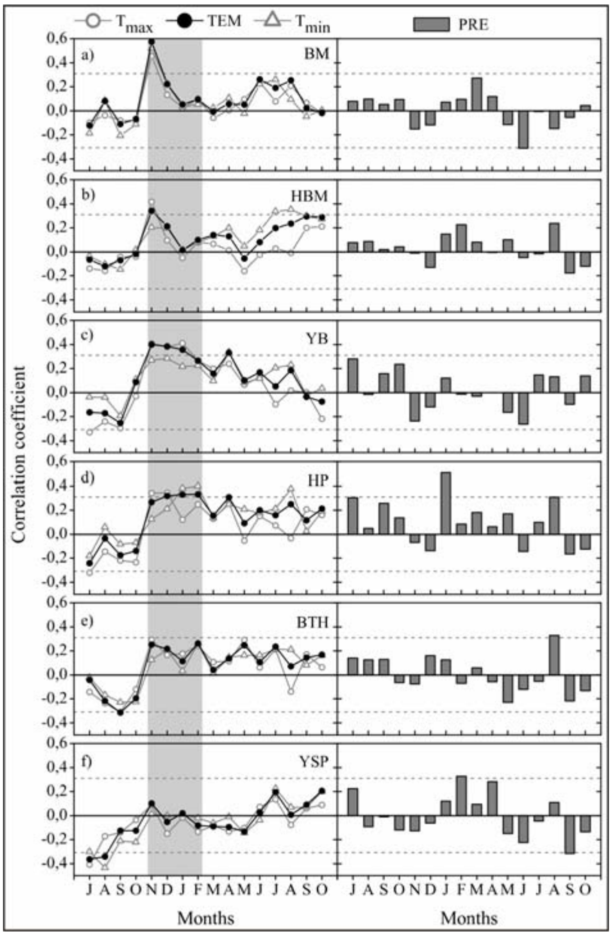

Figure 3: Correlation of six ring-width residual chronologies with regional mean climatic variables from previous year July to current year October over their common period 1958-2004. The horizontal dashed lines indicate the 95% significance level.

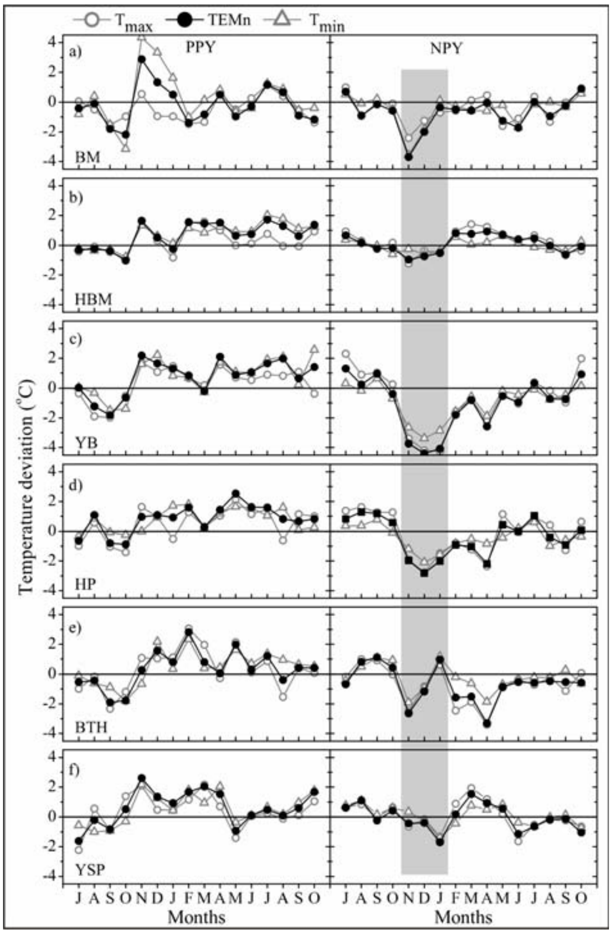

Figure 4: Mean deviations of regional temperatures (T_{max}, TEM and T_{min}) from their long-term mean for all the PPYs and NPYs of the six ring-width chronologies.

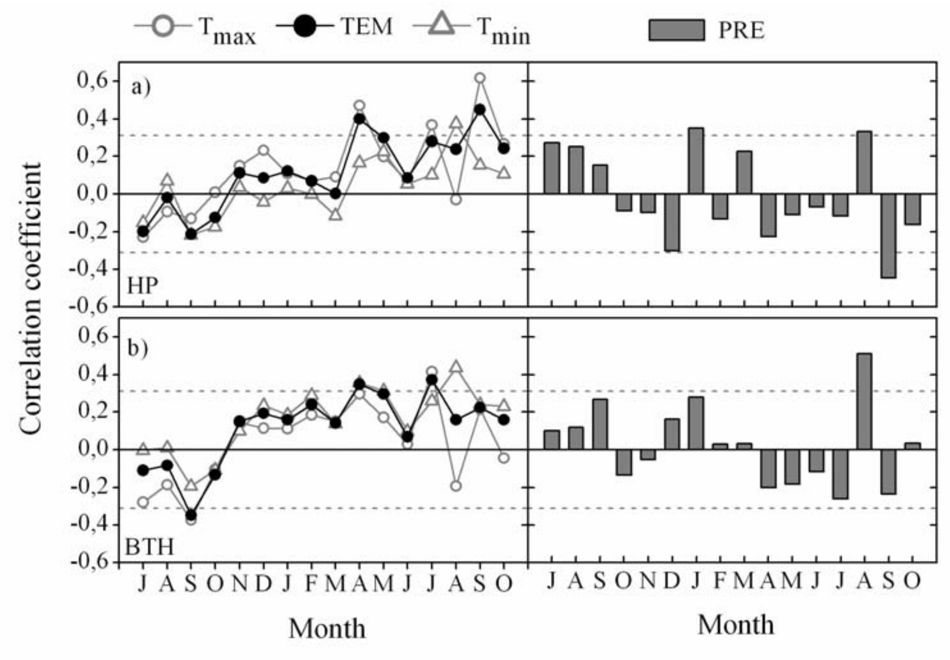

Figure 5 Correlation maximum latewood density standard chronologies at BTH (a) and HP (b) sites with regional temperatures (left; T_{max}, TEM, T_{min}) and precipitation (right, PRE) from previous July to current October over their common period 1958–2004. The horizontal dashed lines denote the 95% significance level.

Results from pointer-year analyses confirmed the growth-climate relationships indicated by correlation functions. PPYs and NPYs correspond with warm and cold winter conditions respectively, while the impact of cold winters on growth reductions is more predominant (Fig. 4). MLD correlates with the temperature variations in the warm season from April to September of the current growth year. Correlations between MLD and rainfall in the growing season are mostly negative and not significant, with the exception of August (Fig. 5).

Discussion

Winter temperature is one of the dominant controls on tree growth at timberline ecotone positions (Körner 1998). In the North Cascade Mountains, Peterson & Peterson (1994) found that growth of all four investigated species was positively correlated with the previous November temperature. Winter temperature has also been found to influence radial growth of tree species of Northeastern America (Pederson et al. 2004). Winter minimum temperatures (prior December to current February) are the most crucial factor limiting radial growth of Balfour spruce (*Picea balfouriana*) (Shao & Fan 1999) and some other coniferous species (Wu et al. 2006) in the west Sichuan Plateau. Similar growth-climate responses were also detected for Qilian juniper (*Juniperus przewalskii*) (Liang et al. 2006, Gou et al. 2007) and Qinghai spruce (*Picea crassifolia* Kom.) (Liang et al. 2006) growing the northeastern Tibetan Plateau. Others studies revealed a considerable winter temperature signal in the Qilian Mountains (Liu et al. 2004) and in the Dulan area (Kang et al. 1997, Liu et al. 2006), northeastern Tibetan Plateau, although spring moisture (May-July) is more important for tree growth in those dry areas (Li et al. 2008). Bräuning (2001) demonstrated that trees growing in the cold-moist environment near the upper treeline in eastern Tibet are mostly sensitive to temperature variations. Therefore, the growth-climate responses found in this study probably reflect a widespread growth-climate interaction close to the upper tree line in the Mountain areas around the eastern Tibetan Plateau and other mountain systems.

The positive influence of winter temperature on radial growth has been attributed to the increase of stem carbohydrate storages in a warm late autumn, thus enhancing earlywood growth in the following spring (Kang et al. 1997, Gou et al. 2007). Moreover, ring-width of high elevation conifers

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is often reduced by low winter temperature as a consequence of bud damage, frost desiccation and reduced root activity due to low soil temperature (Körner 1998). Defoliation and bud mortality would deplete an important pool of stored carbon and reduce a tree's potential for future growth and photosynthetic capture (Lazarus et al. 2004). In addition, after cold winters with delayed snow melt, the following vegetation period is shortened, which may lead to a reduced earlywood width in the following year (Bräuning 2001, Gou et al. 2007).

MLD chronologies show a consistent response to a wider window of warm season temperature (Fig. 5), which is consistent with various studies from boreal temperate zones (Schweingruber et al. 1993; Davi et al. 2003) and in subtropical mountain regions (Hughes 2001; Bräuning & Mantwill 2004). Latewood formation appears to benefit from photosynthate production and elevated hormone levels during the earlywood growth season (April-May). In conclusion, the wood parameters ring width and MLD might be usefully combined to reconstruct long-term variations in regions affected by summer and winter monsoon conditions (Bräuning 2001).

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On the potential of fir ring width data for summer drought reconstruction in southern Moravia, Czech Republic

Hoffmann, K.[1], Büntgen, U.[1], Kyncl, T.[2], Brázdil, R.[3] & J. Esper[1]

[1]Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland
[2]Dendro-Lab Brno, Eliásova 37, 616 00 Brno, Czech Republic
[3]Institute of Geography, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic
Email: buentgen@wsl.ch

Introduction

Low-elevation tree growth of central-eastern European forests is mainly controlled by fluctuations in growing season precipitation and drought (e.g., Breda et al. 2006). Despite the economic value and diversity of such lowland ecosystems and their large area covered, there are only a few dendroclimatological studies that assessed growth/climate response patterns with the final aim of reconstructing local- to regional-scale summer precipitation and/or drought variability. Brázdil et al. (2002) introduced a March-July precipitation reconstruction for southern Moravia (Czech Republic) covering the 1376-1996 period and using tree-ring width (TRW) measurements from living and historic fir (*Abies alba* Mill.) wood. Wilson et al. (2005) developed a near 500-year long reconstruction of March-August precipitation variability for the lower Bavarian Forest in southeast Germany. Most recently, Büntgen et al. (2008) estimated inter-annual to decadal-scale variability in regional summer drought for northern Slovakia back to the early 18th century and forward until 2006. Although all these studies generally revealed high correlations between the TRW proxy and climatic target data, a significant weakening in coherency was repeatedly found during the second half of the 20th century. Moreover, the preservation of lower-frequency information remained challenging due to the homogeneous age structure of the TRW series utilized and the standardization methods applied to remove their age related noise.

Herein, we present an updated fir TRW chronology (AD 1325-2007) that is representative for the wider region of southern Moravia (between Brno in the north and Vienna in the south). The compilation consists of TRW measurements from living trees collected at two new sites and the original composite introduced by Brázdil et al. (2002). Data were analyzed in order to obtain an improved understanding of high- to low-frequency growth variability and subsequently associated with regional-scale fluctuations in precipitation and drought. With respect to the original work by Brázdil et al. (2002), particular emphasize was placed on *i)* the low sample replication at the transition from historic to living material ~1800, *ii)* the records' early ending in 1996, *iii)* the limited preservation of low-frequency variability, and *iv)* the consideration of different climatic target data.

Data and Methods

Fir (*Abies alba* Mill.) TRW data from southern Moravia (Czech Republic) compiled from historical buildings and living trees in the 1990s (Brázdil et al. 2002) are re-considered and combined with an update of two fir sites (*Fir1, Fir2*) extending until 2007 (Fig. 1). The update of 105 core samples (38 in *Fir1*, 67 in *Fir2*) from living trees at elevations between 300-400 m asl was collected in southern Moravia (48-50°N, 15-17°E). Data of these sites extend back to 1794 (*Fir1*) and 1849 (*Fir2*), whereas the original composite chronology (*Comp*) including 145 samples from living and historic wood covers the AD 1325-1996 period.

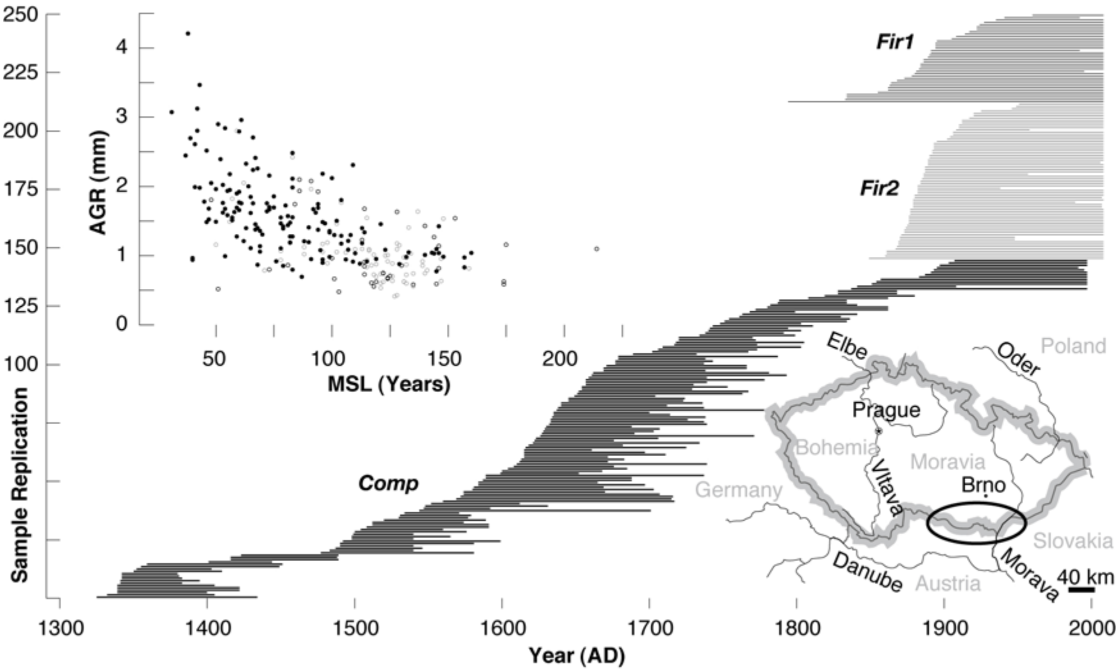

Figure 1: Temporal distribution of the 250 core samples split into the updated living (Fir1, Fir2) and original composite (Comp) sites. The upper left inset denotes the relationship between AGR and MSL of all measurement series (visually classified into the three subsets). The lower right inset shows the location of the sampling sites (circle) in southern Moravia, Czech Republic.

Due to the sample design, including living trees of different age-classes, average growth rate (AGR) is systematically decreasing with increasing mean segment length (MSL) (Fig. 1). MSL of *Fir1* is 120 years ranging from 48 to 214 years with an average growth rate of 1.05 mm/year (ranging from 0.5 to 2.1 mm/year). Similar values are obtained for *Fir2*: MSL is 115 years ranging from 50 to 159 years with an average growth rate of 1.04 mm/year (ranging from 0.4 to 2.8 mm/year). MSL of *Comp* is 81 years ranging from 31 to 160 years with an average growth rate of 1.6 mm/year (ranging from 0.7 to 4.2 mm/year). Replication at the two updated sites is decreasing back in time with the periods before 1868 (*Fir1*) and 1870 (*Fir2*) being covered by less than 10 samples. Due to the composition of material from living trees and historic wood sample replication of *Comp* is highest between AD 1500 and 1800 as well as during the 20th century. Lower replicated intervals were found during the 19th century and before ~1500.

For chronology development, TRW measurements of *Fir1* and *Fir2* were first cross-dated (via COFECHA) and then detrended (via ARSTAN) using 12 different standardization techniques. In order to preserve high-frequency, i.e. inter-annual to decadal-scale variability, TRW series were individually detrended using 32yr, 150yr and 300yr cubic smoothing splines, as well as negative exponential functions with and without applying power transformation (32/32PT, 150/150PT, 300/300PT, neg/negPT; Cook & Peters 1981, Cook & Peters 1997). Variations of the Regional Curve Standardization method (RCS; Esper et al. 2003), that is with and without applying power transformation and considering pith-offset estimates (RCS, RCSpo, RCSPT, RCSPTpo) were additionally used to retain potential longer-term trends in the resulting time-series. The same standardization methods were applied to *Comp*, thus creating 12 different chronologies per site. Comparison of these time-series on a site-by-site level allowed an assessment of the influence of the detrending technique on the common variance and spectral characteristics of mean chronologies, guiding towards the most appropriate proxy for growth/climate response analysis and subsequent reconstruction trials.

For calibration, monthly precipitation totals (CRUTS2.1; Mitchell & Jones 2005) and the self-calibrated Palmer Drought Severity Index (scPDSI; van der Schrier et al. 2006) selected from the 16 nearest 0.5x0.5° grid points located between 48-50°N and 15-17°E and covering the 1901-2002 period were employed as so-called target data. Figure 2 summarizes inter-annual to decadal-scale fluctuations of precipitation and scPDSI anomalies from the 20th century. While no long-term trend is found for precipitation, scPDSI slightly decreases towards present, likely caused by increasing temperatures. Correlations calculated between the 16 grid points are higher for precipitation than for scPDSI with mean values of 0.83 (ranging from 0.56 to 0.98) and 0.81 (ranging from 0.46 to 0.97), respectively.

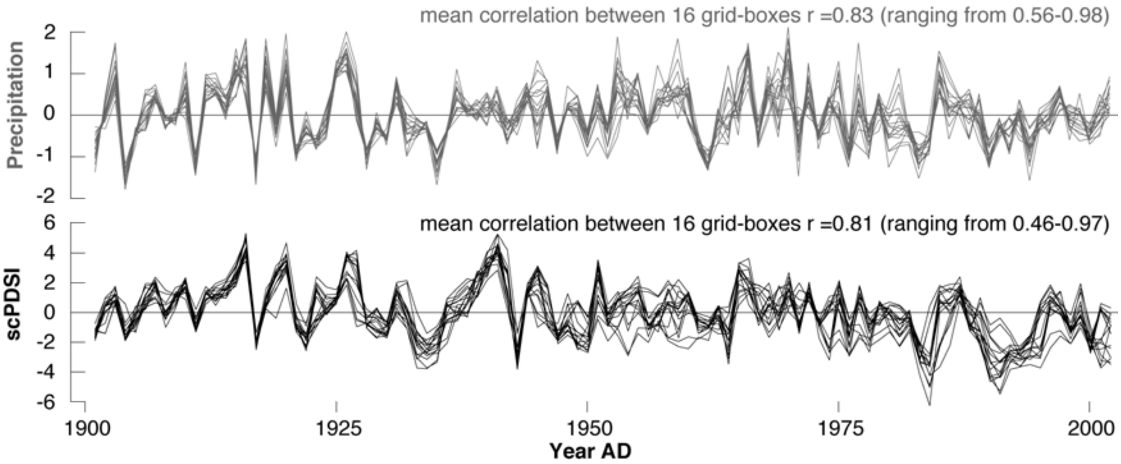

Figure 2: Course of 20th century precipitation and scPDSI anomalies (CRUTS2.1) derived from the 16 nearest 0.5x0.5° grid points (48-50°N and 15-17°E).

For growth/climate response analysis we developed a composite chronology based on all 250 TRW series (*Fir1*, *Fir2* and *Comp*) and using the 12 different detrending techniques as previously introduced. Furthermore, we selected precipitation and scPDSI data from the grid point closest to 48°25'N and 15°25'E. Correlations between proxy and target data were computed over a 20 months window from May of the previous year to December of the current year, plus nine seasonal means combining various months from April to October. Split 1901-1951/1952-2002 periods were considered to assess the temporal stability of the growth/climate relationships.

Results

The new site chronologies (*Fir1*, *Fir2*; after application of 12 different detrending techniques) are shown in Figure 3. 31yr moving standard deviations (STDEV) indicate an increased variance at the beginning and towards the end of the records with lowest inter-annual to decadal-scale variability observed from ~1870 until the 1970s. This is primarily related to the sample design of *Fir1* and *Fir2* using living trees only, i.e. replication decreases monotonically back in time. Assessment of the 12 chronologies revealed that high-frequency information is better preserved than low-frequency variability, a general finding independent of the standardization method applied. A similar pattern is evident for the various chronologies computed for the original composite site (*Comp*).

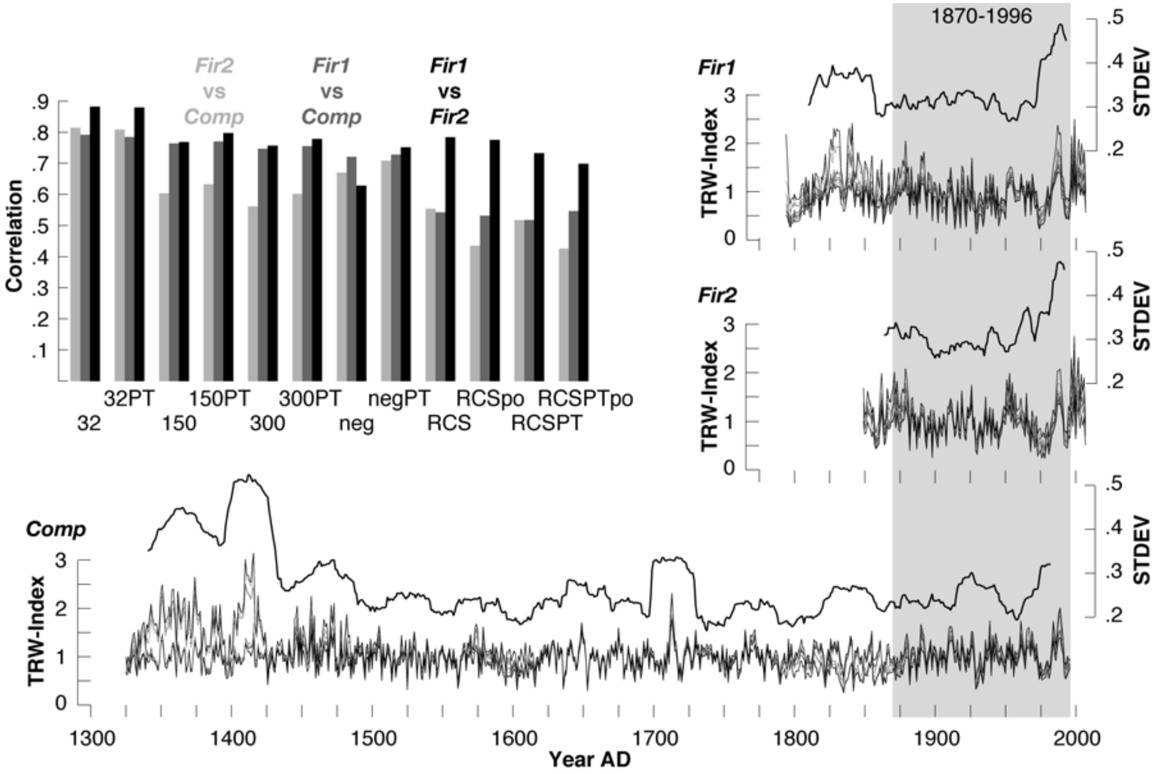

Figure 3: Comparison of the updated living (Fir1, Fir2) and original composite (Comp) chronologies using 12 different detrending techniques (grey curves), with their minimum and maximum values (black curves) describing detrending uncertainty. Upper black curves are 31yr moving standard deviations calculated between the individual time-series. The left inset shows correlations between the three site chronologies after different detrending.

Highest inter-site correlations were found between *Fir1* and *Fir2* independent of the standardization technique, with a mean value of 0.77 ranging from 0.63 (neg) to 0.88 (32) - calculated over the well-replicated 1870-1996 period (Fig. 3). There is a significant decrease of inter-site coherency after applying RCS, with mean correlations ranging from 0.56 (RCSPTpo) to 0.63 (RCS) and overall lowest values achieved for *Comp* versus *Fir1* and *Comp* versus *Fir2* (r_{min} =0.43 for *Comp* versus *Fir2* and RCSPTpo). On the contrary, mean inter-site correlation reaches its maximum after employing 32yr spline detrending (r_{mean} =0.83), thus, common variance between the three site compilations is most evident in the higher-frequency domain, whereas more noise is introduced by detrending techniques that allow longer-term trends to be preserved.

These results are supported by split period correlations ranging from 0.24 (*Comp* versus *Fir2* and RCSPTpo) to 0.90 (*Fir2* versus *Fir1* and 32PT) over the early 1870-1932 period, and from 0.56 (*Comp* versus *Fir2* and 150) to 0.87 (*Fir2* versus *Fir1* and 32) over the late period 1933-1996 (not shown in Fig. 3). Hence, inter-site correlations are less variable over the second half of the 20th century, where sample replication is generally higher.

According to the above results, we combined *Fir1*, *Fir2* and *Comp* to produce a single record based on 250 TRW series (Fig. 4). After applying the various detrending techniques as introduced above, fairly similar high-frequency variability was found for the mid 1500-1800 period as well as from ~1850 to present time, i.e. between-chronology offset over these periods is small. In contrast, detrending uncertainty appears to be most significant during the early period before AD 1500 and at the transition from historic to living material ~1800, where sample replication is low.

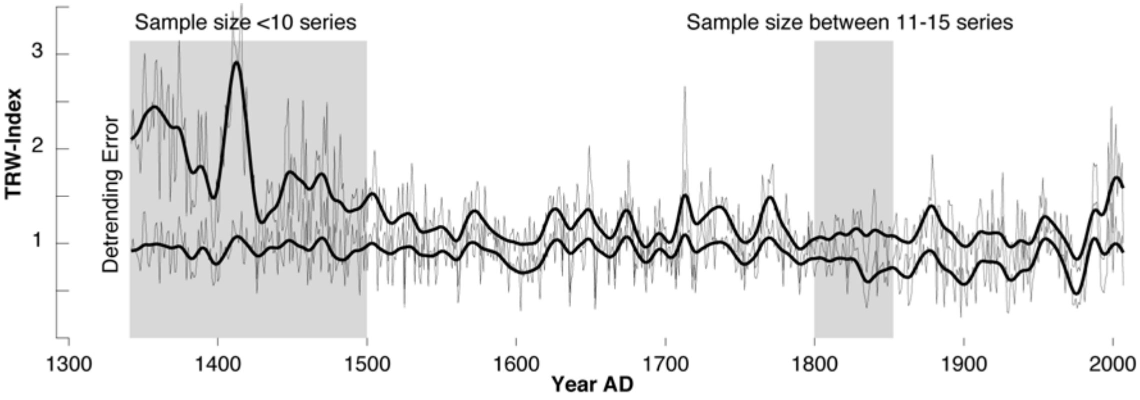

Figure 4: Composite chronology based on 250 TRW series. Thin curves indicate unfiltered and bold curves 20yr low-pass filtered detrending error derived from 12 different detrending techniques. Grey shadings denote early and late periods of low sample replication before AD 1500 and at the transition from historic to living material, respectively.

Comparison between the 12 composite TRW chronologies and monthly precipitation and scPDSI means (wrt. 1901-2002) reveals insignificant influence of previous year precipitation and drought conditions on radial growth (Fig. 5). Correlations are generally positive for the current year summer months May, June and July ranging from 0.14 to 0.38 for precipitation and from 0.16 to 0.43 for scPDSI. Overall highest correlations of 0.46 and 0.44 are found between the 32yr spline TRW chronology and May-July seasonal means of precipitation and scPDSI. Thus, summer precipitation conditions during the year of ring formation appear to be slightly more important for tree-ring growth than drought conditions. In addition, correlation results obtained with monthly scPDSI means are generally less variable than those received with precipitation, a feature inherent to PDSI calculation (Fig. 5; Dai et al. 2004).

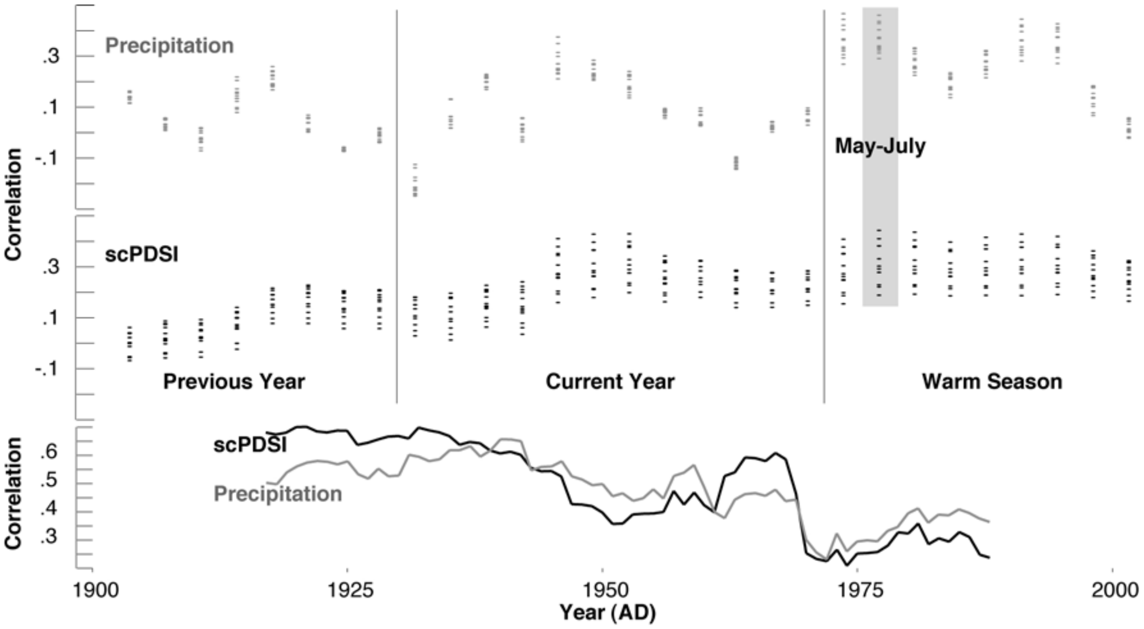

Figure 5: Correlation analysis (1901-2002) between the new composite chronologies based on 250 TRW series and 12 different detrendings, and precipitation as well as scPDSI data from the nearest 0.5x0.5° grid point (48°25'N/15°25'E) using monthly values from previous year May to current year December and various warm season means. Lower panel shows moving 31yr correlation between the TRW proxy (after 32yr spline detrending) and climatic targets.

31yr moving window correlations gathered for the 32yr spline TRW chronology and May-July warm season means of climatic target data (1901-2002) indicate that precipitation and drought conditions have varying effects on radial growth during the first and the second half of the 20th century suggesting temporal instability in the proxy/target relationship (Fig. 5). While the 31yr running correlations between the TRW proxy and precipitation/scPDSI data are fairly robust over the early 1901-1951 period (r_{mean} =0.56/0.67), those from the late period 1952-2002 show lower and more variable values. Stepwise decreases with both precipitation and drought anomalies occurring ~1950 and even more abrupt ~1970 result in mean correlations of 0.44 and 0.41 for precipitation and scPDSI data during the second half of the 20th century. When referring to the whole period 1901-2002, temporal correlation changes appear to be larger for precipitation than for scPDSI.

Discussion

The TRW data collected at two fir sites in southern Moravia (*Fir1*, *Fir2*) allowed us to update the original composite dataset (*Comp*) detailed in Brázdil et al. (2002) until 2007. However, sample replication at the critical transition from historical to living material ~1800 was not increased substantially, since MSL at both new fir sites did not exceed 120 years.

Furthermore, we did not find evidence that tree growth is closer associated to scPDSI than precipitation data.

Referring to the inter-site correlation results obtained for the two updated and the original composite chronologies after applying 12 different standardization techniques, potential longer-term trends in radial growth were hardly preserved as various RCS detrendings led to overall lowest correlation coefficients. However, highest correlations and thus most robust common variance between the three TRW data compilations were achieved for 32yr spline chronologies. Accordingly, the new composite chronologies compiled from 250 TRW series and the application of 12 different detrending methods mainly reflect inter-annual to decadal-scale variations. In particular, one must conclude from the growth/climate response analysis performed over the 1901-2002 period that the 32yr spline TRW chronology contains the overall strongest summer precipitation and drought signal.

One key finding of our study is the temporal instability in the growth/climate relationship over the 20th century, which is most obvious in the correlation results derived from 32yr spline TRW and May-July precipitation and scPDSI data. As already reported by Brázdil et al. (2002), the abrupt decrease in proxy/target coherency ~1950 and even more significant ~1970 might be primarily related to regional atmospheric pollution in central-eastern European states during the 1970s. In this regard, further research is required in order to identify the dominant factors triggering the observed temporal instability in growth responses to climate of low elevation fir forests across southern Moravia. Regardless of a weakening in coherency between the 32yr spline TRW and May-July precipitation and scPDSI data during the second half of the 20th century, enhanced agreement, however, was found during the early 1901-1951 period demonstrating some skill of the new fir TRW composite chronology for reconstructing high- to mid-frequency variations in summer precipitation/drought dynamics of the central-eastern European lowlands.

Conclusion

Based on a collection of 250 TRW series of low elevation fir (*Abies alba* Mill.) from southern Moravia (Czech Republic), a new composite TRW chronology covering the period 1325-2007 was developed. Growth/climate response analyses performed over the 20th century revealed the ability of inter-annual to decadal-scale variations in fir TRW to reflect common signals of regional-scale precipitation and drought variability. While proxy/target coherency is strong during the early 1901-1951 period, low coherency is found during the second half of the past century and particularly after ~1970.

Acknowledgements

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Impact of climatic variation on growth and wood density of young short rotation poplar trees

Olivar, J., Duncker, Ph. & H. Spiecker

Institute for Forest Growth, Albert-Ludwigs-Universität Freiburg, Tennenbacherstr. 4, D-79106 Freiburg Germany
Email: jorge.olivar.ruiz@gmail.com

Introduction

An increased interest in renewable energy requires sound information on options for increasing biomass production. Fast growing short rotation plantation may contribute to the renewable energy supply. Climate scenarios indicate significant warming, greater in winter in the North and in summer in southern and central Europe. Mean annual precipitation is projected to increase in the North and decrease in the South (IPCC Fourth Assessment Report 2007). Drought conditions as a consequence of high air temperature and low precipitation rate may reduce tree growth. In short rotation production, growth variation caused by climatic changes may lead to high fluctuation in biomass supply. Clones of the same species might react differently, both in radial increment as well as in wood density formation.

Climate is the most important external factor affecting wood features such as radial increment and wood density on a relatively short period of time. Apart from natural or artificial events decreasing competition from neighbors, the activity of the cambium and the periodic formation of the wood are mostly influenced by these climatic features. Information about a variety of environmental factors is yielded in the width, density and chemical composition of the rings (Fritts 1976, Schweingruber 1988). Summer 2003 was exceptionally hot and dry over Western Europe. On an average value, the hottest place was centred over a region stretching from France to Northern Italy, Western Switzerland and Germany (Rebetez et al. 2004). Apart from some other problems, this summer drought had a high impact on tree growth and wood density, thus affecting the annual biomass production. Short rotation plantations were strongly affected by this decrease in biomass production as they have less time to recover before harvest.

Besides fibre production, short-rotation forestry is done in order to provide wood to meet the energy markets demands while taking into account the environmental issue. In the light of the enhanced greenhouse effect and the depletion of fossil fuels, short-rotation tree cropping or short-rotation forestry has gained more interest as a source of renewable energy, not only because of its high biomass production, but also for the possibility of carbon sequestration, substitution of fossil fuels, a positive impact on biodiversity, nutrient capture, and carbon circulation in the soil–plant atmosphere system (Perttu, 1995). Where poplar plantations replace row cropping, additional benefits such as water quality and greater floral diversity are improved (Stanturf et al. 2001).

Consequently, the product of a short-rotation, intensive culture plantation should not only be considered to be the biomass in its raw state, but more appropriately be considered in terms of the potential energy yield and the yield of the chemicals to be produced from the biomass. The objective of the present study was to analyze the potential of the annual radial increment and the dielectric constant of the wood as short-term indicators of climate effects on tree growth of poplar species and possible differences in in contrasting sites, clones and years.

Material and Methods

Material

The study area was composed by two short-rotation hybrid poplar clonal trials, Methau II and Thammenhain, established in the region of Saxony (Germany). Both sites are surrounded by former farms and set-aside areas. Poplar species (*Populus* sp.) are typically selected for this kind of short-rotation plantations due to their fast growing behaviour since the beginning of the 90s in Germany.

Both study sites, Methau II (11.5 ha) and Thammenhain (13.4 ha), have quite similar site characteristics. The trees were planted in 1999 and harvested in 2005 after a 6 years rotation time. Air temperature and precipitation data from Methau and Koellitsch meteorological stations provided by the "Sächsische Landesanstalt für Landwirtschaft" prove the extreme arid conditions in summer 2003. According to the Bagnouls-Gaussen Index, months having the ratio between monthly sum of precipitation and mean air temperature of less than two are defined as dry or arid months. This is the case when the grey line for temperature is above the black bar for precipitation in Figure 1. The extreme conditions are even some more pronounced on site Thammenhain than on site Methau II.

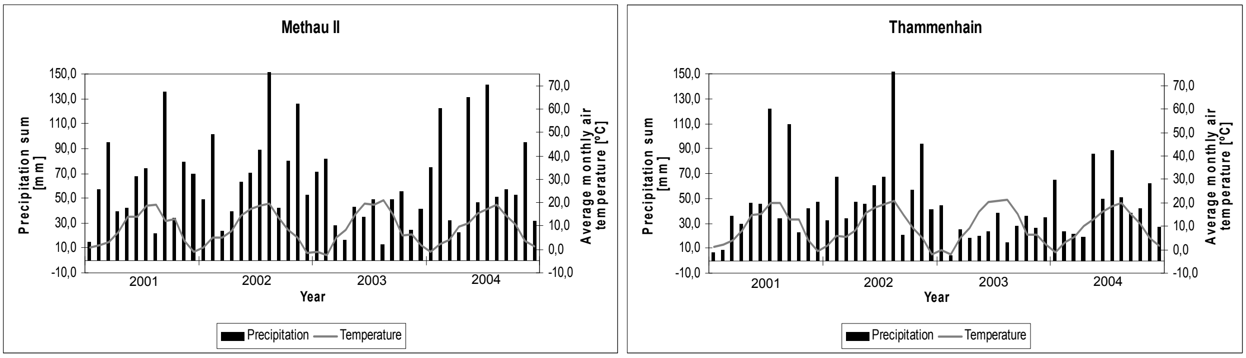

Figure 1: Climograph of Methau II and Thammenhain sites

The data set for the present study consisted of 20 cross-sectional stem discs extracted at the stem height of 1.3 m (breast height) from the trunk of 20 randomly selected young poplar trees. The selected trees were harvested in 5 replicates per clone (Androscoggin and Max 4) and site (Methau II and Thammenhain) after a 6 years rotation (1999-2005) by the felling time.

The pith was included in the annual rings corresponding to the years 1999 and 2000, which impeded proper annual radial increment and dielectric constant of the wood measurements. In addition, harvesting was done during the vegetation period. Due to these limitations, the data belonging to these years were excluded for further analysis. The study was carried out considering the study period from 2001 to 2004.

Methods

The samples were prepared with the diamond tool flycutter (Spiecker et al. 2000) and the measurements of the annual tree radial increment and the dielectric constant of the wood were carried out with the high-frequency densitometer. Based on the propagation of continuous electromagnetic waves, the dielectric properties of the wood are measured to indicate relative density variations along wood surfaces in high-frequency densitometry. The wood surface is in direct contact with a high-frequency transmitter-receiver link of an extremely small electrode system designed as a slit-shaped probe, which is placed at the tip of a steel conical shaped cylinder. The slit-shaped high-frequency probe has to be perpendicularly oriented to the scan direction (Schinker et al. 2003).

Without a wood specimen in position, the space of the electrode system is air-filled with a relative dielectric constant of 1.00059, whereas wood has a relative dielectric constant in the range of 2 to 6 (Torgovnikov 1990). Based on this principle, a high-frequency transmitting electrode and a receiving one, hermetically shielded from each other to prevent mutual interference and very close and parallel oriented, are the main part of the high-frequency probe (Schinker et al. 2003).

Moving along the radius of a cross section, the silt of the high-frequency probe receives a signal that may reach several milli-Volts (mV). This voltage is higher in latewood than in earlywood because of its higher local relative dielectric constant. The dielectric behavior of the wood structure is directly influenced by wood density, caused by differences between cell wall to air-filled cell lumens (Schinker et al. 2003). It should be emphasized that the obtained signals are not yet calibrated to density values in Poplar species. For absolute wood density measurements, each measuring system (probe-transmitter-receiver) needs to be calibrated with standards.

For the statistical analysis of the data, the analysis of variance, often abbreviated ANOVA, was found as the most appropriated for testing differences among groups of samples. The underlying assumptions of normal distribution (Kolmogorov–Smirnov test) and homogeneity of variances (Levene's test) were checked to verify the validity of the parametric ANOVA test for the present sample. If at least one of the assumptions is not fulfilled, then the differences among groups must be tested with a non-parametric test. In the present sample, the annual radial increment data followed a non- parametric distribution of the data, while the dielectric constant of the wood had a parametric distribution.

Differences in in contrasting sites, clones and years were examined in both tree ring features. Possible differences between the two studied sites and clones were tested by the Wilcoxon test for comparison of pairs and annual differences by non-parametric multiple comparisons. The parametric t-test and the Tukey test were carried out in the case of the annual radial increment.

Results

The annual radial increment and the dielectric constant of the wood were analyzed with high-frequency densitometrical methods and possible differences in in contrasting sites, clones and years were defined. Both wood features were afterwards compared to the precipitation and the temperature data of the study period in order to meet possible correlations.

Annual radial increment

The mean annual radial increment measured was 10.4 mm with a range from 20.4 mm to 2.1 mm. The inter-annual patterns and the distribution of the data are shown in figure 2.

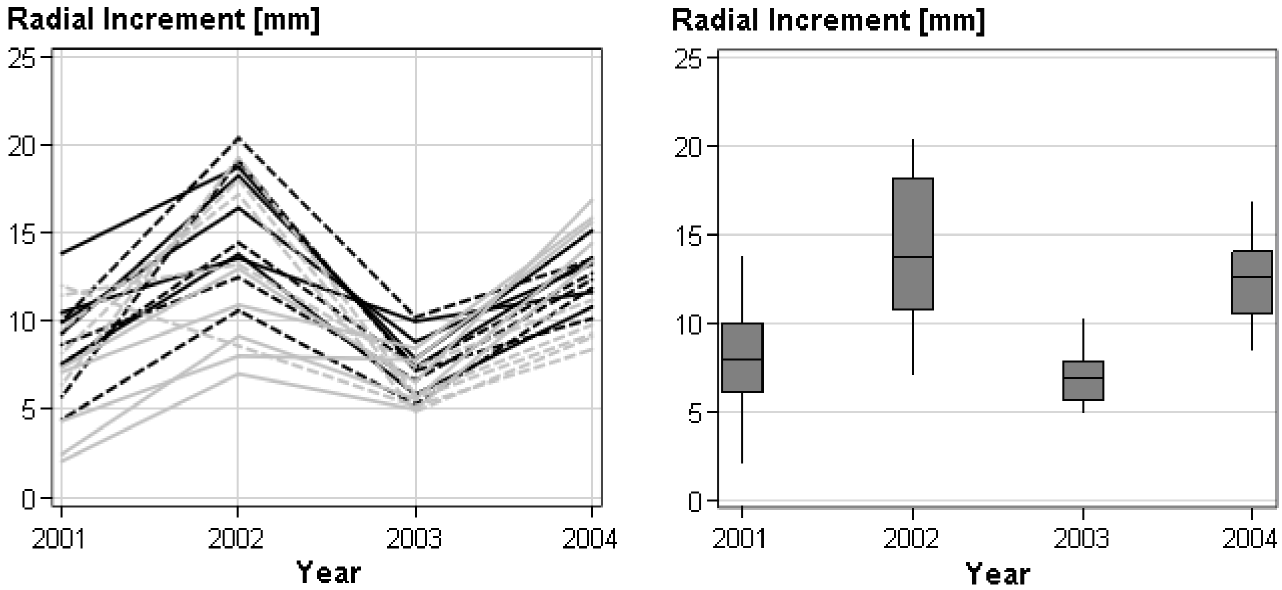

Figure 2: Annual radial increment values of each sample. Solid line = Methau II site. Dotted line = Thammenhain site. Black line = Androscoggin clone. Grey line = Max 4 clone.

As it can be observed in figure 2, the values of the annual radial increment decreased remarkably in the year 2003 (6.9 mm) as compared to 14.1 and 12.5 mm in 2002 and 2004 respectively. The relative small growth in year 2001 might be due to the short period after the cuttings were put into the ground. The root system as well as the leaves may have not yet been well developed. In the right graphic, the distribution of the values is visualized in box plots. The annual radial increment values were afterwards compared on a site, clone or year basis.

As the significance level of the Wilcoxon test was above the limit in both site and clone comparisons, thus the null hypothesis of no significant differences between the values of the annual radial increment according to sites and clones was to be accepted. However, in the case of the annual comparison, this condition was fulfilled in 2 cases (2002 vs. 2004 and 2001 vs. 2003). It can thus be concluded that the data of the years 2001 and 2003 had similar annual radial increment values and that they differed significantly from the annual radial increment values in the years 2002 and 2004.

The inter-annual pattern of the annual radial increment on the period between the years 2001 and 2004 was strongly correlated to the annual rainfall of the study period (Pearson's correlation coefficient = 0.87), but not to the mean annual temperature (Pearson's correlation coefficient = 0.14). It must be highlighted that annual ring width data are also influenced by previous climatic events.

Dielectric constant of the wood

The analysis of the dielectric constant of the wood was carried out in a parallel way to the previously done for the annual radial increment. The inter-annual patterns and the distribution of the values are shown in figure 3.

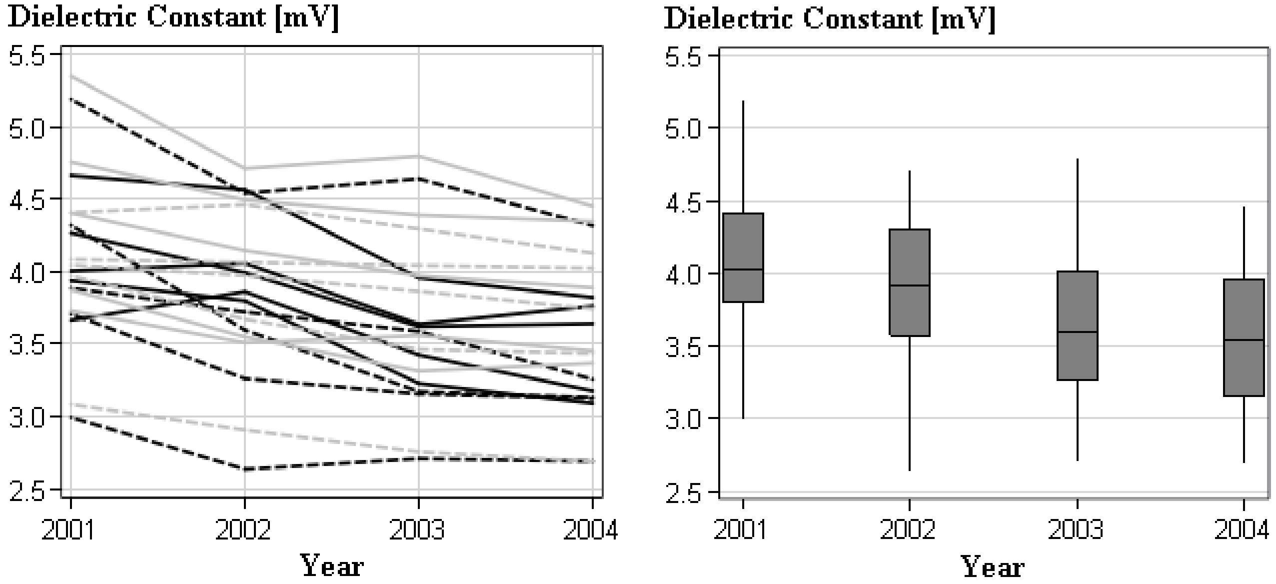

Figure 3: Annual dielectric constant of the wood (ε) values of each sample. Solid line = Methau II site. Dotted line = Thammenhain site. Black line = Androscoggin clone. Grey line = Max 4 clone .

It can be observed in figure 3 that the values of the dielectric constant of the wood decreased with increasing cambial age in the selected trees. As previous studies (i.e. Schinker 2003) demonstrated that, assuming wood moisture to be constant, there is a linear relation between the dielectric constant of the wood and wood density, it can be concluded that, in the study sample, wood density was negatively related to radial growth rate as indicated by annual radial increment. It could also be interpreted as an indicator of a decrease on wood density from pith to bark. A general trend of decreasing density with increasing cambial age can be observed in figure 4. The values of the dielectric constant of the wood were standarised to 100 relative intra-annual positions for a better analysis of the data.

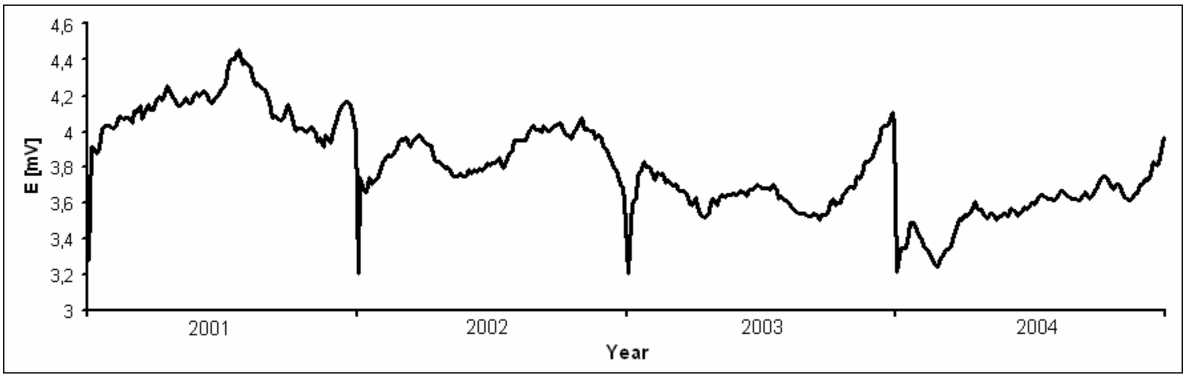

Figure 4: Intra-annual pattern of the dielectric constant of the wood (ε)

For a more detailed analysis, the intra-annual pattern of 2003, when the extreme drought period occurred, was compared to the mean intra-annual pattern of the study sample. Both patterns differ remarkably. Results can be observed in figure 5.

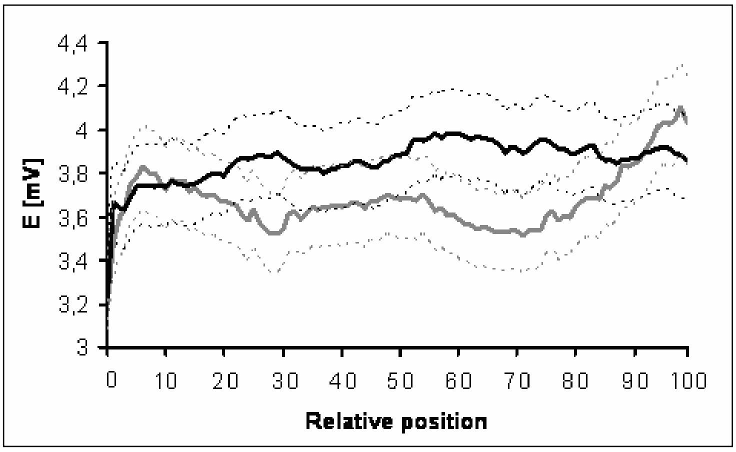

Figure 5: Intra-annual comparison between 2003 (grey line) and the mean intra-annual pattern of the study sample (black line). The dashed lines indicate the standard errors of the mean.

It can be observed how the values of the dielectric constant of the wood were lower than the mean, specially at the central part of the vegetation period. The values of the dielectric constant of the wood were also compared on a site, clone or year basis. The parametric T-test comparison of pairs and the Tukey test were applied and, in all cases, significance levels were lower than the limit. Therefore, significant differences in the mean values of the dielectric constant of the wood were defined in site, clone and year variables.

The inter-annual values of the dielectric constant of the wood were not related to the annual rainfall (Pearson's correlation coefficient = 0.26) or the mean annual temperature (Pearson's correlation coefficient = 0.27) on the study sample. The dielectric constant of the wood decreased gradually along the years of the study period, apparently not influenced by changes in the annual rainfall or the temperature.

Discussion

In general, individual tree growth in natural temperate forests is limited more by disturbance and competition for light and other resources than by climate (Orwig and Abrams 1997). However, trees growing under humid conditions typical of short-rotation forestry plantations may still retain a strong climatic signal, especially during drought years when available soil moisture may be limiting to tree growth.

Tree-ring patterns from arid sites have been shown to be climatically sensitive, or more strongly limited by precipitation (Fritts 1976), whereas radial increments from high altitude trees have been correlated with temperature variables (LeMarche 1982). Despite these confounding factors, several trends became apparent in the ring-width response to droughts examined in this study.

No significant differences in annual radial increment in variables site, clone were defined. Only the inter-annual differences were proved to be statistically significant. The data of the years 2001 and 2003 showed significantly different values of the annual radial increment than the years 2002 and 2004, following a similar pattern to the annual rainfall.

The dielectric constant of the wood data followed a similar intra-annual pattern to the wood density. The lowest values were measured at the end of the winter period. These values were gradually increasing along the vegetation period and reaching its maximum at the end of it, before the latewood production. Moreover, this general pattern becomes clearer in some species than in others. Generally it becomes more apparent in softwood species than in hardwood species.

On the other hand, the inter-annual pattern of the dielectric constant of the wood followed a rather uniform decreasing pattern with increasing ring growth rate in the study sample. These findings confirm those of previous reports of other researchers (i.e. Schinker et al. 2003) and corroborates the idea of a linear relation between the dielectric constant of the wood and the wood density, both decreasing if measured on a radial direction from pith to bark, with no clear impacts from the summer drought on 2003. Moreover, the negative correlation between both parameters in the selected group of trees showed a low relation coefficient ($r = 0.1225$). If compared to climatic data, the values did not seem to be related to any of the studied climatic features (annual rainfall and mean annual temperature) on the study period (2001 to 2004) (compare Fig. 6).

As it is well known, annual ring features are widely used for climatic reconstruction. Temperature and precipitation seem to influence wood features the most. However, it was found that wood density is less sensitive to temperature and precipitation variations. It, on the contrary, is a more sensitive parameter for stress effect of UV-B radiation on coniferous (especially cedar) trees. Therefore, this parameter is commonly chosen as a predictor of total ozone and UV-B radiation (Zuev and Bondarenko 1992). Wood density may be affected by factors other than those which affect tree radial increment and may be more sensitive to environmental changes.

The estimation of the above ground biomass production reveals a considerable decrease in 2003 as compared to the mean annual increment pattern of the period of time between 2001 and 2004. In general terms, Androscoggin clone was more productive in Methau II site, while Max 4 clone was more productive in Thammenhain site. However, stand density data must be taken into account. The annual biomass production was, apparently, more affected by the changes of the annual radial increment than by the changes in the wood density, as it was considered to have rather constant values along the 4 years of the study. Therefore, the decrease in biomass production in the year 2003 might be interpreted as a consequence of the decrease of the radial increment, more strongly influenced by the attenuation of precipitation than by temperature.

Conclusions

The annual radial increment showed its potential as short-term indicator of climate effects on tree growth and impacts on biomass production, while the dielectric constant of the wood appeared to be less sensitive to temperature and precipitation variations. It can be observed on the general pattern of the annual radial increment that greater radial increment reductions were associated with drought periods, having the lowest value in the year 2003, when the extreme drought period occurred. High-frequency densitometry proved to be successful in permitting the assessment of climate variation impacts on growth and wood density of young poplars. The approach used in this study of examining short-term climate responses of young poplar species on contrasting sites, clones and years would appear to be an important first step in understanding and anticipating responses to future climate change.

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Pinus peuce and *Pinus heldreichii* tree rings as a key to past mountain climate in Southeastern Europe

Panayotov, M.[1,2], Bebi, P.[1], Krumm, F.[1] & S. Yurukov[2]

[1] WSL Institute for Snow and Avalanche Research SLF, Davos
[2] University of Forestry, Sofia, Bulgaria
Email: mp2@abv.bg

Introduction

High mountain ecosystems are among the most sensitive to environmental changes (Lloyd 1997, Körner 1998, Moiseev 2002, Camarrero & Guitierrez 2003, Esper & Schweingruber 2004). This is one of the reasons, why many studies on climate and climate change have been focused on treeline forests. For this purpose among the frequently used research methods are dendroecological (Fritts 1976, Schweinguber 1996, Briffa et al. 2001). They are based on the fact, that tree ring formation is strongly dependent on environmental factors and especially on the varying temperature and precipitation (Fritts 1976). Trees in high mountains are growing at limiting temperatures and thus are very sensitive to general variation of temperatures and extreme climate events (Fritts 1976, Tranquillini 1979, Schweingruber 1996, Frank et al. 2005). This, together with the fact that once formed, tree rings do not change with time, makes tree-ring chronologies a “natural archive”, containing information on past climate and historical development of individual sites. In the last decades numerous proxy climate reconstructions based on treeline sites from high elevation and northern environments, have been created for various parts of the world (e.g., Briffa 2000, Esper et al. 2002, Cook et al. 2004, D’Arrigo et al. 2006). Yet, there are still regions, which are particularly important from ecological and climatic point of view, for which long tree-ring chronologies have not been constructed or are scarce. One of these is the Balkan peninsula. Despite its great importance as a border between the Mediterranean and Central European climate zones and the existence of numerous centuries-old forests (Griffiths et al. 2004), still only few attempts to construct long tree-ring chronologies from high mountains have been made (Vakarelov et. al. 2001, Panayotov & Yurukov 2007a, b, Popa & Kern 2008).

The objective of the present report is to present and discuss two tree-ring chronologies from a high mountain location in Pirin Mountains, Southwestern Bulgaria. One is a 655 years long series from Bosnian pine (*Pinus heldreichii* Christ) and the other is a 305 years long series from Macedonian pine (*Pinus peuce* Griseb.). The study sites are located at the same valley, but on opposite slopes. This enables the simultaneous analysis of chronologies composed of trees that are subject to different micro-site conditions, but to the same general climate variability. Despite the long life span of the species and the very suitable locations of the forests for dendro-climatic studies, only few attempts to construct and analyze tree-ring chronologies have been made up to now (Vakarelov et. al. 2001, Panayotov & Yurukov 2007a, b). Also, some of the conclusions for certain time periods based on them are not consistent with each other. Thus, in order to enable the use of these species for proxy climate reconstructions, a necessary step is to study carefully trees’ response to the climate elements especially in the context of micro-site conditions. We present the first simultaneous analysis of the reaction of *Pinus heldreichii* and *Pinus peuce* trees growing at close locations to the same temperature and precipitation regime.

Material and methods

The study area is situated in Bunderitca valley in the Pirin Mountains, Bulgaria, 41˚45′ N, 23˚26′ E (Fig. 1). The *Pinus peuce* trees are located on the North-Western slope of Todorka peak in the treeline belt (2100-2300 m a.s.l.). The *Pinus heldreichii* trees are on the Eastern slope of Vihren peak, from 1950 m to 2200 m a.s.l. Since the slopes are steep and hardly accessible, the forests

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have not been subjected to intensive logging or deliberate firing by shepherds in the past. Thus, these ecosystems can be regarded as natural. According to the Oliver & Larson (1990) classification, the forests are at the old-growth stage. The *Pinus peuce* trees grow on Umbric and Modic Cambisols formed on granite bedrock, while the *Pinus heldreichii* grow on Rendzic Leptosols and Regosols formed on marble bedrock.

Figure 1: Geographic position of the study area

The climate data for the analysis was obtained from Bansko (936 m a.s.l.) and Vihren chalet (1970 m a.s.l.) climate stations. The first one is at the foot of the mountain, 10 km off the study area and provides continuous record for more than 70 years (since 1931). The second is in the study valley, but operated for duration of just 25 years and therefore the record is useful mainly for average data and precise information about extreme climate situations. The climate in the region is typically mountainous, with strong influence of the Mediterranean air masses. The mean annual temperature (Vihren chalet climate station, 1970 m a.s.l.) is 3.5°C. It ranges from a mean monthly temperature of -4.7°C in January to +12.2°C in August. The annual temperature at the treeline, obtained by extrapolation, is 1.6°C, the highest average monthly temperature is 10.2°C. This coincides with the expected values of nearly 10°C in the warmest month at the treeline (Tranquillini 1979, Dakov et al. 1980, Körner 1998). The annual precipitation amounts to 1378 mm, with a maximum in autumn and winter. Deep snow covers are characteristic for the region. Mention deserves the fact that the absolute maximum snow depth for Bulgaria (472 cm) was recorded at the Vihren chalet station. At the same time the summer precipitation minimum combined with shallow soil profiles on steep rocky sites might cause local drought conditions on sites with Eastern and Southern exposure (Panayotov & Yurukov 2007b).

Cores were collected with increment borer at breast height (1.3 m) from 25 to 27 dominant trees that were not affected by avalanches or rock-fall. Tree ring widths were measured in the dendrochronology laboratory at the University of Forestry in Sofia following standard procedures. Rings with specific anatomic features (e.g. “early and latewood frost rings”, “light rings”, “kallus formation”, “rings with reaction wood”) were recorded, photographed and encoded with numbers to facilitate statistical analysis. Obtained tree-ring width series were crossdated with the use of visual clues (Stokes & Smiley 1968) and the computer program COFECHA (Holmes 1983). Then the data was standardized with the software package ARSTAN (Cook 1985) using modified exponential and linear functions. The final chronologies were composed by calculating bi-weighted robust means of annual ring widths. This, as well as the calculation of standard descriptive parameters was performed with the ARTSAN software.

We also used a *Pinus heldreichii* chronology from treeline location in the Olympus mountains in Greece (Schweingruber 1981) in order to calibrate the reliability of our chronology. We used a portion of it with a replication of more than 4 series. The length is 372 years (AD 1609-1981), the maximum number of series – 30.

The *Pinus peuce* chronology was visually compared with a previously published one (Vakarelov et al. 2001) due to un-availability of the original data series. The comparison reveals general synchronous variability, which is expected having in mind the proximity of locations (Panayotov & Yurukov 2007a).

The analysis of the climate-growth relationship was performed with DENDROCLIM2002 software using average monthly temperatures and precipitation sums for months from June of the year prior to growth to September of the current year. The software uses 1000 bootstrapped samples to compute response and correlation coefficients, and to test their significance at the 0.05 level. Median correlation and response coefficients are deemed significant if they exceed, in absolute value, half the difference between the 97.5-th quantile and the 2.5-th quantile of the 1000 estimates (Biondi & Waikul 2004).

Results and Discussion

The *Pinus peuce* chronology consists of cores from 27 trees and has a length of 305 years (AD 1700-2004). Longer series were truncated at that year to avoid low replication. The oldest found *Pinus peuce* tree had 614 tree rings. The mean tree ring width is 0.114 mm, the mean standard deviation of tree ring width is 0.040, the autocorrelation (1-st) is 0.771 and the mean sensitivity is 0.175 (for more details about the *Pinus peuce* chronology, see Panayotov & Yurukov 2007a).

The *Pinus heldreichii* chronology is based on the dataset of Panayotov & Yurukov (2007b) but has been additionally improved by adding samples. It consists of cores from 25 trees and is with length of 655 years (AD 1350-2004). The oldest found *Pinus heldreichii* tree had 762 tree rings. The mean tree ring width is 0.091 mm, the mean standard deviation of tree ring width is 0.037, the autocorrelation (1-st) is 0.772 and the mean sensitivity is 0.195. The minimum number of used series is 4.

The comparison between our *Pinus heldreichii* chronology and the one from Greece reveals high correlation - 0.508 ($p<0.001$). Pointer years coincide, which is a sign of chronology reliability . This also reveals similar climate influence on the trees at both sites. Having in mind the closeness of the mountain ranges and their presence in the same climate region, this is expected.

The correlation analysis between the *Pinus peuce* chronology (Fig.2.) and the climate data from Bansko shows statistically significant positive influence on growth by temperatures from beginning and end of previous vegetation season (June and October) and the respective summer (June) (Fig. 3.). Influence of high precipitation during the growth period is negative. This is most probably due to the negative relationship between precipitation and temperature values (Correlation of average June-August monthly temperatures to precipitation sums is -0.52, $p\leq0.05$), especially in years with extremely high precipitation in summer, such as 1940, 1947, 1949, 1959, 1976, 1983, 1989, 1995 and 2002.

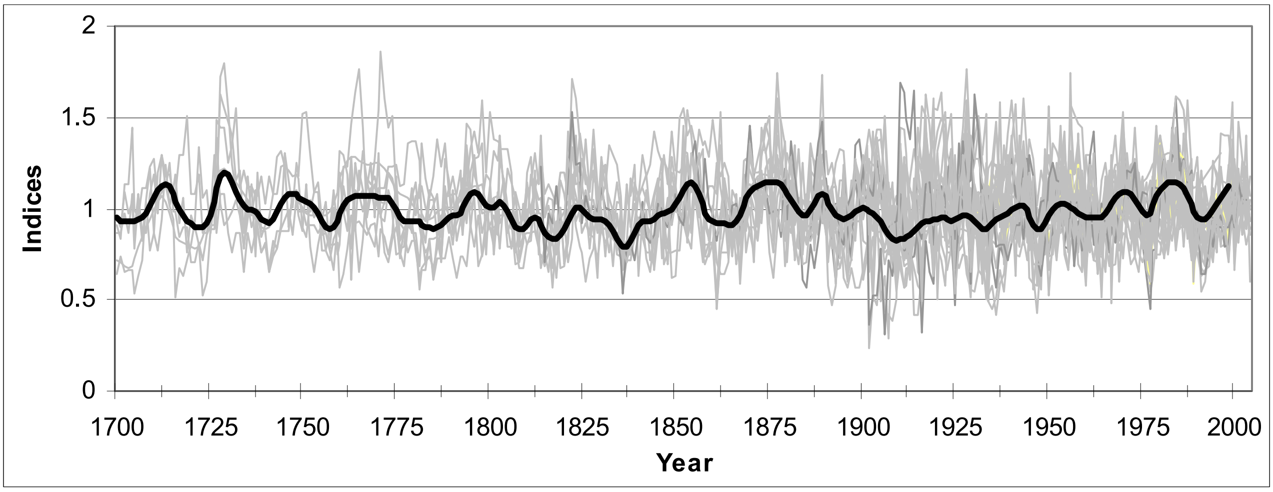

Figure 2: Tree ring chronology from Pinus peuce Griseb., Pirin Mts., Bulgaria. The chronology is presented as 13-year low-passed series.

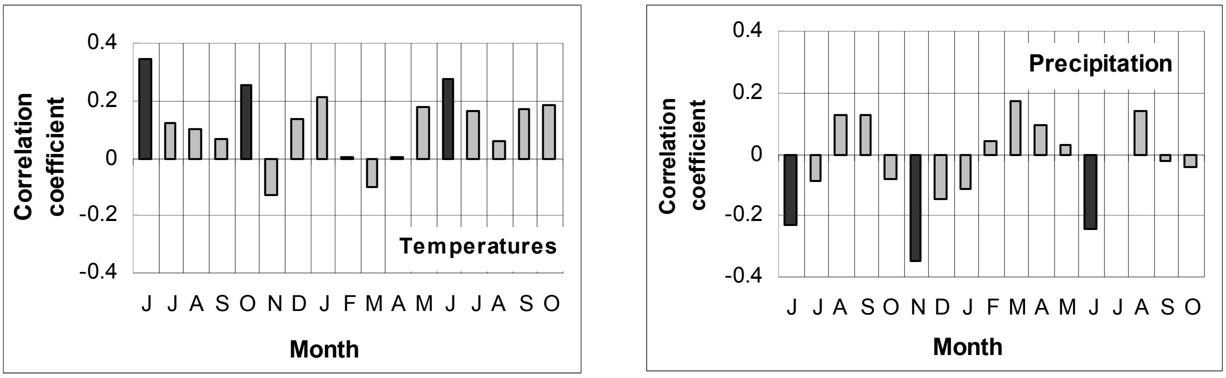

Figure 3: Correlation coefficients for the tree growth – climate relationship of the Pinus peuce chronology. Statistically significant values are marked with black rectangles.

The correlation analysis between the *Pinus heldreichii* chronology (Fig. 4.) and the climate data shows statistically significant negative influence on growth by temperatures of previous and the respective summer (Fig. 5.). Influence of precipitation in the typical summer months is positive.

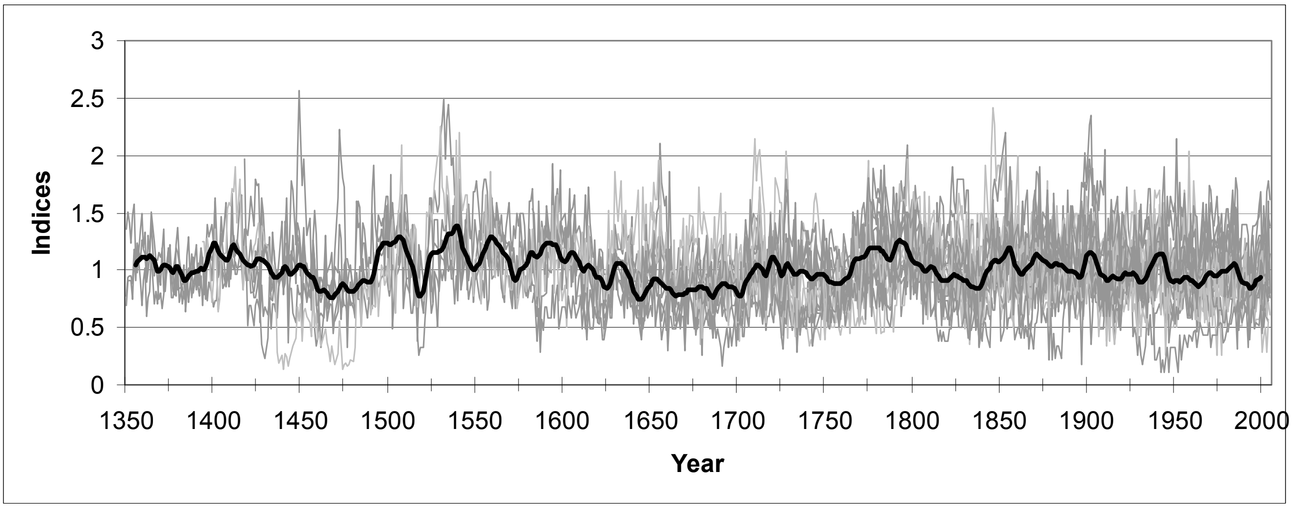

Figure 4: Tree ring chronology from Pinus heldreichii Christ, Pirin Mts., Bulgaria. The chronology is presented as 13-year low-passed series.

The results for the climate-growth relationships demonstrate that although the trees of the two species grow at the treeline in the same valley, they have different reaction to summer precipitation and temperatures. The *Pinus peuce* have the expected reaction for high-mountain site, e.g. limiting influence of summer temperature regime (Fritts 1976). The *Pinus heldreichii* trees react negatively to situations with high temperatures and low precipitation. This demonstrates that even at treeline, the trees are very sensitive to local drought conditions. This is explainable by the extremely steep rocky site, on which the trees are growing and the consequent quick drying of the shallow soil profile in precipitation-free periods. Yet, a climate-growth correlation analysis alone might be misleading in the understanding of tree's reaction to specific climate conditions. Therefore we have also chosen to review the pointer years in both chronologies and to compare them to the climate records for verification. Such analysis reveals that both species have years in which they have reacted in a similar way (e.g. 2000, 1999, 1986, 1970, 1963, 1956, 1946-47, 1938, 1934 in the past century), and years in which they have opposite reactions (e.g. 1993, 1992, 1989, 1987, 1978, 1977, 1976, 1973, 1971, 1958, 1957).

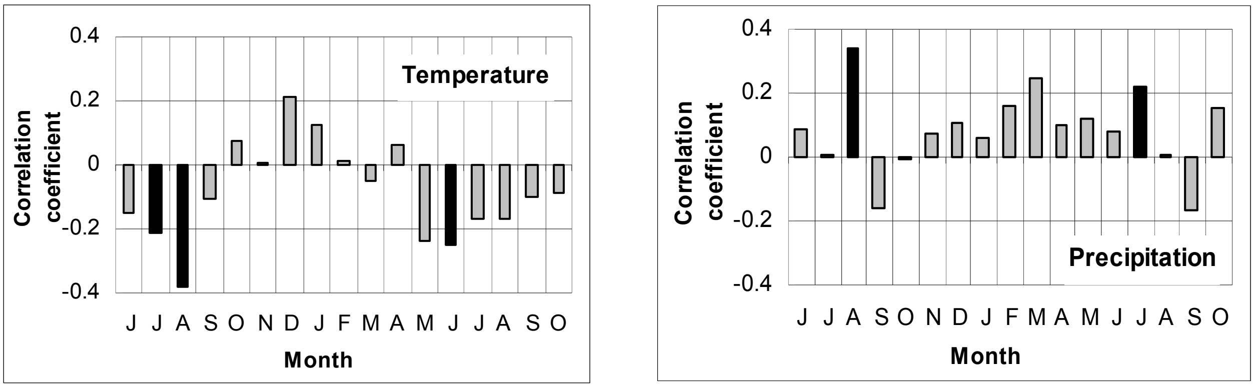

Figure 5: Correlation coefficients for the tree growth – climate relationship of the Pinus heldreichii. Statistically significant values are marked with black rectangles.

The review of the years, in which the trees have reacted in a similar way, reveals two general situations. The first, in which the formed tree rings were wider than the average, the summers were with high or normal temperatures and in the same time with normal precipitation (e.g. 1999, 1986, 1970, 1956). In some of these cases winter and early-spring precipitation was higher than the average. Most of the years, in which both species formed narrow tree rings, were years with very dry July or August (e.g. 2000, 1963, 1938), generally very dry years (e.g. 1946-1947) or years with very cold preceding summer (1934). This demonstrates, that *Pinus peuce* trees although growing at treeline on shady sites also might experience growth problems in years with lack of summer moisture (Panayotov & Yurukov 2007a). As discussed the *Pinus heldreichii* reaction in such years is explainable by the micro-site soil conditions.

The review of the years with opposite reactions reveals two major situations. The first is when *Pinus peuce* trees form narrow tree rings while *Pinus heldreichii* form wide or close to the average. These years are characterized with cold vegetation period, often with higher than normal precipitation (e.g. 1989, 1976, 1971) or with unusually cold previous summer or autumn (e.g. 1992, 1977, 1973, 1971). In some of these years the trees have also formed “light rings”. They are more typical for *Pinus peuce* and are clear markers for unusually cold summers like 1933 and especially 1976 (Panayotov and Yurukov, 2007a). Such reaction is typical for trees, which grow at high altitudes or latitudes (Filion et al. 1986; Gindl 1999; Hantemirov et al. 2004).

Years, in which the *Pinus heldreichii* trees have formed narrow tree rings while the *Pinus peuce* have formed wide or close to the average tree rings are characterized by unusually dry beginning of the summer – June or May (e.g. 1993, 1987, 1978, 1958). This is an additional indication of the importance of local micro-site conditions for the *P. heldreichii* trees. While a drought in July and

August could affect both species, since the moisture reserves in the soils have been exhausted, a precipitation-free period in June could affect only trees that grow on very thin soils with low water-holding capacity and with limited capacity to store the winter moisture reserves for continuous periods. Such reaction is also explainable by the regional climate in Pirin Mountains range. For the Mediterranean climate it is typical to have high precipitation in autumn and winter and low during summer. Since the mountains serve as a climate barrier for the Mediterranean air masses, they are strongly affected by this regime. In terms of climate-growth analysis, this is of high importance since it demonstrates that climate data from other nearby stations, which are less influenced by the Mediterranean climate, should be used very carefully.

Conclusions

The presented results show that *Pinus peuce* and *Pinus heldreichii* trees from Pirin Mountains demonstrate mixed climate signals and are influenced by both low summer temperatures and periods with low precipitation. This means that direct climate reconstructions should be performed only after considering the chance to have pointer years, that might be due to an opposite climate situation. At the same time gives the chance to obtain precise data for past periods with both, extremely dry or cold summers. Such data is scarce for the region, but of great importance. We consider that a proxy record like this can be obtained by simultaneous analysis of chronologies of both species. Therefore it is necessary to improve the existing datasets by adding new series, which is about to be done.

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Negative pointer years from Central European tree-rings caused by circulation patterns

Schultz, J., Neuwirth, B., Winiger, M. & J. Löffler

University of Bonn, Department of Geography, Bonn, Germany
Email: schultz@giub.uni-bonn.de

Introduction

Analyses in temperate Central European forests show only moderate coherency between tree-ring growth and temperature and precipitation (Bonn 1998, Lebourgeois et al. 2004), Water availability seems to be the primary growth-limiting factor for all Central European tree species (Friedrichs et al. 2008b). All climatic factors are controlled by the large-scale circulation, which can be described by a classification primarily introduced by Hess & Brezowsky 1952 (Gerstengarbe & Werner 2005). In total 29 weather regime types, the so called Großwetterlagen (GWL), are divided.

To get a better understanding of the climatic triggering of the detected spatial patterns of growth variations in Central European tree rings (Neuwirth 2005; Neuwirth et al. 2007) this study investigates in a first step the relations between the GWL and extreme growth events. Therefore pointer years for the period 1900 to 1976 will be derived from a tree-ring width network of 373 dendrochronological sites from Central Europe (area between 5° to 15° E and 42.5° to 52.5° N). In a deductive approach the Central European master plot will be compared with GWL anomalies on an interannual scale. Single year analyses of all detected negative pointer years yield to an explanation of the growth anomalies by specific GWL combinations.

Tree-ring data

The study is based on a tree-ring network of 373 sites across Central Europe (Fig. 1a). The dendrochronological network, introduced by Neuwirth (2005), and amplified by following studies of the dendrochronological group in Bonn (Friedrichs et al. 2009, Schultz et al. 2008), represents the ecological spectrum of Central European forest communities.

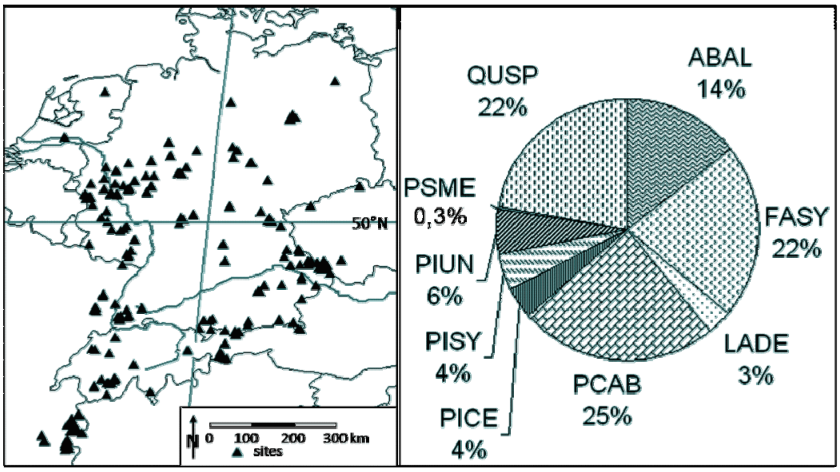

Figure 1: Spatial distribution of the dendrochronological sites and rates of the different tree species.

The investigation includes following species: fir (*Abies alba*, ABAL), beech (*Fagus sylvatica*, FASY), douglas fir (*Pseudotsuga menziesii*, PSME), larch (*Larix deciduas*, LADE), mountain pine (*Pinus uncinata*, PIUN), oak (*Quercus species*, QUSP), spruce (*Picea abies*, PCAB), Scots pine (*Pinus sylvestris*, PISY), and Swiss stone pine (*Pinus cembra*, PICE).

The unequal spreading of tree species portions illustrated in Fig. 1b is mainly caused by the native distribution of tree species in Central Europe. For all dendrochronological sites, the tree-ring width chronologies cover at least the period from 1894 to 1982. A site consists of about 12 dominant trees.

GWL data

The GWL dataset goes back to 1881 and has got a daily resolution. The 29 GWL can be grouped into ten synoptic types which represent the basic flow directions over the North Atlantic and Central European continent (Gerstengarbe & Werner 2005). Each GWL is combined with different air masses and, consequently, different characteristics in terms of temperature and moisture (Bissoli 2001). The weather conditions for one GWL are not homogeneous. So it is always a spatial pattern regarding the weather condition, which is modified by the topography and the changing tracks of the anticyclones and cyclones. Furthermore the spatial weather condition pattern for one GWL shows differences over the four seasons. The short cuts for the 29 GWL are cited at the end of this paper.

Methods

The raw tree-ring width series for each site were checked with TSAPWin (Rinn 2005) and Cofecha (Holmes 1983). Pointer years were calculated according to Cropper (1979) for the period from 1900 to 1976. A 13-year moving average was used to calculate the filter curve and to compute ratios between raw tree-ring width series and the filter curve. The 373 sites were averaged to cropper site series and a z-transformation was carried out to make the different sites comparable. Based on the 373 z-transformed cropper series a master plot was built. A classification of the pointer years yields to weak pointer years, if their index values are below -0.6. Values below -0.75 are defined as strong negative pointer years, and values below -1.0 as extreme negative pointer years. After coding, the GWL data for each GWL monthly sums were calculated. These sums are called monthly GWL sums (MGS). Additionally for every GWL monthly GWL means (MGM) for period from 1900 to 1976 were computed. To calculate monthly GWL anomalies the MGM were subtracted from the MGS. To calculate yearly GWL anomalies the absolute values of the monthly GWL anomalies were added up.

Results

For the time period from 1900 to 1976 seven years could be classified as pointer years (1901, 1929, 1930, 1934, 1948, 1956, and 1976), the years 1929 and 1976 were strong negative pointer years and 1948 was an extreme negative pointer year. The comparison between the master plot and the yearly GWL anomalies in days (Fig 2) shows nearly no synchronicity pattern on an annual scale.

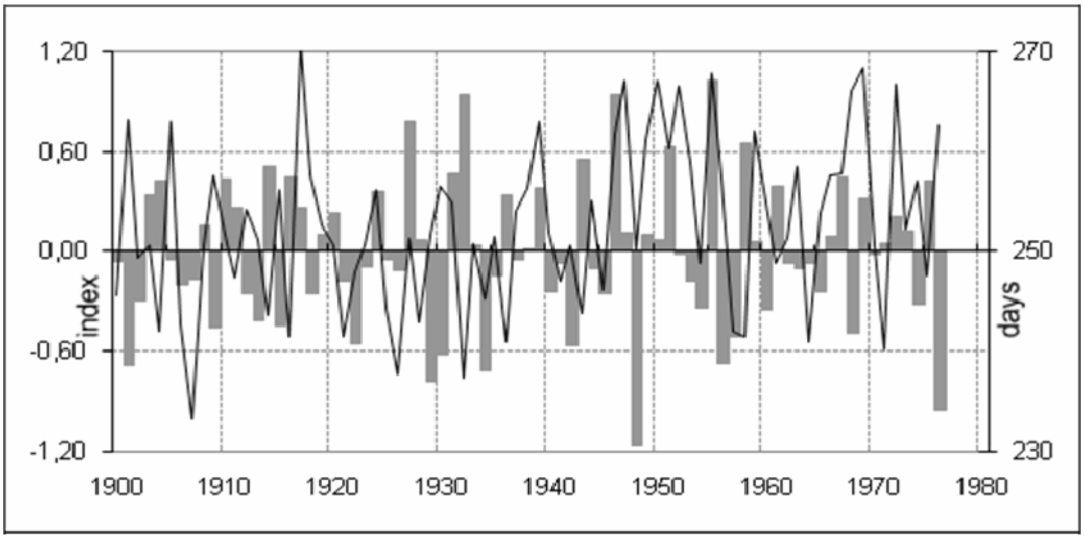

Figure 2: Master plot (grey bars) and the GWL anomalies (black line) in days from 1900 to 1980.

For example the year 1955, which has the highest index value, the numbers of GWL anomalies are also high, but for 1976 we find the opposite situation: a high GWL anomaly corresponds with a strong negative pointer year (low index value) and therefore with narrow tree rings in Central Europe. 1948, the year with the smallest tree rings, shows nearly no GWL anomalies.

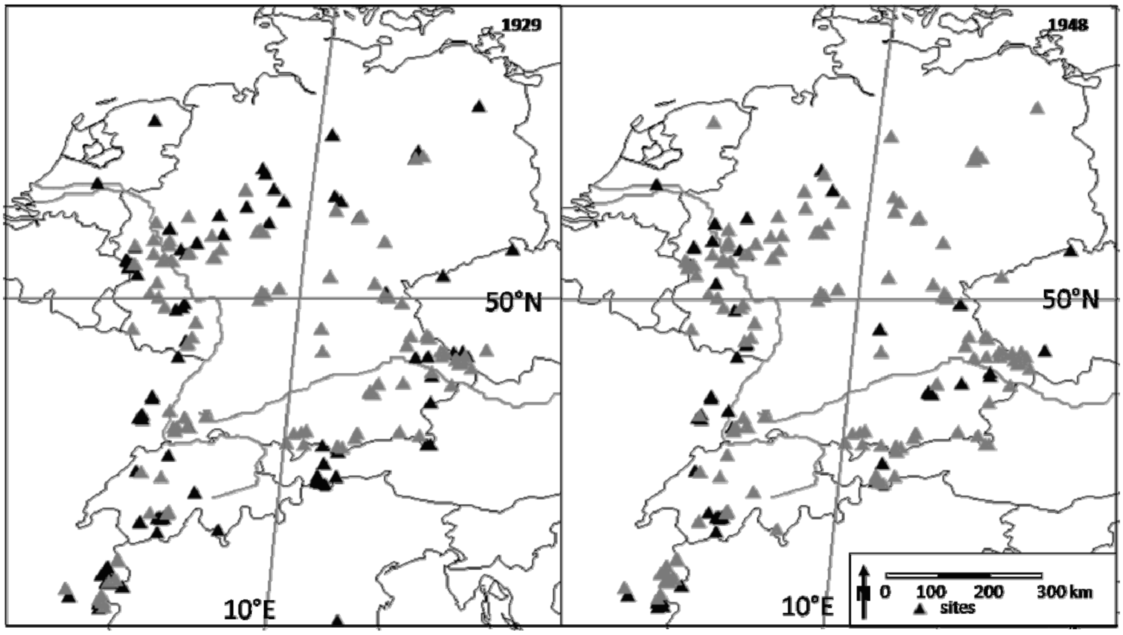

Figure 3: Spatial distribution of sites with negative pointer years (index below -0.6; black triangles) and with extreme negative pointer years (below -1.0; grey triangles) for 1929 (left) and 1948 (right).

In consequence, on an annual scale it is not possible to link the number of GWL anomalies with the observed growth reactions expressed by pointer years.

A comparison between the strong pointer year 1929 and the strongest pointer year 1948 is illustrated in Fig. 3. The spatial distribution of sites with negative pointer years and the distribution of sites with extreme negative pointer years (grey triangles in Fig. 2) show no conspicuous differences between the years 1929 and 1948. Regarding the extreme reactions (grey triangles in Fig. 2) we see a lower number of reacting sites in 1929 (left part of Fig. 2). In 1929 only 171 sites, that is curtly one-half of the 373 sites, show an extreme negative pointer year. In opposite, in 1948 more than two-third (=256 sites) of all sites show an extreme negative reaction, but the spatial distribution of sites with extreme negative reactions is similar in both years.

Due to the fact that it is not possible to link GWL anomalies on an annual resolution with pointer years and that there are differences regarding the intensity and number of reactions, it was necessary to investigate the GWL anomalies for all pointer years on a monthly basis. Exemplary the results for the year 1929 are presented in figure 4.

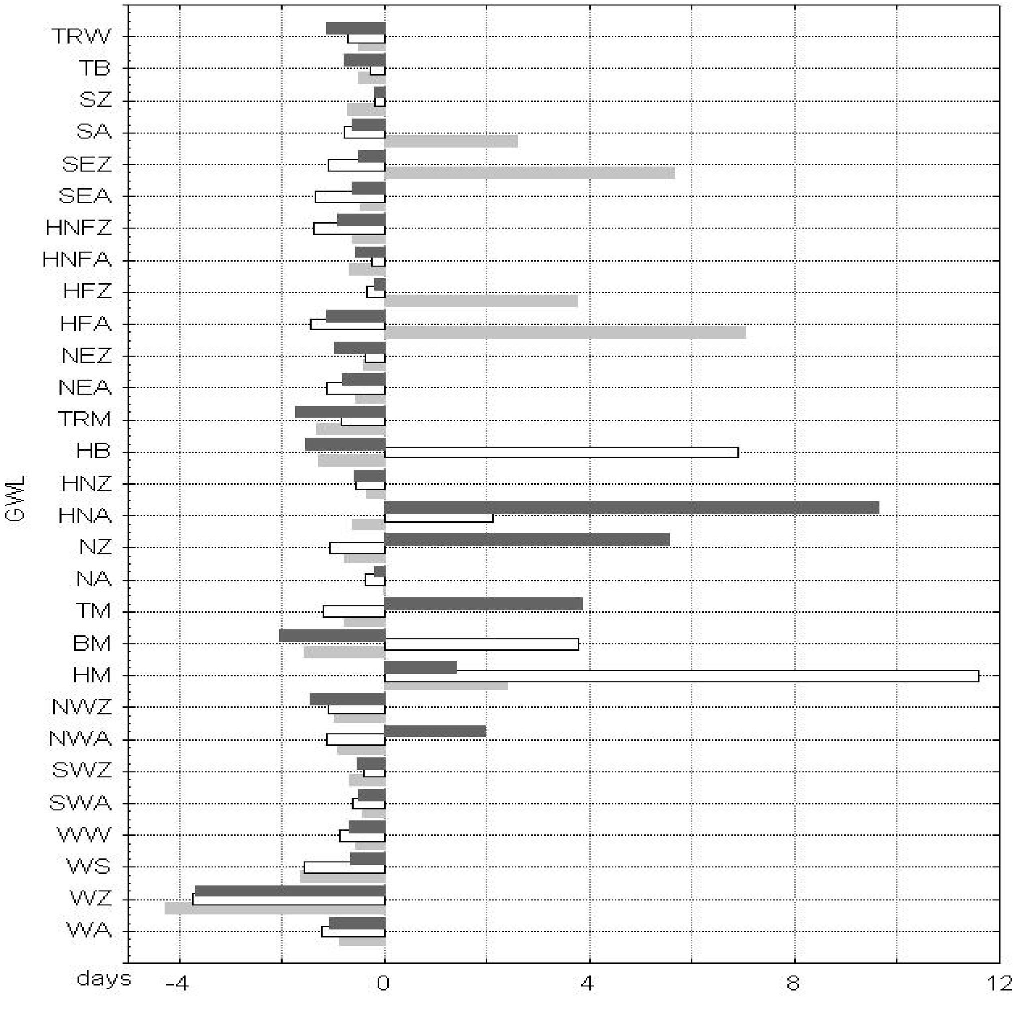

Figure 4: GWL anomalies for February (grey bars), March (white bars) and April (dark grey bars) in days for the year 1929.

The figure shows the GWL anomalies in days calculated between the MGM and the real appearance in the specific month for the beginning of the 1929th vegetation period.

February 1929 is characterized by an anomaly of nearly 18 days. The appearance of the GWLs SA, HFZ, SEZ and HFA is more frequent than usual. This constellation leads to cold and dry conditions. In March an anomaly of 22 days could be observed due to the more frequent appearance of the GWLs BM, HB, HM, causing cold temperatures. In April NZ, TM, and HNA appeared exceptionally numerous causing extreme cold conditions. Only a short warmer period from 3 days caused by HM in the middle of April interrupts this extreme cold period. Therefore it is useful to take the sequence respectively the persistent of the different GWLs into consideration, because they can strengthen or weaken each other.

The late winter / early spring situation in 1929 is characterized by GWLs which are combined with mainly continental and consequently cold and dry air masses. The GWLs of the zonal circulation type played no direct decisive role in 1929.

The analyses of the other remaining six pointer years show characteristic constellations of GWL anomalies, which were responsible for the negative growth reactions in the corresponding years. Always a combination of GWLs is responsible for the negative pointer year, never only a single GWL. Furthermore the GWL constellations, which were responsible for the negative pointer years were always different.

The findings of the analysis for all 7 negative pointer years for the period from 1900 to 1976 are summarized in figure 5.

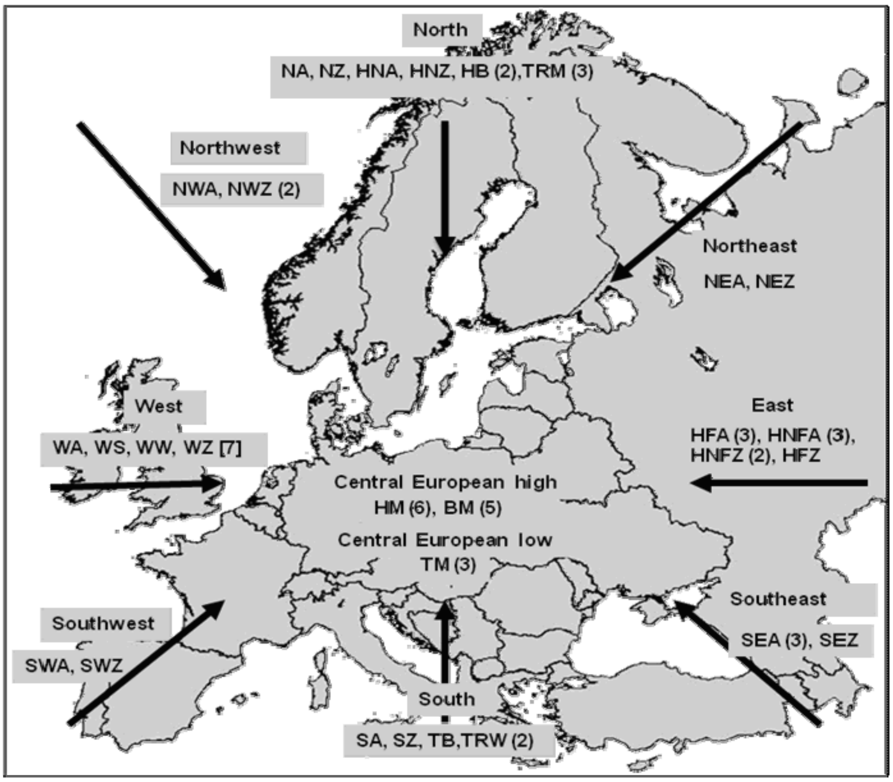

Figure 5: Frequencies of GWL impacts on negative pointer years (ciphers in brackets) for the period from 1900 to 1976 differentiated into the 10 synoptic types and their main air masses tracks over Central Europe. GWLs are only displayed if they were responsible for more than one pointer year. Squared brackets indicate GWLs with a reduced frequency, parenthesis indicate GWLs with an increased frequency in the pointer years. Abbreviations of the GWLs are listened at the end of this paper.

The ciphers in brackets behind the GWL abbreviations indicated the number of years in which the particular GWL is responsible for a negative growth anomaly. In all of the seven pointer years WZ shows an anomaly regarding the frequency, but in all pointer years except 1948 the frequency of WZ is reduced. Therefore it seems to be no direct influence of WZ on tree ring growth because the lack of WZ is filled with other GWLs which play the decisive role.

In pointer years especially the GWLs of the synoptic types East, Central European high, Central European low, and the GWLs HB, TRM and TRW show an increased frequency in comparison to the mean for the period from 1900 to 1976. The GWLs of the types Southwest and West are unimportant for the explanation of the investigated negative pointer years followed by the synoptic types South and Northwest.

In consequence mainly those GWLs which bring continental air masses in the research area are responsible for the investigated pointer years.

Conclusion and Discussion

The target of this investigation was to find out the impact of the large scale circulation pattern expressed by the GWL dataset on Central European pointer years. The investigation shows that there is no link between GWL and negative pointer years on an interannual scale – the peaks of GWL anomalies do not agree with the peaks of the Central European master plot. The interpretation of the spatial distribution of sites with strong reactions yields to the finding that there is no variation between the strongest negative pointer years. Only the number of sites with extreme negative pointer years is reduced, not their distribution.

The single year analyses show that for all investigated negative pointer years always different GWL constellations were responsible. Common to all negative pointer years is, that GWLs which are combined with continental air masses play the decisive role whereas GWLs of the zonal circulation types are not direct relevant. Another point to mention is that the sequence of different GWLs is quite important because the different GWLs can strengthen or weaken each other.

Further investigations are necessary regarding an expanded time window and regarding the sequence of the various GWLs with a daily resolution.

GWL abbreviations

Following abbreviations are used for the 29 GWLs: West Anticyclonic (WA), West Cyclonic (WZ), Southern West (WS), Angleformed West (WW), South-West Anticyclonic (SWA), South-West Cyclonic (SWZ), North-West Anticyclonic, (NWA), North-West Cyclonic (NWZ), Central European High (HM), Central European Ridge (BM), Central European Low (TM), North Anticyclonic (NA), North Cyclonic (NZ), North Iceland High Anticyclonic (HNA), North Iceland High Cyclonic (HNZ), British Isles High (HB), Central European Trough (TRM), North-East Anticyclonic (NEA), North-East Cyclonicl (NEZ), Fennoscandian High Anticyclonic (HFA), Fennoscandian High Cyclonic (HFZ), Norwegian Sea - Fennoscandian High Anticyclonic (HNFA), Norwegian Sea - Fennoscandian High Cyclonic (HNFZ), South-East Anticyclonic (SEA), South-East Cyclonic (SEZ), South Anticyclonic (SA), South Cyclonic (SZ), British Isles Low (TB), Western European Trough (TRW)

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High-resolution dendrometer measurements in a tropical mountain rainforest and a dry forest in South Ecuador

Volland-Voigt, F.[1]**, Bräuning, A.**[1] **& O. Ganzhi**[2]

[1]*University of Erlangen-Nuremberg, Institute of Geography, Kochstr. 4/4, D-91054 Erlangen, Germany*
[2]*University of Loja, Agricultural Science, Loja ; Ecuador*
Email: fvolland@geographie.uni-erlangen.de

Introduction

During the last decades, tree-ring research in tropical regions has made considerable progress. Overviews are given by Wimmer & Vetter (1999), Worbes (2002) and Brienen (2005). However, there are still debates about the ages of tropical trees (Brienen 2005, Worbes 1999) since clearly detectable annual ring boundaries are often not visible. To close the gap between tree-ring analysis and wood anatomy of tropical trees, we applied high-resolution dendrometer measurements to register seasonal stem diameter variations. The use of dendrometers is a standard approach to register growth rates of trees inside and outside tropical climate zones (Biondi et al. 2005; Hauser 2003).

The two study sites are located in South Ecuador. The dry forest is located in the "Reserva Laipuna" between 575 - 1100 m a.s.l. In this seasonally dry climate, average temperature is ca. 25°C and average annual rainfall is about 633 mm (Anuario Meteorologico INAHMI 1993). Rainfall is mainly limited to March until May (ca. 550 mm; Peters pers. comm 2008). In some years, single rainfall events also occur in September. The studied *Tabebuia chrysantha* (Bignoniaceae) and *Terminalia valverdeae* (Combretaceae) are located on a northeast facing slope. In total, dendrometers were attached to 12 trees in two different sites in 575 and 1050 m altitude, respectively. The tropical mountain rainforest "Estaciòn Cientìfica San Francisco" (ECSF) is located at ca. 2000 m a.s.l. The mean temperature is 15.5°C and average precipitation is 2100 mm (Emck 2007, Peters pers. comm. 2008). The seasonality of rainfall is only weak, but April to June is the wetter season and September to February tend to be drier. *Cedrela cf. montana* (Meliaceae) and *Tabebuia chrysantha* (Bignoniaceae) are located on a north slope at an altitude between 1980 and 2030 m a.s.l. In total, 24 trees in six different sites were furnished with dendrometers (Bräuning & Burchardt 2006, Bräuning et al. 2008).

Dominant and co-dominant trees with a straight trunk and a trunk diameter of more than 25 cm were sampled. In "Reserva Laipuna", the two species *Tabebuia chrysantha* (Bignoniaceae) and *Terminalia valverdeae* (Combretaceae) dominate the forest canopy at the collected sites. In the ECSF forest, however, ca. 250 different tree species occur and no single species becomes dominant.

Material and Methods

After a wood anatomical screening of ca. 200 tree species growing in the tropical mountain rainforest, we selected species with clear growth boundaries in both study areas (Bräuning & Burchardt 2006, Bräuning et al. 2008). Point dendrometers are a non-destructive method to evaluate continuously growth rates of trees. We installed dendrometers in a height of ca. 1.5 m on the stems at a position parallel to the slope to avoid a possible influence of reaction wood. Measurements of stem radius changes were taken in 30 min. intervals and stored in a data logger. Besides registering long-term growth rates related to cambial activity, point dendrometers are able to detect short-term stem diameter variations that result from fluctuations in the water status of the tree. The original climate data are from a project network of meteorological stations in ECSF forest and Reserva Laipuna (Peters unpubl.). Our data analysis includes inter-specific and intra-specific comparisons of the dendrometer measurements and local climate data.

Results

Data on daily and seasonal variations of stem diameter in relation to local climate for the tropical mountain rain forest (ECSF) and for the dry forest (Reserva Laipuna) are shown in figures 1A, 1B, 1D and 1E, respectively.

The radial diameter changes of four studied individuals of *Cedrela cf. montana* (Fig. 1A) and three individuals of *Tabebuia chrysantha* (Fig. 1B) shrink very synchronously even in short dry periods. This can be seen e. g. for the periods 26th of October until 5th of November 2007 (except for *Tabebuia chrysantha* B3), 27th of November until 9th of December 2007, 9th until 23rd of January 2008 and 6th until 15th of March 2008. As indicated by the daily sums of rainfall (Fig. 1C), available moisture was low during these periods. As a result, water pressure deficit is high and the trees transpire a lot of water. This water loss is responsible for the observed shrinkage of the stems. These results demonstrate that even in very humid tropical mountain climates, cambial activity reacts very sensitive to moisture availability. Surprisingly, a few consecutive dry days are enough to cause a drastic decrease in cambial activity.

A rainfall extreme on the 12th of August 2007 triggered a swelling process or maybe also real cambial growth in *Tabebuia chrysantha* (Fig. 1B, curves 1+2). However, this reaction is not seen in *Cedrela cf. montana* (Fig. 1A). It has yet to be confirmed if this different reaction can be species dependent or caused by a different social tree status or different microclimatic condition.

A period of real stem increment caused by cambial activity occurred during 14th of June until 14th of July 2007 for *Cedrela cf. montana* (Fig. 1A). The climatic conditions during this period with nearly daily rainfall, relatively high air humidity and a slightly lower mean temperature are probably responsible for the observed growth increase.

Due to the different site conditions between the tropical mountain rain forest and the dry forest the trees exhibit strongly different growth dynamics. At the dry forest site in Laipuna, *Tabebuia chrysantha* and *Terminalia valverdeae* stop growing at the end of the wet season around mid-May. At the end of the rainy season in May the stem diameters shrink synchronously in all trees regardless of the species. Despite of the similar breast height diameter, the intensity of shrinkage varies between individual trees as a result of individual plant morphology or local soil conditions. With the beginning of the wet period in January stem diameters of all studied individuals increase rapidly. At first, stem diameter increase compensates for the shrinkage that occurred during the dry season. Cambial growth starts around mid-January, when stem diameters of all trees exceed the maximum diameters reached at the end of May of the previous year.

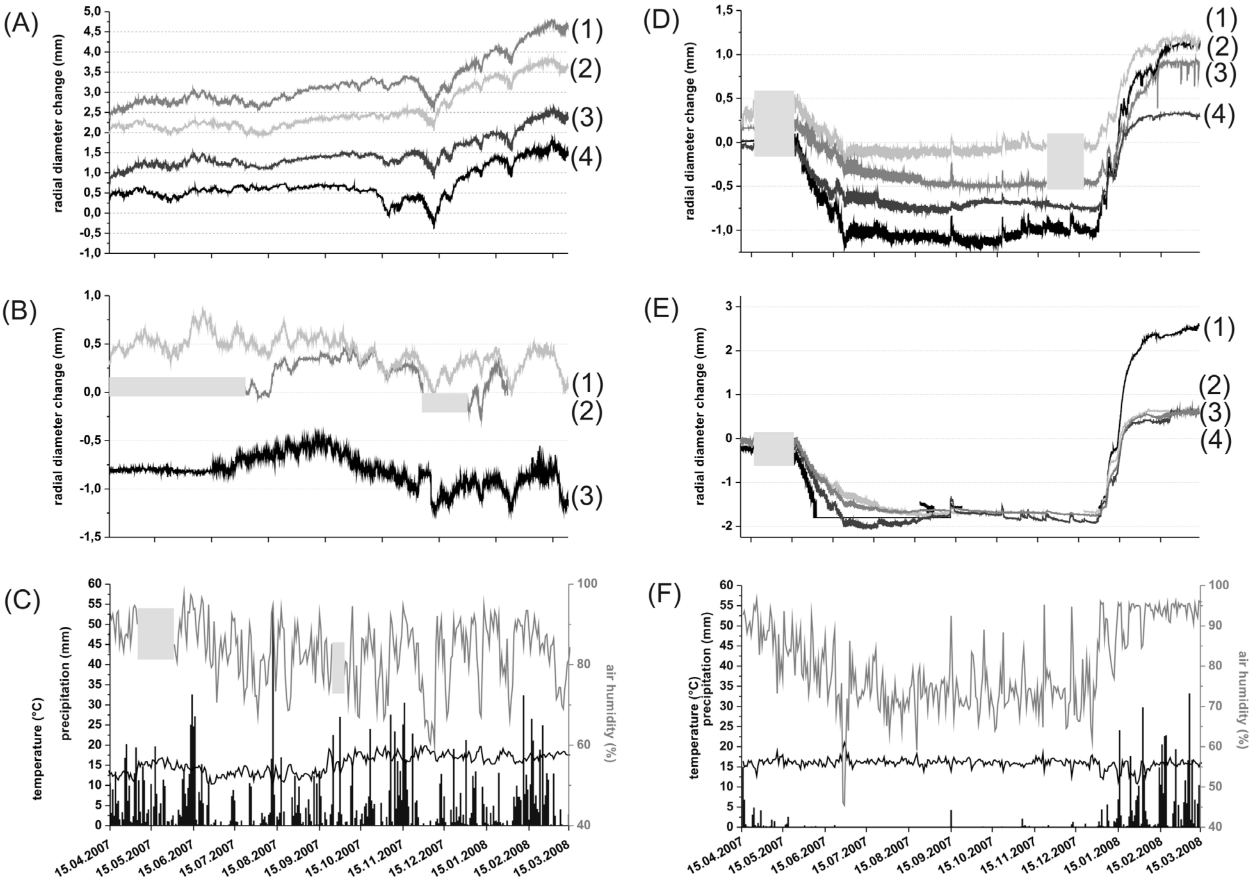

Figure 1: The diagrams show daily and seasonal variations of stem diameter (A,B,D,E) in relation to local climate (C: tropical mountain forest; D: tropical dry forest). Graph (A) shows very synchronous growth increments of the four Cedrela cf. montana (A1-4), in contrast to the growth patterns of the three studied Tabebuia chrysantha (B1-3). Graph (D) shows very synchronous growth of the four Terminalia valverdeae (D1-4), in contrast to the more or less analogue progress of Tabebuia chrysantha (E1-4). Data gaps are highlighted as grey bars.

Tabebuia chrysantha (Fig. 1E, curve 1) shows an even more intense shrinking then *Terminalia* during the dry period, however, both species respond synchronously with stem swelling and cambial activation at the beginning of the wet period.

It is interesting to note the species-specific reaction to the extreme climatic conditions during 28th and 30th of June 2007 (see Fig. 1F), when mean daily temperature rise to 20°C and relative air humidity dropped to 45%. This short-term climate event is caused by a change in the wind direction from dominantly South to North. This induces much stronger stem shrinkage in *Terminalia* than in *Tabebuia.*

Discussion

Although the studied time period reported here is quite short, the data reveal a first impression of growth dynamics of tropical trees in two different ecological forest types. Now we start to understand the relation between tree growth dynamics and the seasonal climatology in a humid tropical mountain climate and a seasonally dry climate in the Ecuadorian Andes.

The diurnal stem size fluctuations observed in our study were mainly controlled by radiation, which increased the water pressure deficit and hence tree transpiration (Bräuning et al. 2008). On sunny and dry days, stem shrinkage was larger than on cloudy and wet days. Zweifel et al. (2000) observed the same interrelation in Norway spruce (*Picea abies*) under laboratory conditions.

Besides weather and local moisture conditions, the amount of shrinking and swelling also depends on the wood anatomy. Therefore, we will analyse the wood anatomy of the studied tree species in a next working step. To finally understand the seasonal growth dynamics in relation to the local climate, the following investigations are needed: long-term point dendrometer measurements and climate data, analyses of wood anatomy and stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes variation in wood cellulose of the studied tree individuals.

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SECTION 2

ISOTOPES

800 years of tree-ring δ^{18}O reflect variability of precipitation in southeastern Tibet

Grießinger, J.[1], Bräuning, A.[1], Helle, G.[2], Thomas, A.[3] & G.H. Schleser[2]

[1]*Institute of Geography, Friedrich-Alexander-University of Erlangen-Nürnberg, Germany,*
[2]*Research Centre Jülich GmbH, Institute of Chemistry and Dynamics of the Geosphere ICG-V: Sedimentary Systems, Germany*
[3]*Institute of Geography, Justus-Liebig-University of Gießen, Germany*
Email: jgriess@geographie.uni-erlangen.de

Introduction

The climate on the Tibetan Plateau (TP) is mainly influenced by the Indian and Asian Summer Monsoons. On the other hand, many studies show strong evidence that the TP exerts profound thermal and dynamical influences on the regional weather and climate as well as on atmospheric circulation in the Northern Hemisphere (Manabe & Terpstra 1974, Webster et al. 1998, Thompson et al. 2000). New scenarios of global climate change on the TP single out different warming trends with simultaneous comments about the sketchy proxy records in this region (IPCC 2007) The aim of our study is to reconstruct the history and variability of the summer monsoon with stable oxygen isotopes (δ^{18}O) as part of a comprehensive climate reconstruction. Within this project, stable oxygen isotopes of tree rings from a relict juniper stand (*Juniperus tibetica*) in the semi-arid south-eastern part of the Tibetan plateau are analyzed on an annual basis. Our southern exposed investigation site is characterized by slope angles between 30 and 35°, well drained soil conditions and is situated in the sub-alpine belt at 4300 to 4400 m. a.s.l. As former analyses of ring width showed, trees at this site are very sensitive to variations in precipitation and therefore well suited for a detailed climate-proxy investigation (Bräuning 1999).

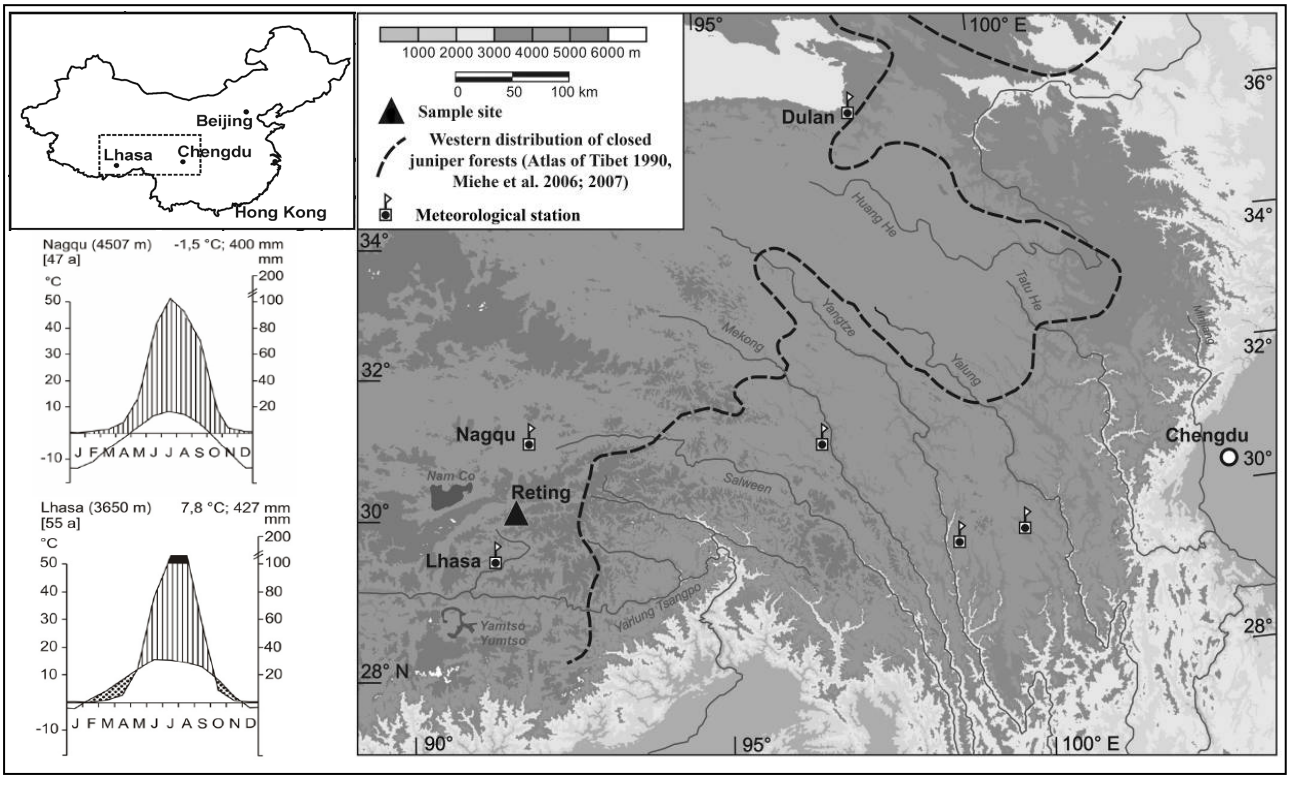

Figure 1: Location of the sample site Reting (triangle) and surrounding meteorological stations (symbols) including the climate charts of Lhasa and Nagqu (left side). Map: Bräuning 2007.

Material and Methods

For the isotope analysis, 4-10 cores (with one core per tree) of dominant trees from the sampling site were selected. According to standard dendrochronological procedures (Cook et al. 1990), each core was measured and synchronized with the existing site chronology from Bräuning (2001). After dating, tree rings were separated under magnification on an annual base using a razorblade. Same calendar years were pooled prior to isotopic analysis, following a method suggested by Leavitt & Long (1984) and Borella et al. (1999). Thereafter, resins and cellulose were extracted adapting a standard procedure described by Kürschner & Popik (1962). Measurement of the stable oxygen isotope ratios of wood cellulose was carried out at the Research Centre of Jülich, ICG-V with an elemental analyzer interfaced to a continuous flow IRMS (Micromass Optima). The $\delta^{18}O$ values of wood cellulose were expressed in the delta notation:

$$\delta_{Sample} = (R_{Sample}/R_{Standard}-1) \times 1000$$

where R_{Sample} is the $^{16}O/^{18}O$ ratio of the sample and $R_{Standard}$ is the $^{16}O/^{18}O$ ratio of an internationally accepted standard (here: VSMOW) (for further details see McCarroll & Loader 2004; 2006).

Overall, we were able to establish an annually resolved $\delta^{18}O$-isotope series reaching from 1180 to 2005 AD (Fig. 2).

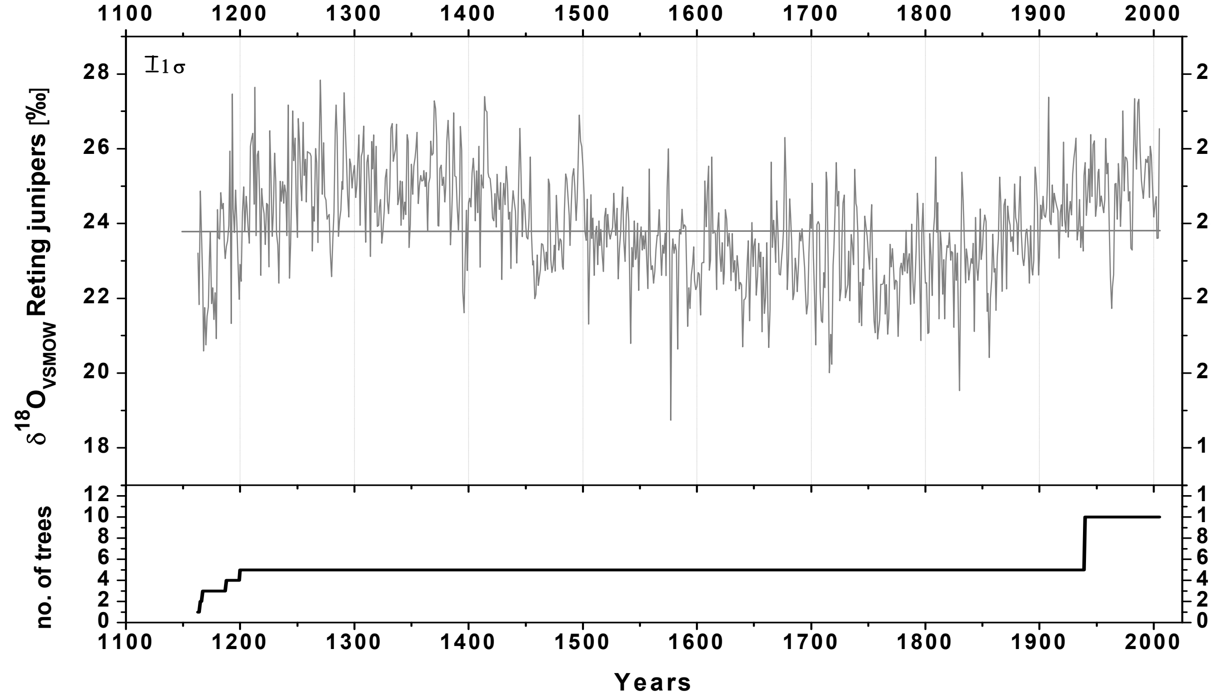

Figure 2: $\delta^{18}O$-isotope series and sample depth at Reting, SE-Tibet. The $\delta^{18}O$-data before 1200 AD is not regarded within this investigation because of non-sufficient sample replication.

To investigate the climate-proxy relationship concerning the $\delta^{18}O$-series at Reting, we compared different climate parameters such as temperature, precipitation and potential evapotranspiration (PET). The climate data originates from adjacent meteorological stations, extended by calculated PET-datasets by Chen et al. (2006). Especially the incorporation of the more complex climate parameter PET should help to investigate site specific transpiration rates and $\delta^{18}O$-fixation in tree rings.

To ensure spatial representativeness, we built a regional mean from the meteorological stations Nagqu and Lhasa (Fig. 1), following the methods of Jones & Hulme (1996). In summary, the calibration period covers 50 years for temperature and precipitation datasets and 43 years for the PET dataset, respectively (Fig. 3).

Results and discussion

In a first step, we calibrated our oxygen isotope series with the common climate parameters temperature and precipitation (Fig. 3, left column). Correlations with temperature are predominantly positive, although not highly significant (for $p<0.1$). In contrast, calculations with precipitation during the summer months of the actual and previous year indicate highly significant negative relationships between $\delta^{18}O$ and monthly and seasonal means of precipitation during summer monsoon season from May to September. Correlation is highest with the previous years´ precipitation in August ($r=-0.61$, $p<0.01$). Due to site conditions with steep slopes and well-drained soils, influence of ground-water during water uptake in the vegetation period can be excluded. Since the south-eastern part of the TP is characterized by the lack of persistent snow covers during winter (Weischet & Endlicher 2000), possible isotopic shifts caused by melt-water uptake in spring can also be excluded.

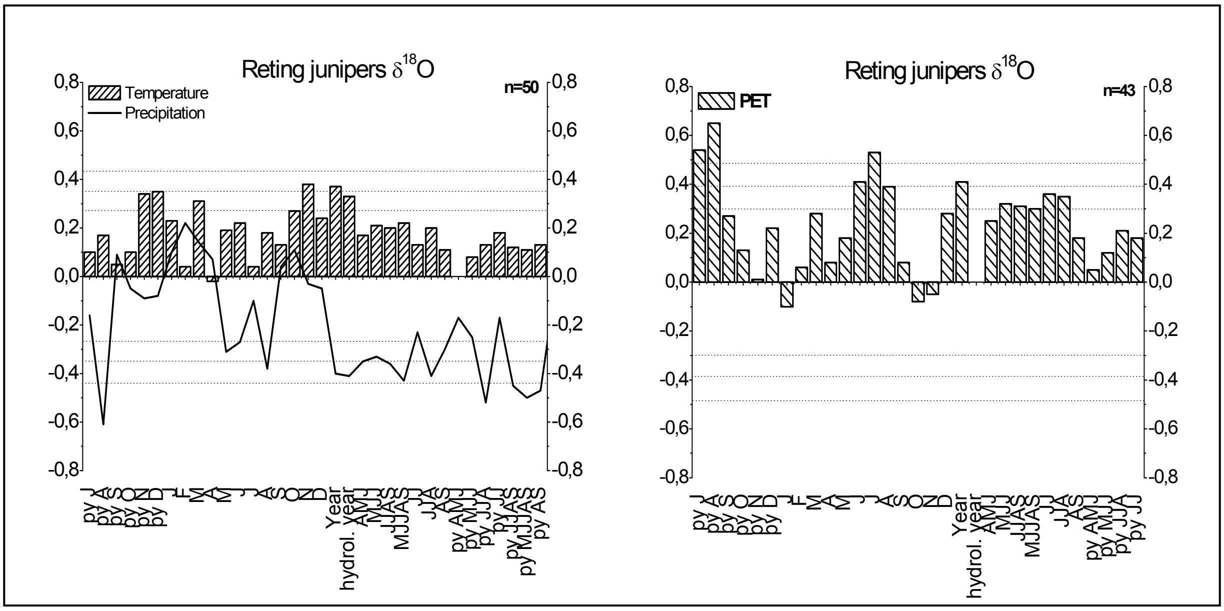

Figure 3: Climate-proxy relationships between $\delta^{18}O$, temperature and precipitation (left column) and between $\delta^{18}O$ and potential evapotranspiration (PET, right column) for monthly means of the actual and the previous year (py). Dotted lines represent levels of significance with $p<0.5$; $p<0.1$ and $p<0.01$.

The observed time lag within the climate-proxy-relationship could be caused by a storage effect during $\delta^{18}O$-fixation which leads to a re-mobilization of previous years´ storage into the tree ring of the actual year. This could be interpreted as a local plant physiological adaptation at semi-arid site conditions towards water stress during the vegetation period. In summary, these results leads to the assumption of a distinct summer monsoon signal, recorded in the tree-ring $\delta^{18}O$-variations at Reting.

The calibration with potential evapotranspiration dataset (PET) displays a strong influence of site specific transpiration rates on the variations of tree-ring $\delta^{18}O$ at Reting (Fig. 3, right column). For this semi-arid site, high significant positive correlations with single monthly means are prevailing. The highest significant correlation with $r=0.65$ ($p<0.01$) is - similar to our results and explanation with the precipitation dataset - apparent for the previous years´ August. This leads to the assumption that during summer monsoon season water supply by precipitation combined with high temperatures leads to higher transpiration rates and therefore higher δ^{18}O-values.

Conclusions

In summary, the results of the calibration study strictly reflect the climatic conditions at our study site. During summer monsoon season from May to September water supply and air temperatures respectively, (and therewith evapotranspiration) reach their yearly maximum (see Fig. 1). This causes a strong tracing of different summer monsoon signals into the tree-ring δ^{18}O-values at Reting (Grießinger 2008). Thus, our δ^{18}O-timeseries is a well suited proxy for the reconstruction of monsoonal activity and of summer monsoon history in the SE-part at the TP. As a preliminary result, the oxygen isotope series at Reting reveals a continuous ncrease in precipitation from 1500 to 2005 AD, interrupted by a short period with lower precipitation from 1940 to 1980 AD.

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Carbon and oxygen stable isotope signals in *Juniperus excelsa* from Anatolia, Turkey

Heinrich, I.[1], Touchan, R.[2], Weidner, K.[1] & G. Helle[1]

[1]Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Telegrafenberg C323,
14473 Potsdam, Germany
[2]Laboratory of Tree-Ring Research, The University of Arizona, Tucson, USA
Email: heinrich@gfz-potsdam.de

Introduction

The climate of the eastern Mediterranean is characterised by extremes of heat, highly variable precipitation, and limited water resources. These features are of great significance to the growing human populations and can play a role in the dynamics of regional demographic, socio-cultural, economic, and environmental changes of the area (Türkeş 1998). Therefore, understanding natural climate variability is of great importance as it will help to better predict its future variability, thus helping the societies affected to better adapt to the effects of climate change. Developing this understanding is difficult from the relatively short instrumental record available for the eastern Mediterranean region (Türkeş & Erlat 2003). Natural archives such as tree rings and other proxy records can be used to capture information about climate variability on longer time scales. Dendroclimatology has only recently been applied systematically in the eastern Mediterranean region (D'Arrigo & Cullen, 2001; Touchan et al., 2003; Akkemik & Aras, 2005; Akkemik et al. 2008; Touchan et al. 2005, 2007) and studies of carbon and oxygen stable isotopes in tree rings are still lacking. We present first carbon and oxygen stable isotopes series derived from tree rings of *Juniperus excelsa* M. Bieb. trees from a site in Antalya, Turkey. Since these are the first tree-ring isotope records from Turkey their usefulness for further palaeoclimatology is evaluated. Moreover, the study investigates the climate response of the isotope records and the spatial and temporal correlation patterns of the climate growth relationships over the 20th century.

Material and Methods

Study site

The study site Jsibeli is situated near Elmali in the Antalya district, Turkey (Fig. 1). It is located in the Akdağlar mountain range at an elevation of 1853 to 2022m a.s.l. (Touchan et al. 2007).

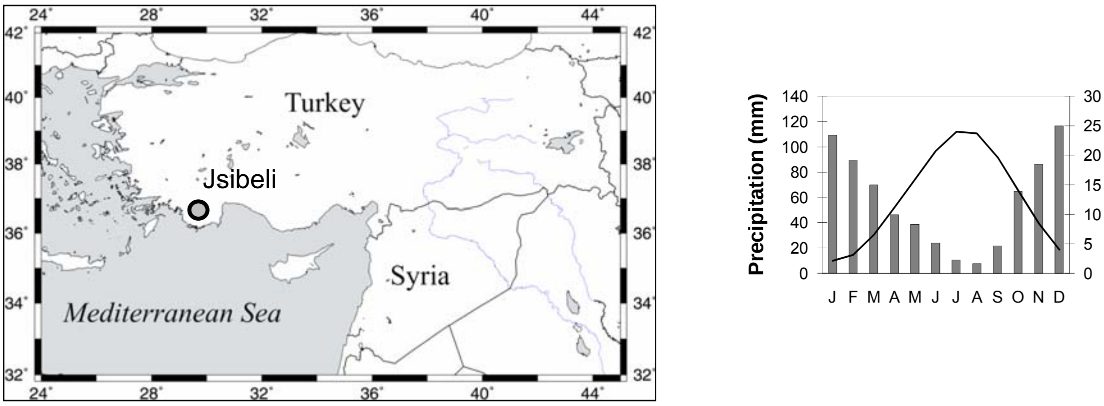


Figure 1: Map with location of the sample site Jsibeli and climate diagram for Elmali weather station (2000-1960) (Turkish General Directorate of Meteorology, 2001). Jsibeli (36°36'N / 30°01'E) is located near Elmali, Antalya district, southwest Turkey at an elevation of 1853 to 2022m a.s.l. (Touchan et al. 2007)

The Mediterranean climate at the site is characterised by dry, hot summers and cool, rainy winters (Türkeş et al. 2002) with a total annual rainfall of approximately 750mm. The site is covered with snow from December to April (Touchan et al. 2003).

Sample material

At least three cores per tree of 12 *Juniperus excelsa* living trees were taken. In addition, full cross sections were sampled from 14 stumps and logs (Touchan et al. 2007). This resulted in a sample pool of 54 cores and 14 stem disc samples which were fine-sanded and crossdated using standard dendrochronological techniques (Stokes & Smiley, 1996). The annual ring widths of each core and cross-section were measured to the nearest 0.01 mm (Touchan et al. 2007).

After measuring and crossdating the ring widths, seven trees (15 cores of five living trees and two cross-sections cut from stumps) were chosen for further isotope analysis and analysed individually. However, in some instances pooling of up to 5 cores from the same tree was done to produce enough sample material for further isotope analyses. The selection criteria for the samples were a high correlation with the site chronology, smallest possible numbers of missing rings, no tree-ring sequences with ring widths below 0.1mm, no significant growth suppressions and releases and no scars, reaction wood or other wound reactions. The individual tree rings were first separated with a scalpel. Cellulose was then extracted following standard procedures (*e.g.*, McCarroll & Loader 2004) and burned to CO_2 or pyrolised to CO at a temperature of 1080 ºC for $\delta^{13}C$ or $\delta^{18}O$ mass spectrometer analysis, respectively.

$\delta^{13}C$ values are expressed as deviations from the Vienna Pee Dee Belemnite (VPDB) standard and $\delta^{18}O$ values as deviations from the Vienna Standard Mean Ocean Water (VSMOW) standard (Mook 2001). Carbon isotope records were corrected for the decrease of atmospheric $\delta^{13}C$ values due to fossil fuel burning since the beginning of industrialisation AD 1850 (Friedli et al. 1986, Francey et al. 1999). In addition, the new "pin-correction" by McCarroll et al. (2008) was applied to the data. The correction procedure uses non-linear regression but de-trending is restricted by two logical constraints based on the physiological response of trees. The $\delta^{13}C$ and $\delta^{18}O$ site chronologies were then correlated with monthly, seasonal and annual climate data (precipitation and temperature) from the meteorological station Elmali, located near the study site, using Pearson's simple correlation coefficient. Temporal correlation between the self-calibrating Palmer Drought Severity Index (scPDSI) and the $\delta^{18}O$ site chronology was evaluated with Pearson's correlation coefficient in a moving window of 31 years. Spatial correlation was analysed in the KNMI climate explorer (van Oldenborgh 1999).

Results and Discussion

The raw $\delta^{13}C$ series show a decline especially between 1950 and 2006 due to the decrease of atmospheric $\delta^{13}C$ values (Fig. 2A). The correction for the decrease of atmospheric $\delta^{13}C$ values and the pin correction have removed this trend and resulted in an increase of the rbar/EPS statistics from 0.24/0.69 to 0.48/0.86, respectively (Fig. 2B). Such significant increases of the rbar/EPS statistics have been reported in several studies focusing on various tree species at different locations in Europe and they indicate that the pin correction is successful in increasing the quality of the $\delta^{13}C$ chronologies (Young and McCarroll 2008). The higher rbar and EPS values indicate that the mean $\delta^{13}C_{pin}$ chronology is a robust estimate of annual changes in $\delta^{13}C$ and that it is suitable for further dendroclimatic research. The mixture of core samples from living trees and cross sections from dead stumps and logs accounts for the smaller sample depth between 1980 and 2006 (Fig. 2D).

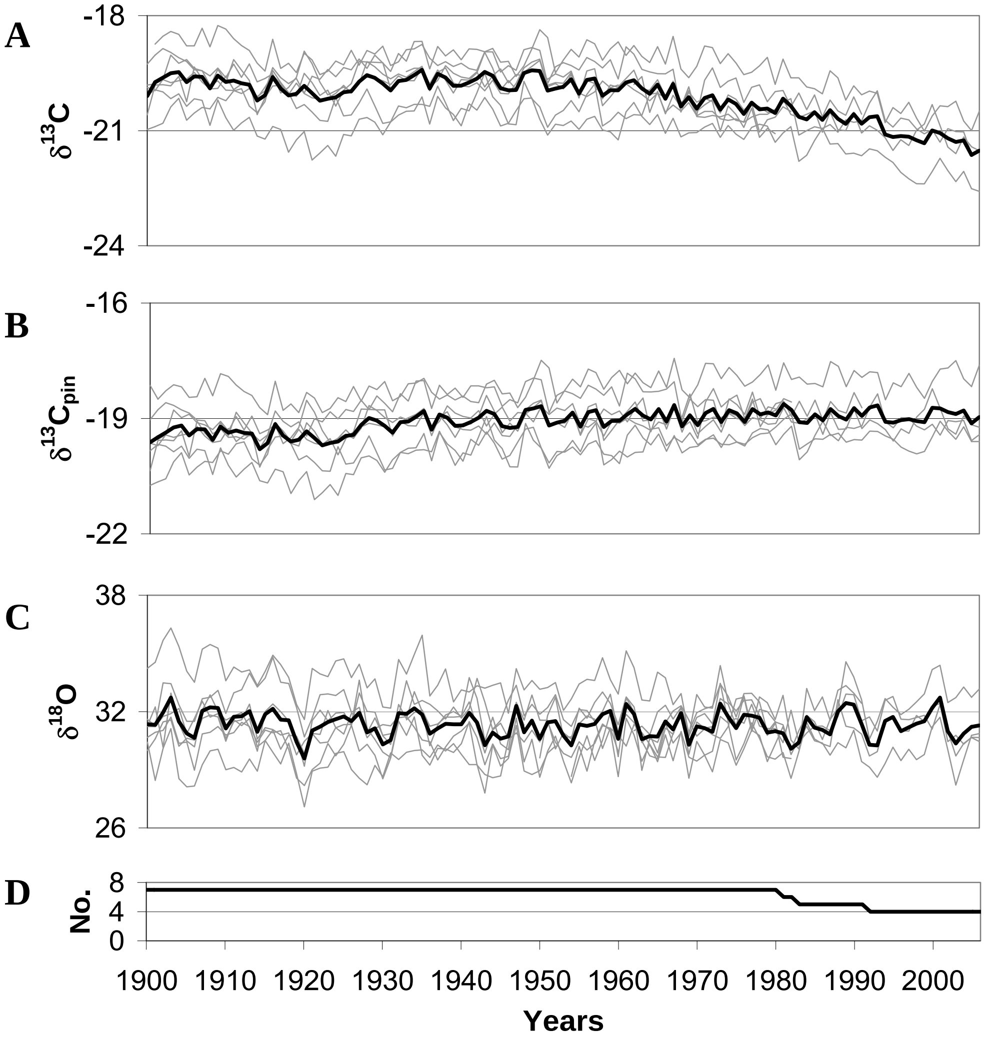


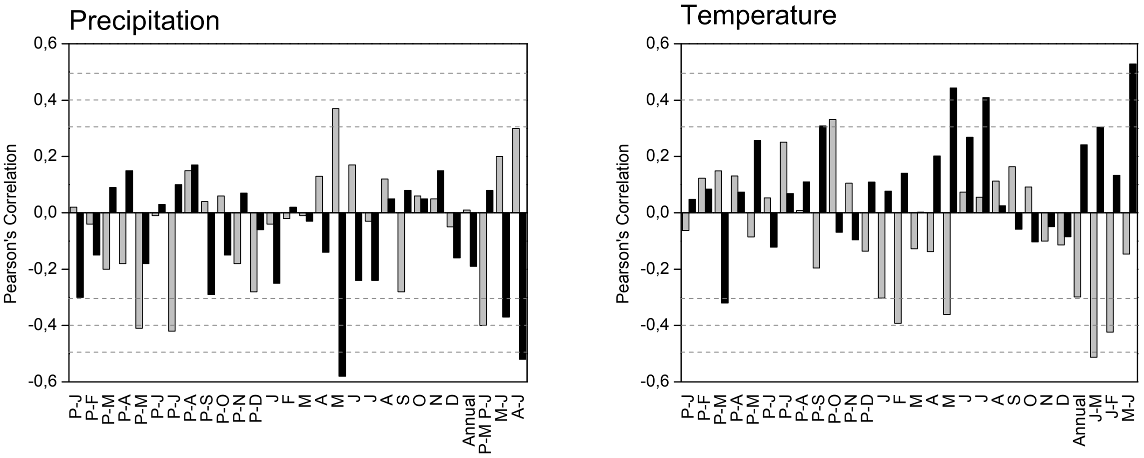
Figure 2: Plots of the raw δ^{13}C series (A), pin corrected δ^{13}C series (B), δ^{18}O series (C) and sample depth through time (D). The black graphs represent the means of the raw and corrected series, respectively.

The mean $\delta^{13}C_{pin}$ chronology exhibits low values in the period 1900 to 1930 and then varies relatively stable around the value of -19 until 2006. Years with values above -19 are visible in the late 1940s, early 80s and early and late 90s. Periods with values below -19 are displayed in the mid 40s and mid 90s.

The $\delta^{18}O$ series does not contain a long-term trend as the $\delta^{13}C_{pin}$ values but show more high-frequency variability (Fig. 2C). The rbar=0.44 / EPS=0.85 statistics imply a good quality of the mean $\delta^{18}O$ chronology and that it is also suitable for dendroclimatic research. The mean $\delta^{18}O$ chronology contains periods with low values in the early 1920s and 30s, the mid 40s and 60s and in the early 80s, 90s and 2000s, while periods with high values are discernible in the early 1900s, 30s, 60s and early and late 90s.

The climate response plots present correlations between the isotope chronologies and climate data. The analysis includes monthly climate data of the current (J-D) and previous (P-J to P-D) year, annual and selected seasonal climate data. The analysis shows highly significant negative correlations between $\delta^{18}O$ and May and also April to July precipitation (r=-0.58 and r=-0.53, respectively) and between $\delta^{13}C_{pin}$ and January to May temperature (r=-0.51) (Fig. 3). Overall, this leads to the assumptions of a distinct summer precipitation signal, recorded in the isotope records.

Highly significant positive correlations are also noted for $\delta^{18}O$ and May to July temperature (r=0.53).


Precipitation

Temperature

Figure 3: Climate response of the $\delta^{13}C_{pin}$ series (grey) and $\delta^{18}O$ series (black) to monthly, annual and seasonal precipitation (left) and temperature (right). Dotted lines represent levels of significance with p<0.5, p<0.1 and p<0.01.

The correlation patterns between the climate data and the $\delta^{13}C$ series are somewhat surprising as they are opposite in sign to what is usually expected. Since these are the first $\delta^{13}C$ series derived from tree rings in Turkey, more investigations need to focus on this particularity, *e.g.*, choosing a sampling site farther away from the Mediterranean Sea and at higher altitudes.

The distinct summer precipitation signal is also reflected in the correlation between scPDSI and the isotope series, in particular, $\delta^{18}O$ (Fig. 4). The correlation between scPDSI and $\delta^{18}O$ is highly significant for all months of the current year, for the annual and seasonal May to July value. The highest correlation is reached in June (r=-0.58). Monthly scPDSI values of the previous year, in comparison to the current year, correlate less significant with $\delta^{18}O$ but more significant with $\delta^{13}C_{pin}$. Overall, the strong precipitation signal in the isotope chronologies corroborate results by Touchan et al. (2007), who found highly significant correlations (r=0.71 for the calibration period 1931-2000) between their regional tree-ring chronology from southwestern Anatolia in Turkey and May to June precipitation.

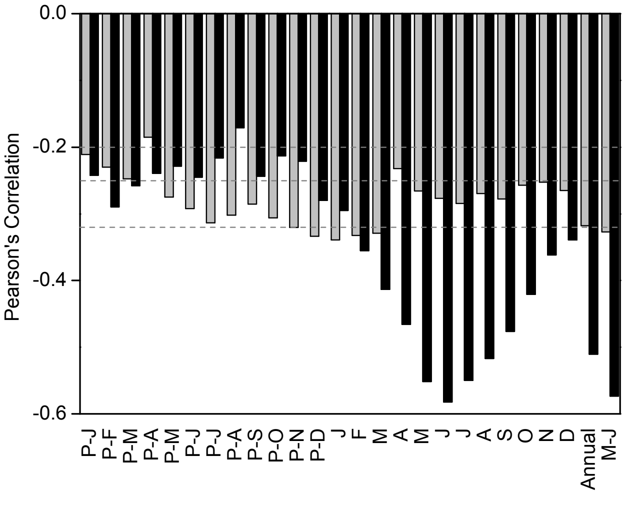


Figure 4: Climate response of the $\delta^{13}C_{pin}$ series (grey) and $\delta^{18}O$ series (black) to scPDSI (monthly, annual and seasonal). Dotted lines represent levels of significance with p<0.5, p<0.1 and p<0.01.

In a next step, the temporal stability of the climate growth response was investigated by analysing the relationship between scPDSI and $\delta^{18}O$ in a moving window of 31 years on a monthly basis for the current and the two previous years (Fig. 5). The results indicate the strongest and most stable correlation between the proxy and monthly values of the scPDSI for the current year. In general, the correlation is significant for the entire period of the current year. The strongest correlation is apparent for the period 1960 to 1975 and the weakest during the 1940s. The correlation between the scPDSI of the two previous years and the $\delta^{18}O$ chronology is less significant and temporally unstable. The correlation between the scPDSI of 2 years before the current and $\delta^{18}O$ turns to highly significant positive values for the period 1915 and 1935. However, this correlation pattern cannot be explained ecophysiologically but seems to be a statistical artefact.

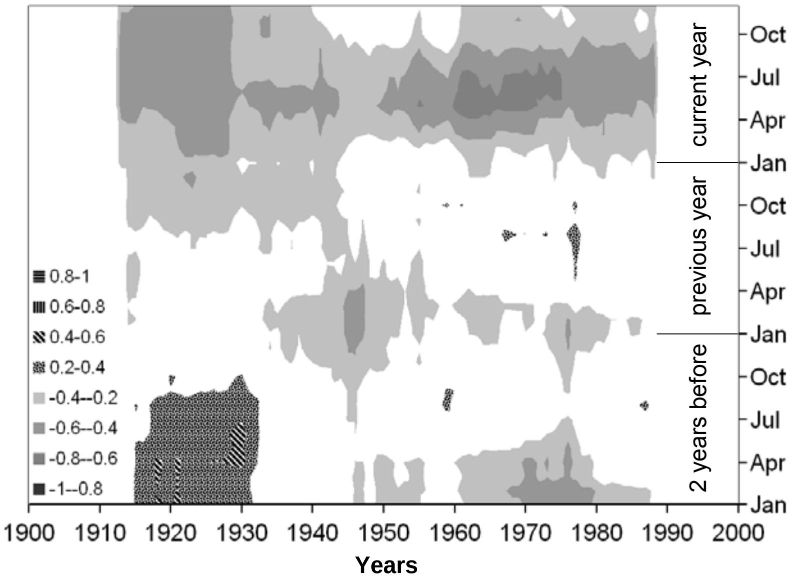


Figure 5: Temporal correlation between scPDSI and $\delta^{18}O$ series for the current and two previous years. Pearson's correlation coefficient calculated monthly for the current and the two previous years in a moving window of 31 years.

The spatial field correlation maps (van Oldenborgh 1999) demonstrate that the correlation between the $\delta^{13}C_{pin}$ chronology and the mean Jan-May temperature covers a larger area around the study site in southwest Turkey than the correlation between the $\delta^{18}O$ series and the mean May-Jul scPDSI (Fig. 6). Since temperature is usually distributed spatially more homogenously, this result is not surprising. Interestingly, however, the $\delta^{13}C_{pin}$ chronology seems to have the power to explain significantly the variance in Jan-May temperature of most of Turkey, Syria and northeast Africa. In contrast, the result for the $\delta^{18}O$ chronology suggests little potential for further large-scale spatial climate modelling because $\delta^{18}O$ is only correlated with the mean May-Jul scPDSI of southwest Turkey and small parts of south Greece, Syria, Iran and Iraq. Intriguingly, most of the field correlations of both the $\delta^{13}C_{pin}$ and $\delta^{18}O$ chronologies are oriented towards the south and east of the study site and no spatial correlation with Europe is indicated. It is surprising that there seems to be no common variance between our climate proxy record from Turkey and climate records from other Mediterranean countries such as Spain or Italy. Further research should first concentrate only on spatial correlations of meteorological climate data from countries neighbouring Turkey in order to verify the results suggested by the tree-ring proxies. Moreover, teleconnections between the new Turkish climate-sensitive isotope proxies and regional climate forcing patterns such as the North Atlantic Oscillation (Türkeş & Erlat 2003), the El Niño Southern Oscillation (Mariotti et al. 2002) and the Indian Ocean Dipole Mode Index (Saji et al. 1999) need to be investigated.

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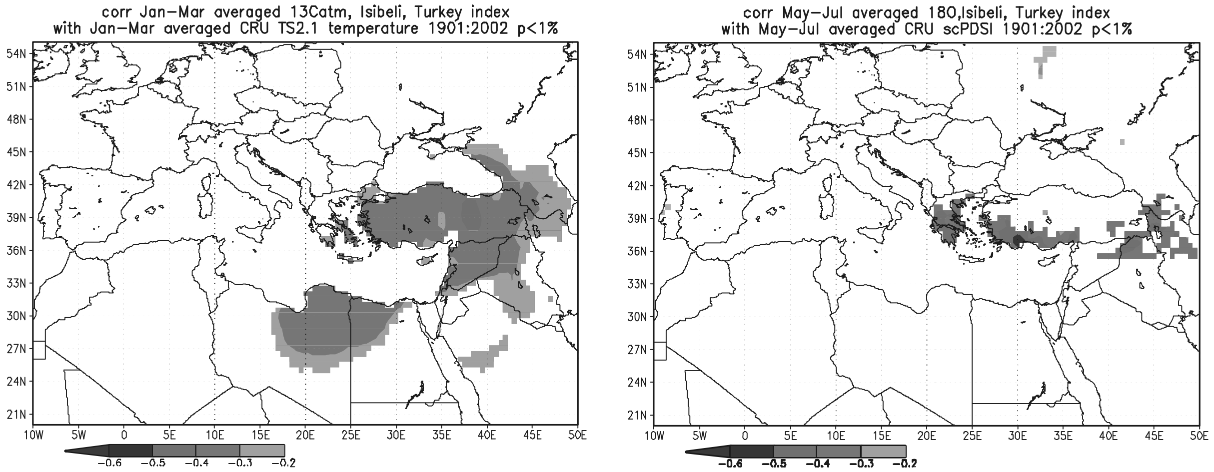

Figure 6: Spatial field correlations (van Oldenborgh 1999) between mean Jan-May temperature and $\delta^{13}C_{pin}$ series (left) and mean May-Jul scPDSI and $\delta^{18}O$ series (right).

In conclusion, it has been established that $\delta^{13}C$ and $\delta^{18}O$ in tree rings are useful proxies to reconstruct climate in Turkey. The presented tree-ring chronologies of $\delta^{13}C$ and $\delta^{18}O$ are the first of their kinds in Turkey. The climate growth relationships are relatively stable in time but spatially restricted, especially regarding precipitation. The new records help broaden the climatic information resources to the eastern Mediterranean region where heretofore there was little long-term tree-ring isotope data available.

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Investigation of drought reaction in juvenile aspen wood (*Populus tremula* L.)

Matthias Meyer[1], Björn Günther[2], Gerhard Helle[3], Doris Krabel[1]

[1] Technische Universität Dresden, Institute for Forest Botany and Zoology, Pienner Str. 7, D-01737 Tharandt, Germany
[2] Technische Universität Dresden, Institute for Forest Utilisation and Forest Technology, Pienner Str. 19,D-01737 Tharandt, Germany
[3] Forschungszentrum Jülich GmbH, ICG Nr. V, Leo-Brandt Str., D-52425 Jülich, Germany
E-mail: matthias.meyer@mailbox.tu-dresden.de

Introduction

The decline of the world's resources of fossil fuels and climate change in the foreseeable future are two major reasons for a persistent demand for renewable energy research in forestry and agriculture in Germany. One option for the future energy supply mix will be the production of liquid fuels from woody biomass (Kaltschmitt 2007). Short rotation forestry in coppices of fast growing tree species - in Central and Northern Europe mainly poplar (*Populus* spp.) or willow (*Salix* spp.) - on farmland is a management system that combines the advantages of a low energy input forestry system with agricultural cropping. The energy input to output ratio (1:21) is the best compared with other bio-energy purposes (Schneider 2007) because the intensity of the agricultural activities can be reduced to the initial plantation. Furthermore, the established poplar root system can be used for an additional rotation period after the first harvesting step. Finally this management system increases the ecological value of the agricultural ecosystem for breeding bird populations, for mammals and for accompanying vegetation.

The major problem concerning short rotation coppices of poplar or willow is their low profit due to a high water demand for a satisfactory growth. Recent studies showed that there are considerable differences in intrinsic water use efficiency (WUEi) represented by δ^{13}C between current licensed cultivars (Dillen et al. 2008, Monclus et al. 2005).

In our study tree ring investigations were used to describe the performance in WUEi and drought tolerance of two contrasting aspen populations - a natural and a planted crossbred - in their juvenile stage. We discuss the usefulness of mean annual δ^{13}C, mean X-ray density and other tree ring specific / wood anatomical traits for selection of drought tolerant genotypes.

Material and Methods

Plant material

The aim of our study is providing data for genetic mapping of quantitative trait loci (QTL) using an aspen F1-mapping population (*Populus tremula* x *P. tremula*). This population was derived from a controlled cross between two elite aspen trees collected in the “Elbsandsteingebirge”, a protected mountainous area near the Elbe river, 50 km south of Dresden, Germany. The 103 even aged F1-offspring (full-sib) were established in the greenhouse and planted in the field of the tree nursery of the Saxonian state-owned forest enterprise, Graupa near Dresden in 1998 on well drained sandy soil (1.0 m groundwater level).

A second population - 35 not even aged genotypes reference population - was selected from autochthonous material growing in natural succession on sandy dry or contrasting wet riparian sites between Berlin and Dresden, Germany. This population was used to obtain information about the typical growth and tree ring performance representative for the natural spectrum of autochthonous aspen sites under the continental climate conditions of Central and East Germany. Wood discs from stem were collected from the F1-population about 10 cm above ground and from the reference population about 30 cm above ground.

Cell length of vessels and fibres

Tree ring specific wood samples representing the complete growing period were obtained as described in the paragraph “Tree ring isotopes” of this chapter. The wood samples were incubated with Jeffrey’s maceration solution (Trendelenburg & Mayer-Wegelin 1955) for five hours at room temperature. After three washing steps the macerates were stained with safranin dye (1% aqueous solution) followed by additional three washing steps, careful manual cell separation in a droplet of water and fixation on a microscope slide with glycerine gelatine. Microphotos were taken at 50-times magnification. Cell length was measured for at least 10 vessels and 50 fibres per tree ring. The length of each intact cell (vessel VL and fibre FL) was measured (software package AxioVision, Carl Zeiss AG, Germany) in order to avoid bias of tree ring mean, due to subjective selection of cells with a specific length. All available tree rings were investigated.

X-ray wood densitometry

The measurements of mean tree ring wood density (XD) were performed as initially described for purposes of dendrology (Eschbach et al. 1995, Schweingruber 1988) on a Dendro Workstation (Walesch Electronics GmbH, Switzerland) except some modifications described by Günther (2004). Wood extractives had not to be removed before taking the X-ray radiography because of delayed heartwood formation in aspen (Wagenführ 2007). All tree rings of the respective tree populations were investigated.

Tree ring isotopes

Stem discs, approximately 1.0-1.5 cm thick, were sampled and stored at -20°C to avoid metabolic isotope fractionation or microbial activity. Cross and radial sections (20 µm and 100 µm), were dissected on a sliding microtome beginning at the same angle of the wood sample. Cross sections were stained with safranin dye (1% aqueous solution) in order to visualize tree ring boundaries positions which were transferred to the radial sections. Tree ring wood samples representing the whole growing period were separated by cutting the radial sections with a scalpel at the tree ring boundary lines. The α-cellulose was extracted from the annual ring slice samples following a procedure described in detail by Wiesberg (1974). All samples were processed using sodium hydroxide for chemical disintegration and sodium chlorite for bleaching. Homogenized cellulose samples were pyrolised to obtain either CO_2 for carbon isotope analyses or CO for oxygen isotope analysesThese combustion gases were separately analysed for ^{13}C or ^{18}O isotope contents using an element analyser linked with a mass spectrometer (Helle 1996, Treydte et al. 2006). Only the tree rings of 2002 (rather regular weather conditions at the sampling sites) and 2003 (drought year, but increased groundwater level following the big “2002 flood”) were investigated. Carbon isotope ($\delta^{13}C$) and oxygen isotope ratios ($\delta^{18}O$) were calculated according to Schleser (1995).

Results

Significant differences between the two populations were obtained for the performance of the young trees concerning all investigated traits. For the reference population, VL and FL mean tree ring values show the expected development (Zobel & van Buijtenen 1989) resulting in an increase approximately by 50 % (FL) and 40 % (VL) with cambium age from juvenile to adult tree rings (Fig. 1). XD is more variable in the first three tree rings than in the following ones. The reference population starts growing with a high mean value of 582 kg/m³ in the first tree ring (cambium age 1) and subsequently lowers the wood density in the next two tree rings to 525 kg/m³. The later tree rings have mean XD values around 550 kg/m³ and show a slightly downward tendency of XD with cambium age. The trend of the radial increment (i_r) is shown in figure 1. It follows a typical growth pattern of pioneer forest trees with a comparatively early culmination at cambium age 6. Only the first six years of growth were investigated in the F1-population (Fig. 1). Unlike the reference population, the even aged F1-population starts with higher mean values for VL and FL (cambium age 1, 1998). During the next two years VL and FL decrease, most probably due to a plant water deficit in the absence of a well developed root system. After the third year, tree rings have higher FL and VL with a tendency to increase. In the drought year 2003 the FL follows this tendency, while mean VL remains stagnant.

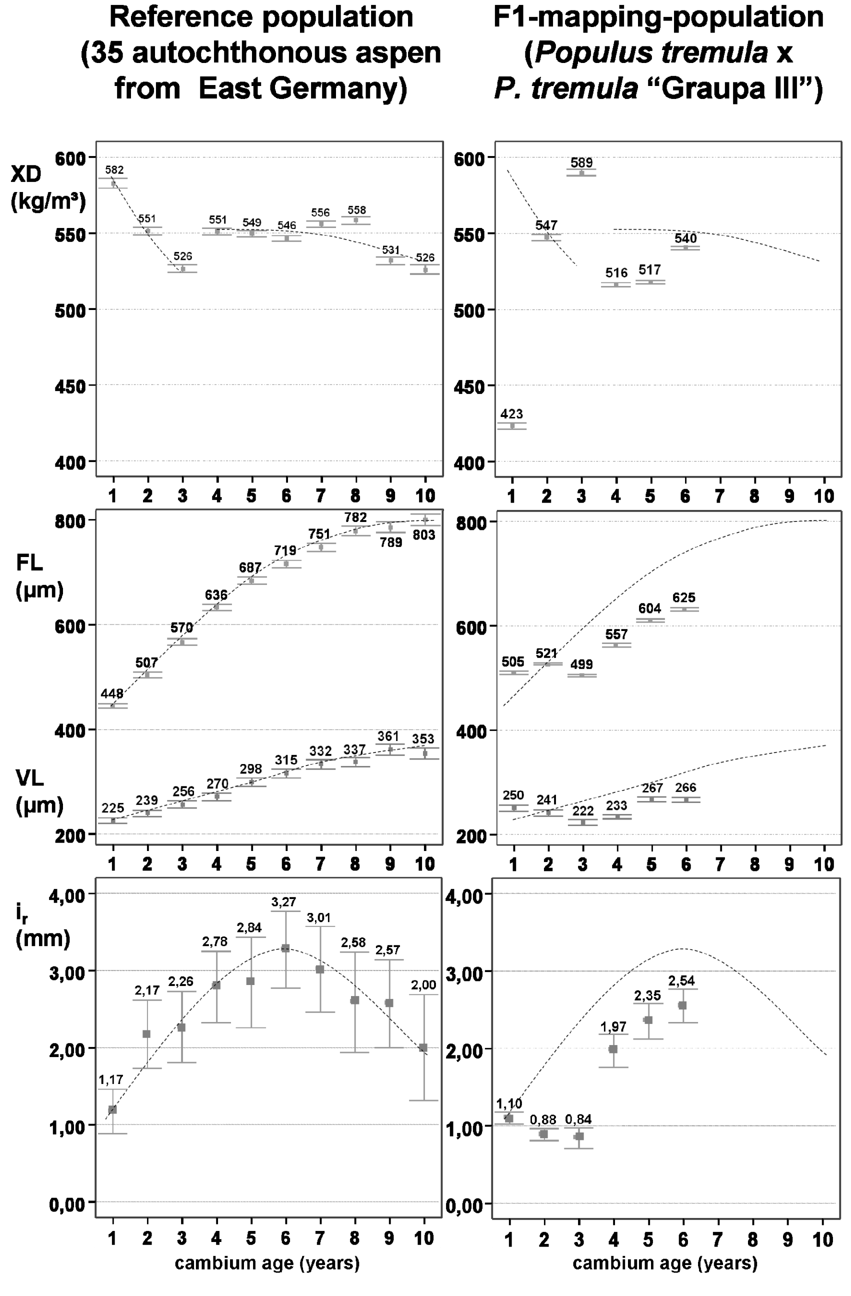

Figure 1: Mean X-ray wood density (XD), fibre length (FL), vessel length (VL) and radial increment (i_r) of the tree rings of two contrasting aspen (Populus tremula) populations – one not even aged from natural succession in East Germany on the left-hand side and one even aged F1 full-sib crossbred offspring on the right-hand side. Dotted lines (curve manually fitted) show the juvenile trend pattern of the respective trait in the reference population.

A pattern of adaptation to a water deficit after the transfer from the greenhouse to the field – combined with the absence of a root system – becomes also evident in the XD data for the F1-Population. In contrary to the XD values of the reference population, mean XD is very low in the first tree ring (423 kg/m³), and increases within the next two growing seasons to 588 kg/m³. The following two tree rings have nearly the same mean XD (517 kg/m³ or 518 kg/m³) while an increase of wood density was evident in the drought year of 2003, even though the trees had water supply from ground water. The mean i_r performed similar to FL. It starts with a value comparable to that of the first tree ring in the reference population. Unlike the reference population, the F1-population shows decreasing i_r in the next two vegetation periods and increasing values after successful root establishment.

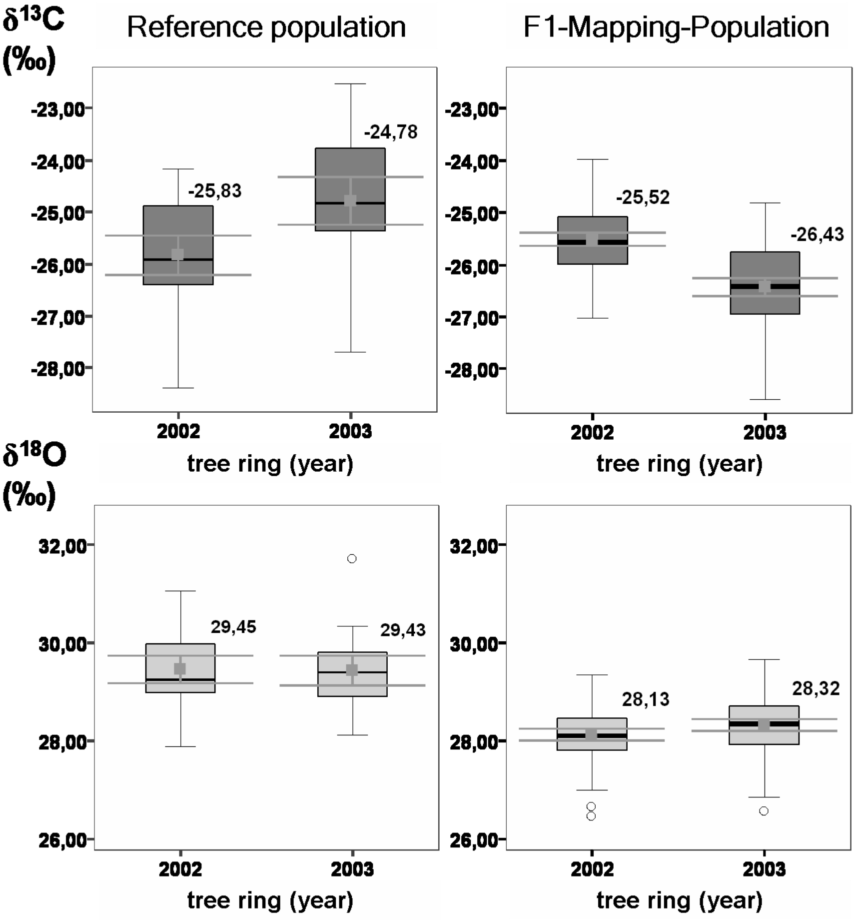

Figure 2: Mean $\delta^{13}C$ and $\delta^{18}O$ of the 2002 and 2003 tree rings of two contrasting aspen (Populus tremula) populations – one not even aged from natural succession in East Germany on the left-hand side and one even aged F1 full-sib crossbred offspring from a tree nursery without irrigation but good water supply via groundwater during 2003 summer drought vegetation period on the right-hand side.

$\delta^{13}C$ (Fig. 2) of the reference population, is significantly higher in 2003 (drought year) than in 2002 (rather normal year). The opposite behaviour is shown for $\delta^{13}C$ in the F1-population in 2003 compared with 2002. No changes between 2002 and 2003 were obtained for mean $\delta^{18}O$ in the reference population whereas a slightly increased mean $\delta^{18}O$ was detected in the 2003 tree rings of the F1-population (Fig. 2, T-test: P≤0,001; Wilcoxon-test: P≤0,002).

Discussion

The investigation showed that classical dendrological tree ring analysis can be used to compare the drought reaction of tree populations. With respect to the behaviour of the F1-population our results indicate that the effects of juvenility and drought interfere each other in young poplar because the root system has to be developed first. Compared with the reference trees which mainly originate from root sprouting, the F1-population trees suffer from water deficit in the first three years until root establishment. In the following years the F1-trees show the typical juvenile trend of FL, VL and i_r, but never reach the mean value level of the reference population. Therefore, our results support the assumption that the adaptation of trees during the first years can be essential for the performance of the poplar culture during the whole rotation period. This might be the major drawback for the establishment of poplar plantations on set-aside agricultural land, where the yield of the trees is markedly lower under suboptimal water supply (Röhle et al. 2008, Röhle et al. 2005, Wolf & Bönisch 2004).

In terms of tree breeding, drought resistance is not a directly measurable trait. It can only be determined indirectly by using other traits as proxies which are measurable and related with the trees reaction to water deficits. In cereal crop breeding, the most practicable proxy for drought tolerance of a genotype is its productivity under drought (Fischer & Maurer 1978). Therefore, in terms of tree breeding for agricultural purposes, drought tolerance should not be defined as the ability of a tree to withstand dry conditions or even long lasting drought periods but as the ability of maintaining yield under dry conditions. Drought tolerance of a tree in a narrow sense means that its yield reduction following drought is minimised. But most of the adaptations shown by the possible proxy-traits, result in an undesirable reduction of productivity in *Populus* (Marron et al. 2006, Monclus et al. 2006). To solve this problem in breeding practise, one has to find proxy-traits which are not negatively correlated with biomass yield because a high yield is the primary objective in agriculture. Dillen et al. (2008) and Monclus et al. (2005) investigated $\delta^{13}C$ in different poplar genotypes. They found out that the trees substantially differ in their WUEi under drought conditions and that these differences were not correlated with biomass yield as indicated by radial increment. Their conclusion was that this opens a perspective for breeding new stable cultivars with a minimum reduction of their productivity under drought. This conclusion was restricted to conditions of moderate drought, because tree growth is always depending on water availability and the trees ability to water uptake (Monclus et al. 2005).

With respect to the reaction of the F1-population in 2000 (comprehensive drought) and 2003 (atmospheric drought), we could show that some traits seem to answer only to a comprehensive plant water deficit (FL, i_r), whereas other seem to represent adaptation to atmospheric drought or water vapour deficit (VL, XD, $\delta^{13}C$, $\delta^{18}O$). In 2003, the radial increment – one parameter determining biomass yield, i.e. carbon gain – was not reduced. Wood density, the other indicator for carbon gain is higher, what points to some adaptation to drought. However, WUEi was reduced, as shown by the lower $\delta^{13}C$ value of the F1-population, in average by 9µmol CO_2 /mol H_2O (±30µmol/mol). The results support some of the conclusions of Dillen et al. (2008) and Monclus et al. (2005). We could show that a high XD is also a trait, which does not necessarily result in a yield reduction if radial increment does not decline unproportionally. Therefore, it might be a useful proxy for drought tolerance in breeding of poplar. It is well known that increased wood density results in a higher resistance to air embolism which is a severe damage to the hydraulic architecture of trees under drought (Cochard et al. 2007, Hacke et al. 2001). However, it is not known from literature if – in addition to the hydraulic safety aspect - a higher wood mean density can help to minimise increment decline under drought. Therefore, the factors influencing wood biomass yield under drought, e.g. vessel diameter, pit diameter and cell wall thickness as expressed by radial increment and density, have to be clarified in more detail in further investigations including stable isotope analyses as indication for water use efficiency.

Acknowledgements

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Natural and artificial defoliation impact on tree ring stable isotopes

Simard, S., Morin, H. & C. Krause

Dept. Sciences Fondamentales, Université du Québec à Chicoutimi, 555 Boul. de l'Université, Chicoutimi, Québec, G7H 2B1, Canada
Email: sonia_simard@uqac.ca

Introduction

Natural disturbance regimes are intrinsic ecological processes to forest ecosystems driving the forest dynamics. Besides forest fires, insect outbreaks are one of the most important disturbance in the North American boreal forest and have a substantial impact on the structure and composition of large forest areas. In the eastern part of the boreal forest, the spruce budworm (*Choristoneura fumiferana* Clem.) recurrently defoliates balsam firs (*Abies balsamea* [L.] Mill.), white spruces (*Picea glauca* [Moench] Voss), and also black spruces (*Picea mariana* [Mill.] B.S.P.), seriously decreasing the radial growth of trees up to the death of trees during high population episodes. During the last outbreak (1974-1988), more than 55 millions ha of forest were affected. Based on dendrochronological studies, spruce budworm outbreaks have been known to have a return interval of 32 ± 5.1 years since the last 450 years (Jardon et al. 2003, Boulanger & Arsenault 2004). However, the age of living forest, as well as historical wood, limits the length of reconstruction.

Subfossil woods buried in mires are another source of material available for outbreak reconstruction. As the standard methodology to identify insect outbreaks in a dendrochronological perspective consists of comparing radial growth patterns of host and non host trees (Swetnam et al. 1985), this approach is unlikely to be used due to the inherent difficulties encountered while building chronologies from subfossil trees. Moreover, while the traditional dendrochronological methods are sensitive to severe spruce budworm defoliation episodes they are not reliable indicators of moderate to light episodes and, consequently provide inaccurate estimates on the length and frequency of those outbreaks. It quickly appears that other proxies besides ring width are needed to better assess passed defoliation periods.

The objective of the research was to verify if carbon and oxygen stable isotopes could assist dendrochronological identification of past spruce budworm outbreaks in a multi-proxy approach. Mechanisms underlying the response of trees to defoliation were studied in a controlled experiment.

Material and Methods

Mature trees – Natural defoliation

Five different sites were selected for sampling, three for *A. balsamea*, one for *P. mariana* and one for *P. banksiana*. All sites were located within a 20 km radius, about 100 km north of Chicoutimi (48° 25'N, 71° 4'W), Quebec, Canada. They belonged to the east balsam fir – white birch domain of the continuous boreal forest. Regional climatic conditions for 1942-1990 (Bagotville meteorological station, 48°20'N, 71°0'W, 159 m a.s.l.) are characterized by a mean temperature of 2.2°C and a mean annual precipitation of 930 mm, 37% of which fell as snow during this period.

Sampled *A. balsamea* and *P. mariana* were part of *Abies balsamea – Picea mariana* mixed mature stands located on slopes surrounding depressions forming peatlands. The minimal mean age of *A. balsamea* stand was 75 years (age at breast height), 140 years for *P. mariana* and 71 years for *P. banksiana*.

Two cores from the five best crossdated trees per site, i.e showing the highest correlation and also large growth reduction during outbreak periods in the early 1950s and 1970s, were chosen for carbon and oxygen stable isotope analyses. Exact dating of the rings was ensured by synchronizing growth patterns with existing chronologies. Standard dendrochronological methods were applied.

Since the two most recent outbreak periods in the studied area occurred in the 1950s and 1970s (Morin & Laprise, 1990), annual rings from the 1940-1990 period were separated from each core with a scalpel, under a binocular microscope, at the latewood-earlywood border of the subsequent year, the entire ring being analysed. Within each site, tree rings of the same calendar date were pooled prior to isotope analyses. Rings were ground using a steel ball mill (MM200; Retsch, Haan, Germany). Holo-cellulose was isolated by delignification in an acetic-acid-acidified sodium chlorite solution, after first removing oils and resins with toluene-ethanol and ethanol soxhlet extractions. Holo-cellulose was then reduced to alpha-cellulose in sodium hydroxide. Samples for carbon isotopic analysis were converted to CO_2 with an elemental analyzer (ECS 4010, Costech Analytical, Valencia, CA) and analyzed with a continuous flow isotope ratio mass spectrometer (Delta PlusXP, Thermofinnigan, Bremen). Samples for oxygen isotopic analysis were converted to CO with a pyrolysis elemental analyzer (TC/EA, ThermoFinnigan, Bremen) and also analyzed with a continuous flow isotope ratio mass spectrometer (Delta PlusXP, Thermofinnigan, Bremen). Isotopic results are reported in per mil (‰) relative to VPDB (Vienna Peedee belemnite) and VSMOW (Vienna Standard Mean Ocean Water) standards, respectively.

Young trees – artificial defoliation

A growth experiment to test the effects of different degrees of defoliation on tree-ring widths and wood holo-cellulose isotope composition ($\delta^{13}C$ and $\delta^{18}O$) was conducted in both open field and greenhouse settings at the Université du Québec à Chicoutimi, Canada. The defoliation experiment was performed during four growing seasons (natural and simulated) between 2005 and 2006 on five year-old *A. balsamea* seedlings. When kept in greenhouse, a drip irrigation system supplied an amount of water equal in mass to the daily loss in seedling biomass while maintaining the soil at 85-90% field capacity. When placed outdoor, they received both water from precipitations and irrigation system. The simulated summers were initiated by raising the greenhouse temperature to 22 °C and maintaining a nighttime temperature of 17 °C. These temperatures reflect the maximum and minimum temperatures recorded during the months of June-July in the central part of the geographical distribution of the studied species. To mimic the open conditions of the boreal forest during the growing period, the photoperiod was extended to 18 h with an extra photosynthetic photon flux of 115 µmol•m-2•s-1 provided by 400-W wide-spectrum high-pressure sodium bulbs (Lucalox LU400, General Electric Co., Cleveland, OH).

The experiment was designed as a three-block, fully randomized split-plot design, with four growth seasons of treatments application as the main plot, four different levels of current year needles defoliation (0%, 33%, 66% and 99%) [CYD] and two levels of past years defoliation (0% and 50%) [PYD] as the subplot. The defoliation was done manually using scissors. Gas exchange measurements were taken during all four growing seasons using a LI-6400 portable photosynthesis system (LI-COR Inc., Lincoln, NE). The measurements were made in the nursery holding area before midday under supplemental fluorescent lighting to ensure that the seedlings received saturating photosynthetically active radiation (>1 000 μmol m-2 s-1) while needle light-saturated CO_2 assimilation (A) and stomatal conductance (g_s) was being evaluated. During the gas exchange evaluations a cylindrical conifer foliage cuvette was alternatively placed over the lateral branches of the first and second verticils representing the current year and 1 year-old shoots, respectively.

Seedlings were harvested after each growing seasons. Serial transversal cross-sections (90 µm thickness) were removed from stem sections using a sliding microtome (Leica SM2400, Germany). Annual rings corresponding to growing seasons 1 to 4 were subsequently scalpel separated (latewood-earlywood border) under a binocular microscope for all the different defoliation treatments. Holo-cellulose was extracted and isotope analysis performed as described above.

Results and Discussion

The dendrochronological analysis revealed important growth reduction during the known spruce budworm outbreaks that occurred in the 1950s and 1970s in the host species but not in the non-host one (Fig. 1). Despite a severe outbreak in the 50s, the ring widths of the secondary host *P. mariana* did not record well the impact of the defoliation. Nealis and Regnière (2004) showed that *P. mariana*, although vulnerable to spruce budworm attacks during infestation, is generally less defoliated than other host species. This lower vulnerability is explained by a temporary reduction in susceptibility of the tree species resulting from a lack of synchronism of spring larval emergence and bud burst. However, both defoliation periods seemed to be well captured by the carbon isotopic signal in both host species. Carbon isotope values enriched of about 1‰ in parallel with ring width decrease. The following carbon depletion occurred apparently in synchronization with growth recovery. Although the analysis covers only the last outbreaks, no significant growth reduction nor carbon isotope response were observed in the end of the 70s for *P. banksiana,* a non-host species to the spruce budworm. That host - non-host comparison suggests carbon enrichment as a result of defoliation (Fig. 1). Despite high agreement between *P. mariana* and *A. balsamea* oxygen isotope series, no clear pattern in association with outbreak periods was evidenced. Moreover, correspondence with the δ^{18}O series of *P. banksiana* likely indicates variations originating from a common source, presumably of climatic origin.

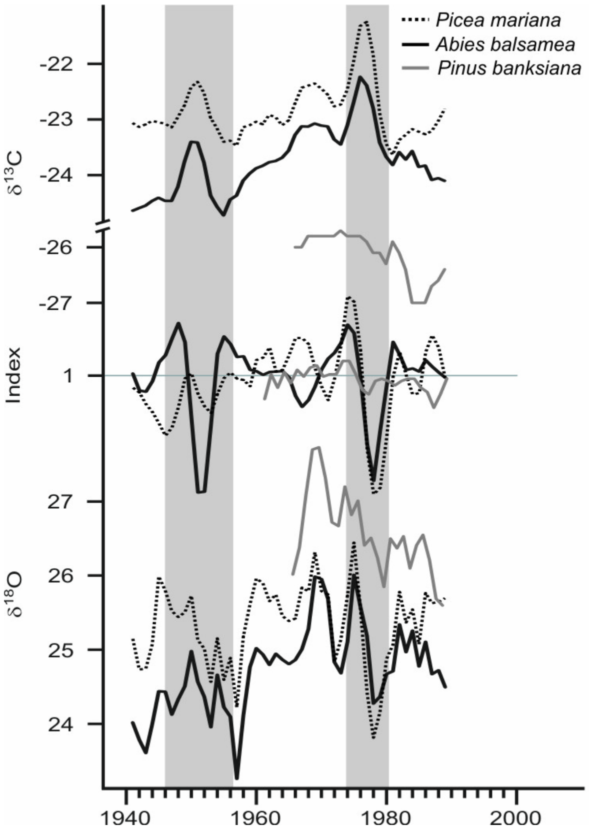

Figure 1: α-cellulose carbon isotope composition, tree-ring indices and α-cellulose oxygen isotope composition of Picea mariana, Abies balsamea and Pinus banksiana. Shaded areas indicate aerial survey observations of defoliation caused by the spruce budworm in the region (Hardy et al., 1985) covering the period 1930-80. All curves were smoothed using a 3-year moving average. (Modified from Simard et al. 2008)

Defoliation is known to alter the gas exchange functions in trees. Increased photosynthetic rate per unit area of residual and/or regrowth foliage as a compensatory mechanism has been observed in *A. balsamea* (Lavigne et al. 2001, Little et al. 2003), as well as in other coniferous species (Reich et al., 1993, Vanderklein & Reich 1999, Chen et al. 2001). Those modifications affect the ratio of the partial pressure of CO_2 in the leaf intercellular spaces (c_i) to that of the ambient air (c_a), variations of which control the carbon isotope compositions of tree-ring cellulose (Farquhar et al. 1982). Reduced discrimination against ^{13}C due to increased CO_2 assimilation rate is suggested as one of the mechanisms responsible for the enriched tree-ring cellulose carbon isotope composition, at least at the beginning of the outbreak period. However, other mechanisms most likely also contribute to the carbon isotope response. Starch reserves stored from previous growing seasons provide enough pre-cellulose substrate for compensated growth during defoliation episodes. The starch in tree species tends to be carbon isotope enriched (Brugnoli et al. 1988, Le Roux et al. 2001 Damesin & Lelarge 2003, Helle & Schleser 2004) and, therefore, any compensated mobilization and incorporation of reserved cellulose substrate, during even moderate to light defoliation episodes, should also contribute to the enrichment observed.

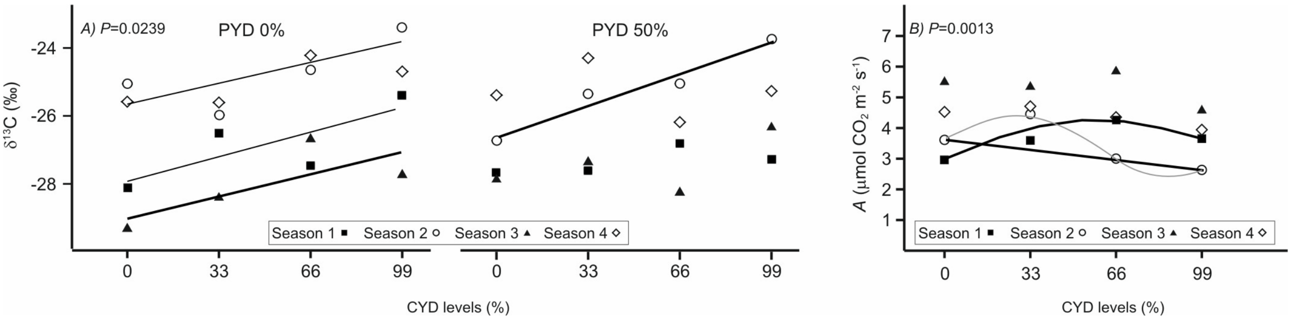

Figure 2: A) Tree-ring carbon isotope composition ($\delta^{13}C$) variations in response to the four growing season current- and past-years defoliation treatments. Bold and thin lines indicate greater than 95% ($P<0.05$) and 90% ($P<0.10$) significance, respectively (table 1a) and B) Light-saturated CO_2 assimilation rate (A) of combined current-year and 1-year old foliage of balsam fir seedlings in response to different levels of current-year artificial defoliation measured during the four growing seasons (Tab. 1b).

This hypothesis was supported by the controlled experiment carried out on young *A. balsamea* (Fig. 2A, B) (Tab. 1A). A linear relationship between the carbon enrichment with increasing magnitudes of current-year needles defoliation was reproduced artificially (Tab. 1a; Fig. 2A). This positive relationship was evidenced during the three first seasons and seems to hold mainly when parts of current-year needles only were removed from the seedlings. Changes in *A* associated to artificial defoliation were also found to be significant during the first season of the experiment (Tab. 1B; Fig. 2B). The significant quadratic relationships observed during the first season suggest that low to intermediate levels of defoliation are more susceptible to stimulate compensating increases in *A* than heavy defoliation. Although the linear relationship reached a higher level of significance for season 2, the cubic one also achieved a highly significant one (P=0.001 vs P=0.006, respectively) suggesting that increased *A* might also play a role but only for the light level of defoliation.

While compensating increases in CO_2 assimilation rate may play a role in the early part of the defoliation period, the absence of response in seasons 3 and 4, as well as for the heaviest level of defoliation (99%), suggests that other mechanisms contribute to the observed carbon isotopic enrichments, most likely the use of enriched reserves as previously mentioned.

The c_i/c_a ratio variations which control the carbon isotope compositions of tree-ring cellulose can arise by either reduced stomatal conductance or increased photosynthetic capacity, the other being equal (Farquhar et al. 1982, Scheidegger et al. 2000). At a constant relative humidity, markedly reduced stomatal conductance rates would have likely resulted in depleting oxygen isotope trends with increased defoliation treatment magnitudes. However, this relationship was not evidenced in fig. 2A or tab. 1A. The defoliation had no significant impact on oxygen isotopes ratios in tree rings or on the stomatal conductance of the needles (Tab. 1A, B).

Table 1: Summary of A) a) repeated-measures ANOVA (F- and P-values) for wood cellulose carbon isotope compositions (δ^{13}C) and oxygen isotope compositions (δ^{18}O) and b) within season contrasts for δ^{13}C values during the four growing seasons. P-values for repeated-measures ANOVA are presented with Huynh-Feldt corrected probabilities, and B) ANOVA (F- and P-values) for light-saturated CO_2 assimilation rate (A) and stomatal conductance (g_s) during four growing seasons. Bold numbers indicate greater than 95% significance (P<0.05). ndf = numerator degrees of freedom; ddf = denominator degrees of freedom, CYD = current-years defoliation, PYD = past-years defoliation. ^{a} Ln transformed data.

A)		δ^{13}C			δ^{18}O		
Source	***ndf***	***ddf***	***F***	***P***	***ddf***	***F***	***P***
a) Between-subjects							
block	2	14	3.50		9	5.99	
CYD	3	14	2.50	0.102	9	1.24	0.352
PYD	1	14	0.12	0.738	9	1.03	0.337
CYD*PYD	3	14	0.52	0.676	9	0.84	0.507
Within-subject							
time	3	42	45.10	**<.0001**	27	4.64	**0.009**
time*CYD	9	42	0.95	0.493	27	1.28	0.290
time*PYD	3	42	1.44	0.243	27	1.80	0.171
time*CYD*PYD	9	42	2.47	**0.023**	27	1.61	0.162
b) Within season contrasts							
Season 1							
CYD lin (PYD0)	1	14	4.08	0.063			
CYD lin (PYD50)	1	14	0.30	0.590			
CYD quad (PYD0)	1	14	0.09	0.771			
CYD quad (PYD50)	1	14	0.13	0.725			
CYD cub (PYD0)	1	14	2.45	0.139			
CYD cub (PYD50)	1	14	0.29	0.601			
Season 2							
CYD lin (PYD0)	1	14	3.93	0.067			
CYD lin (PYD50)	1	14	8.70	**0.010**			
CYD quad (PYD0)	1	14	2.37	0.145			
CYD quad (PYD50)	1	14	0.00	0.956			
CYD cub (PYD0)	1	14	0.50	0.490			
CYD cub (PYD50)	1	14	0.45	0.512			
Season 3							
CYD lin (PYD0)	1	14	5.82	**0.030**			
CYD lin (PYD50)	1	14	1.90	0.189			
CYD quad (PYD0)	1	14	2.70	0.122			
CYD quad (PYD50)	1	14	1.38	0.260			
CYD cub (PYD0)	1	14	1.77	0.204			
CYD cub (PYD50)	1	14	2.47	0.138			
Season 4							
CYD lin (PYD0)	1	14	1.10	0.312			
CYD lin (PYD50)	1	14	0.15	0.700			
CYD quad (PYD0)	1	14	0.07	0.798			
CYD quad (PYD50)	1	14	0.01	0.921			
CYD cub (PYD0)	1	14	0.71	0.412			
CYD cub (PYD50)	1	14	2.23	0.157			

B)		A^a			g_s		
Source	***ndf***	***ddf***	***F***	***P***	***ddf***	***F***	***P***
Main plot							
block	2	5.94	0.51		4.49	0.87	
time	3	7.67	15.68	**0.001**	7.61	25.86	**0.0002**
Subplot							
CYD	3	62.05	3.44	**0.022**	64.25	0.40	0.751
PYD	1	84.43	0.71	0.401	74.93	0.02	0.876
CYD*PYD	3	62.22	0.63	0.593	64.28	0.23	0.869
time*CYD	9	62.98	3.53	**0.001**	64.65	1.52	0.157
Contrasts							
Season 1							
CYD lin	1	104.94	3.78	0.054			
CYD quad	1	82.10	13.42	**0.044**			
CYD cub	1	104.94	1.36	0.246			
Season 2							
CYD lin	1	105.48	10.80	**0.001**			
CYD quad	1	80.96	4.31	**0.041**			
CYD cub	1	51.29	8.23	**0.006**			
Season 3							
CYD lin	1	111.72	0.89	0.346			
CYD quad	1	89.29	1.38	0.243			
CYD cub	1	55.35	0.90	0.347			
Season 4							
CYD lin	1	105.00	1.01	0.317			
CYD quad	1	82.96	0.21	0.651			
CYD cub	1	53.64	0.18	0.671			
time*PYD	3	84.36	1.03	0.382	74.93	0.50	0.681
time*CYD*PYD	9	63.12	1.19	0.312	64.62	0.49	0.874

Other environmental modifications as drought could also lead to a similar ring print in terms of δ^{13}C and tree-ring widths variations. However, stable carbon isotope enrichments and possible ring width reductions would originate from a modification of the stomatal conductance, and as a consequence, of the tree-ring stable oxygen signature also. Those three variables, in the context of outbreak detection, should then be analysed and viewed in a multi-proxy approach.

Conclusions

The objective of this research was to validate the use of stable isotopes as an efficient and sensitive indicator of defoliation, in a multi-proxy approach, in order to better identify past spruce budworm outbreak periods. Evidence has emerged suggesting that carbon isotopes are in fact sensitive to foliage losses. Although low to moderate defoliation levels do not necessary leave a distinct tree ring growth reduction, they seem to trigger a physiological response early in the "outbreak" period in terms of increased CO_2 assimilation rate which can be traced back in the ring as enriched ^{13}C cellulose. This signal, along with the oxygen isotope one, makes stable isotopes an interesting and valuable tool in the reconstruction of the dynamics of past defoliating insect outbreaks.

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SECTION 3

ECOLOGY

Relationships between tree-ring width and date of phenophases: A case study with silver birch (*Betula pendula* Roth.)

Bijak, Sz.[1] **& K. Jatczak**[2,3]

[1] Department of Dendrometry and Forest Productivity, Faculty of Forestry, Warsaw University of Life Sciences-SGGW
[2] Meteorology Centre, Institute of Meteorology and Water Management, Warsaw, Poland
[3] Department of Plant Ecology and Nature Protection, Faculty of Biology, Warsaw University
Email: Szymon.Bijak@wl.sggw.pl

Introduction

The annual course of climate factors like solar radiation, temperature or precipitation is reflected in various characteristics of a tree, especially in its diameter increment. Favourable conditions result in a wider tree-ring, while the impact of unfavourable factors produces very small increment (Fritts 1976, Schweingruber 1996). Cambium activity and hence duration of tree-ring formation are limited to the vegetation season. So it could be hypothesised that the longer it lasts, the more possibilities the tree has to utilise resources more effectively for the growth (Wojda 2004).

Changes in leaf cover status are the most visible indication of tree's activity and their record (phenological observations) can bring valuable information about the tree growth (Wojda 2004, Hajkova et al. 2007). On the basis of such research, different phases of the growing season can be distinguished. When the buds sprout and leaves unfold, the auxin begins to circle and cambium cell division initiates. Analogously, leaves fall may indicate alternation of growth processes and preparation for the winter dormancy. Accordingly, the length of the tree activity should translate into the tree-ring width. Hence, the earlier the leaves appear and/or the longer they stay on the tree, the wider the ring should be formed.

Although the growth of silver birch is recognised well (Prevosto et al. 1999, Dmyterko & Bruchwald 2000, Bruchwald et al. 2001, Bruchwald 2002), studies on the relations between its wood formation, tree-ring width and phenology are rather limited (Lagefoged 1952, Schmitt et al. 2004, Rousi & Pusenius 2005). The objectives of the study were to determine the relationship between annual diameter increment and the date of phenological phenomena as well as to analyse whether it is possible to predict the tree-ring width basing upon the date of phenophases. If so, such knowledge could be a useful support in, e.g., forest practice for the simple forecast of the timber production for a given year.

Data

We tested our hypothesis by using silver birch (*Betula pendula* Roth.) growing in north-eastern Poland as an example. Phenological data originate from archives of the Institute of Meteorology and Water Management. The dates of leaves unfolding and fall have been registered at Dąbrowa Białostocka and Mielnik study plots. Dendrochronological records were supplied from the database of the Department of Dendrometry and Forest Productivity (WULS-SGGW). Tree-ring width measurements were carried out at Czarna Białostocka, Supraśl and Sarnaki sites. A short overview on the analysed data is given in table 1. The air temperature records describing the climatic conditions in the region were delivered from the Institute of Meteorology and Water Management, and represent the Siedlce and Białystok stations.

The common time span for all data types covers the period of 1951-1990, which was also used for the analyses. The length of that period is large enough to consider the obtained results to be statistically representative.

Table 1: Data description

site	tree-ring series [indices]			
	time span	# of series	minimum	maximum
Czarna Białostocka (Cz)	1911-1999	16	0,685	1,513
Sarnaki (Sa)	1871-1999	21	0,536	1,641
Supraśl (Su)	1936-1999	20	0,759	1,158
site	**date of leaves unfolding [days from Jan. 1st]**			
	time span	**mean**	**minimum**	**maximum**
Dąbrowa Białostocka (D)	1951-1992	122	94	135
Mielnik (M)	1951-1990	118	98	132
site	**date of leaves fall [days from Jan. 1st]**			
	time span	**mean**	**minimum**	**maximum**
Dąbrowa Białostocka (D)	1951-1992	269	221	288
Mielnik (M)	1951-1990	296	278	316

Methods

Tree-ring standard and residual chronologies were built using the CRONOL program from the DPL package (Holmes 1999). Relationships between tree-ring width indices and dates of phenophases were described with linear regression models. Dendrochronological data from Czarna Białostocka and Supraśl were related to phenological records from Dąbrowa Białostocka, while tree-ring widths from the Sarnaki site were compared with Mielnik dates. The significance of the model parameters was checked with Student's t-test at the level of 0,05. Statistical analyses were performed using Statgraphics Plus 4.0. In order to investigate the influence of climate factors on both features, i.e. tree-ring widths and date of phenophases, their response to temperature was analysed using response function analysis (Fritts 1976). Parameter determination and their significance tests were performed with the DendroClim2002 software (Biondi & Waikul 2004). Białystok served as the climate reference station for Czarna Białostocka, Dąbrowa Białostocka and Supraśl data, while temperature from Siedlce was used for Mielnik and Sarnaki analysis.

Results

Linear models (y = ax+b) of the dependence of the annual diameter increment on the date of the phenophases occurrence were determined (Fig. 2, 3; Tab. 2).

Table 2: Parameters of the linear regression models for the dependence of silver birch tree-ring width on the date of leaves unfolding and fall.

	leaves unfolding		
relation	**a**	**b**	**R^2**
Cz-D	-0,0034	1,3657*	0,037
Sa-M	0,0035	0,5632*	0,073
Su-D	-0,0031	1,3439*	0,058
	leaves fall		
relation	**a**	**b**	**R^2**
Cz-D	-0,0033	1,8867*	0,085
Sa-M	0,0022	0,3150	0,032
Su-D	-0,0005	1,1017*	0,003

a, b – parameters; R^2 – coefficient of determination;
Cz, D, M, Sa, Su – see table 1.; * values significant at the 0,05 level.

In Czarna Białostocka and Supraśl sites earlier leaves unfolding was followed by wider tree-rings. However later leaves fall did not result in larger diameter increment. As far as the Sarnaki site is concerned, the analysed relationship is opposite (Fig. 2, 3).

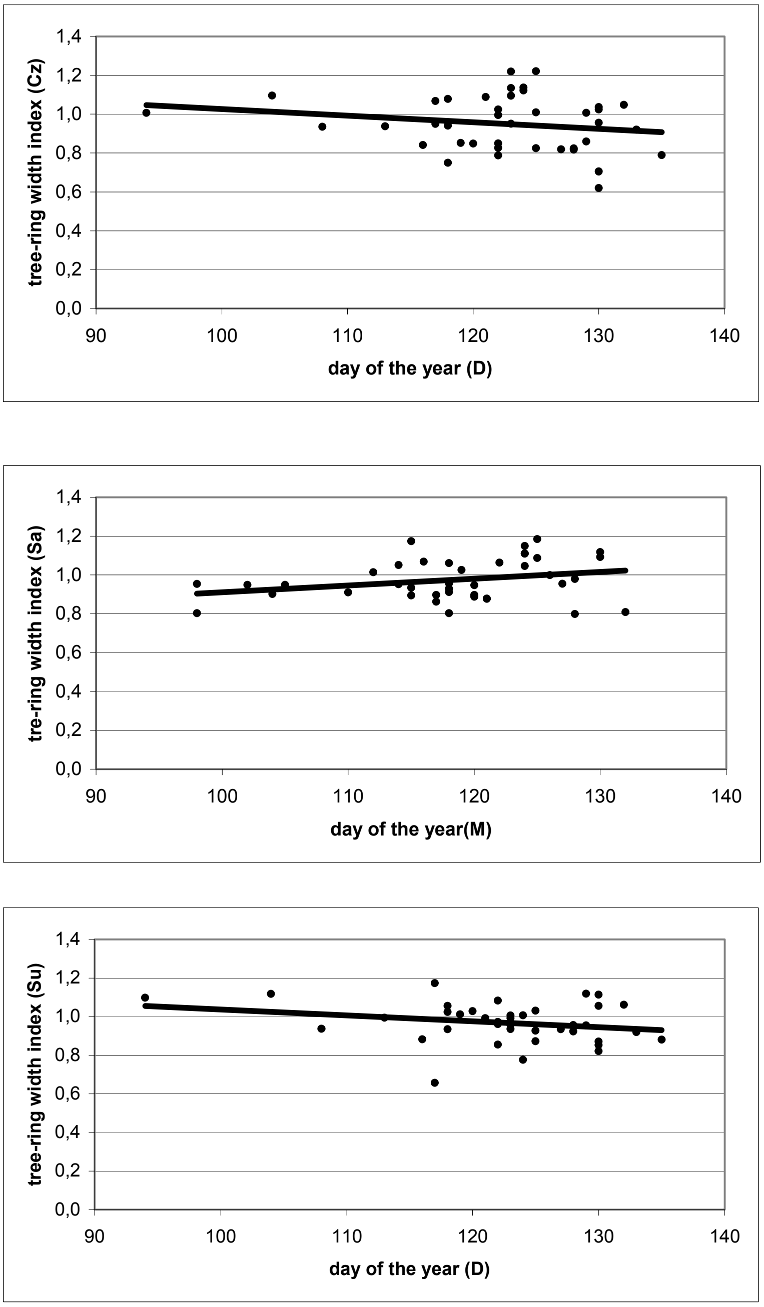

Figure 2: Dependence of silver birch tree-ring width on the date of leaves unfolding; Cz, D, M, Sa, Su – see table 1.

The date of leaves unfolding is mainly driven by spring temperature, which is confirmed by significant negative correlations between these features for March (Dąbrowa) and April (Dąbrowa and Mielnik) (not shown). Date of leaves fall is less thermal-dependent as there is no significant relationship for Mielnik and in case of Dąbrowa only influence of temperature in August is statistically important. In this case, precipitation might play a more important role. In turn, tree-ring width seems to be governed by thermal conditions in early summer. Temperature of June is negatively correlated with tree-ring width for all sites and this relation is significant for Czarna and Sarnaki.

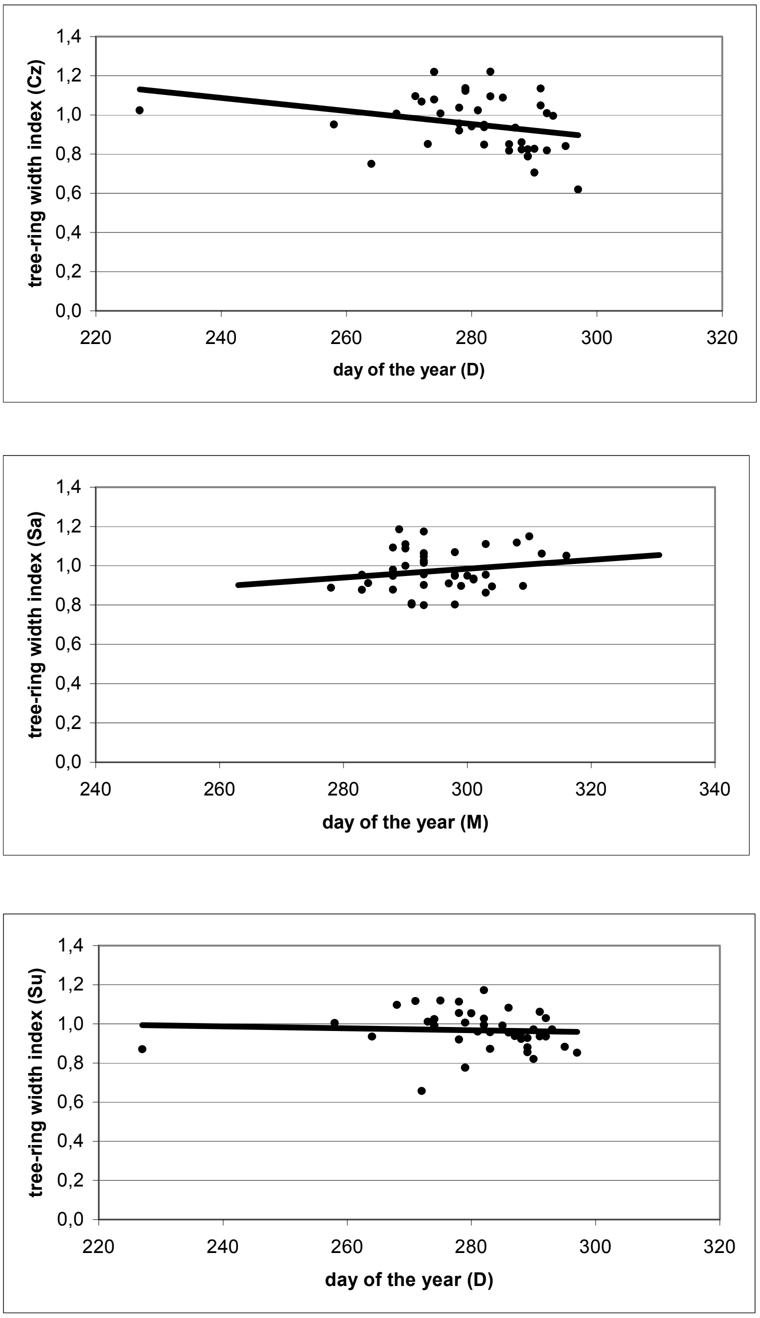

Figure 3: Dependence of silver birch tree-ring width on the date of leaves fall; Cz, D, M, Sa, Su – see table 1.

Discussion

Schmitt et al. (2004) reported that in general cambium activity of birch in Finland starts to proceed when leaves are fully unfolded. In turn, Ladefoged (1952) informs that the tree-ring of birch begins to form about one month later than the leaves appear on the branches. The relationship between tree-ring width and date of phenophases in north-eastern Poland turned out to follow the expectations only to some extend. Earlier leaf unfolding is followed by wider tree-rings at Czarna Białostocka and Supraśl sites. At the Sarnaki study plot, the pattern is opposite. Similar situation can be observed when relationship between tree-ring width and leaves fall is concerned. These differences in the relationship pattern that are observed between northern (Czarna, Dąbrowa, Supraśl) and southern (Mielnik, Sarnaki) sites may be the result of trees genetic origin. Wojda

(2004), as well as Rousi & Pusenius (2005), report that similar climate conditions cause slightly different phenological reaction among various provenances of *Betula* spp.

Climate conditions seem to have different influence on phenology and wood formation of silver birch. While leave unfolding depends mostly on the thermal conditions of early spring (Lechowicz 2001), tree-ring formation is mainly influenced by conditions in the middle of the growing season (Schweingruber 1996). Response function analysis shows that leave unfolding in north-eastern Poland is driven by temperature in April whereas diameter growth depends on thermal conditions in June and July. Relationship of leaves fall is more complex and it seems that precipitation plays more important role in this case.

Conclusions

No obvious or significant correlation between silver birch tree-ring width and date of leaves unfolding and fall was found for north-eastern Poland. This puts in doubt potential application of the phenology in approximate forecast of the tree annual diameter increment. It could be the result of different dependence of these two features on climate factors, especially temperature. Moreover, there might be other conditions (e.g. genetic regulations, soil fertility, and water/moisture availability) that may also influence cambial activity.

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Air pollution and forest disaster in the Western Sudetes in the light of high elevation spruce tree ring data

Godek, M., Migała, K. & M. Sobik

Department of Meteorology and Climatology, University of Wroclaw, 8 Kosiby Str. PL 51-670 Wroclaw
Email: godek@meteo.uni.wroc.pl

Introduction

The Karkonosze are the highest part of the Sudetes mountains, located in the western part of this area, in the vicinity of numerous industrial centres. Intensive development of power industries in the surrounding of the Sudetes, started in the 1950ies and resulted in a catastrophic ecological disaster in the Western Sudetes, clearly visible since 1978. The industry is mainly based on output and combustion of sulphur-containing hard coal, responsible for the emission of gaseous pollutants from the territory of Poland (Bogatynia-Turoszów), the Czech Republic (Most, Jezeři) and Eastern Germany (Hirschfelde). The mechanism of air pollution deposition in the Sudetes is very efficient and is strictly connected to two simultaneous processes: wet deposition (fog and rime) and “seeder-feeder” effect (Sobik & Migała 1993, Sobik 1999). Fog and rime deposition is most important in the context of the role of trees as a barrier for humid air-flow during direct contact between clouds and mountain slopes (Błaś 2001).

Despite the moderate altitude, the Karkonosze are characterized by the highest frequency of fog observed in Europe, reaching up to 300 days per year (Błaś & Sobik 2000). The so called seeder-feeder effect is observed, while precipitation generated in synoptic-scale clouds above the atmospheric boundary layer is enriched with polluted water from lower local-scale orographic clouds, that are not able to generate any precipitation by themselves (Carruthers & Choularton 1983). This process results in an increase in precipitation and as well strongly reduces its pH value. Average fog frequency on the summit of Mt Szrenica is 274 days per year (1364 m a.s.l.), which is representative for the western part of the Karkonosze (Błaś & Sobik 2000). Annual total of precipitation at the same place amounts to 1430 mm (Dore et al. 1999). On the climax of the air pollution deposition in the highest part of the Western Sudetes pH values of the precipitation of below 3,8 were registered. Due to this situation, the Sudetes and other mountain areas near the intersection of the borders of the three above-mentioned countries have received name “Black Triangle Region”.

Air pollution concentration in this area reached the highest level ever measured in Europe in the period 1979-1982. The most important pollutants were SO_4, SO_2, NO_3 and NH_4, formidable chemical compounds for spruce ecosystems (Michaelis 1997). Strongly limited acid buffering capacity of granite bedrocks and dominant, monocultural structure of anthropogenic coniferous forests significantly worsened the situation in the Western Sudetes. At this time, widespread areas of mountain spruce-forests had withered (Fig. 1). In the Polish part of the Sudetes 13500 ha of forest have been destroyed and 92,7% of the remaining conifers were classified as partially damaged. The most destroyed parts have been situated on the wind-exposed slopes. Natural spruce forest survived only on small areas and is classified as Calamagrostio villosae – Piceetum hercynicum, formed by the hercynian spruce subspecies (Matuszkiewicz 2002).

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Figure 1: Deforested area in the Giant Mountains in Western Sudetes, beginning of the nineties (photo by M. Sobik).

Material and Methods

Four dendrochronological samples from high elevation spruce stands located in the zone of the Karkonosze tree line (1150-1280 m a.s.l.) were collected in 1999 (Migała 2005). Three of them were taken from below the tree line from trees rising in partially damaged forests and one was taken from a single tree growing beyond the tree line, in the surrounding of dwarf-mountain-pine. All samples came from trees from north- to north-west-exposed slopes and were taken at stem height of 130 cm above the ground level. The main goal of the research was to identify the meteorological conditions associated with spruce-forest dieback and to estimate the influence of air pollution deposition on tree ring growth dynamics in the Sudetes, using dendrochronological methods. Moving averages (5-years) of the relative stem diameter increment of the four spruce trees were compared with estimated and measured air pollution deposition rates.

Results

A period of reduced vitality of spruce between the years 1965 and 1985 was identified, after which a systematic increase in increments was evident (Fig. 2).

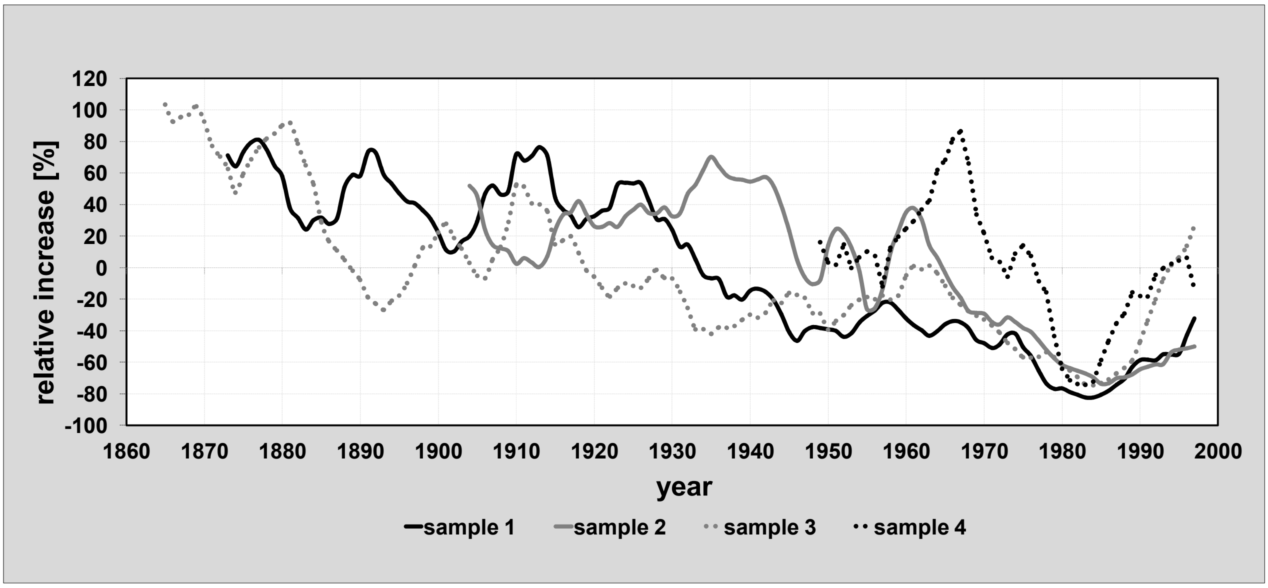

Figure 2: Moving averages (5-years) of relative stem diameter of the spruce (Picea abies) sample trees on the tree line in Western Karkonosze.

For each sample in the first half of the eighties the minimum relative increment was between -70% and -85%. Before this breakdown of the forest ecosystem the spruces had relative increment rates above +60%. The analysed trees were different in age and had periods of optimal vitality in different decades during the XX century. Reduced vitality of trees between 1965 and 1985 is still strongly visible for each sample and related to increase of air pollution deposition. Power production, based on bituminous coal increased in Poland from 7 TWh in 1950 to 79 TWh in 1985. The production, based on more sulphur-containing, hard coal increased in Poland from 0 TWh in 1950 to 46 TWh in 1985 (KSE 2005). A similar process took place in Czech Republic and then in Eastern Germany.

It was concluded, that the contemporary improvement of forest condition in the Black Triangle Region is an effect of two simultaneous processes. First of them is the gradual decrease of air pollution concentration (Błaś et al. 2007). The average SO_2 concentration in Poland decreased from 11,301 µgS/m³ in 1985 to 2,688 µgS/m³ in 2000; and concentration of SO_4 decreased from 4,282 µgS/m³ in 1985 to 1,091 µgS/m³ in 2000 (Fig. 3). Average NH_3 + NH_4 concentration in Poland decreased from 4,886 µgN/m³ in 1985 to 2,629 µgN/m³ in 2000; pH of precipitation on the Mt. Śnieżka changed from 3,9 in 1985 to 4,4 in 2000 (EMEP 2008).

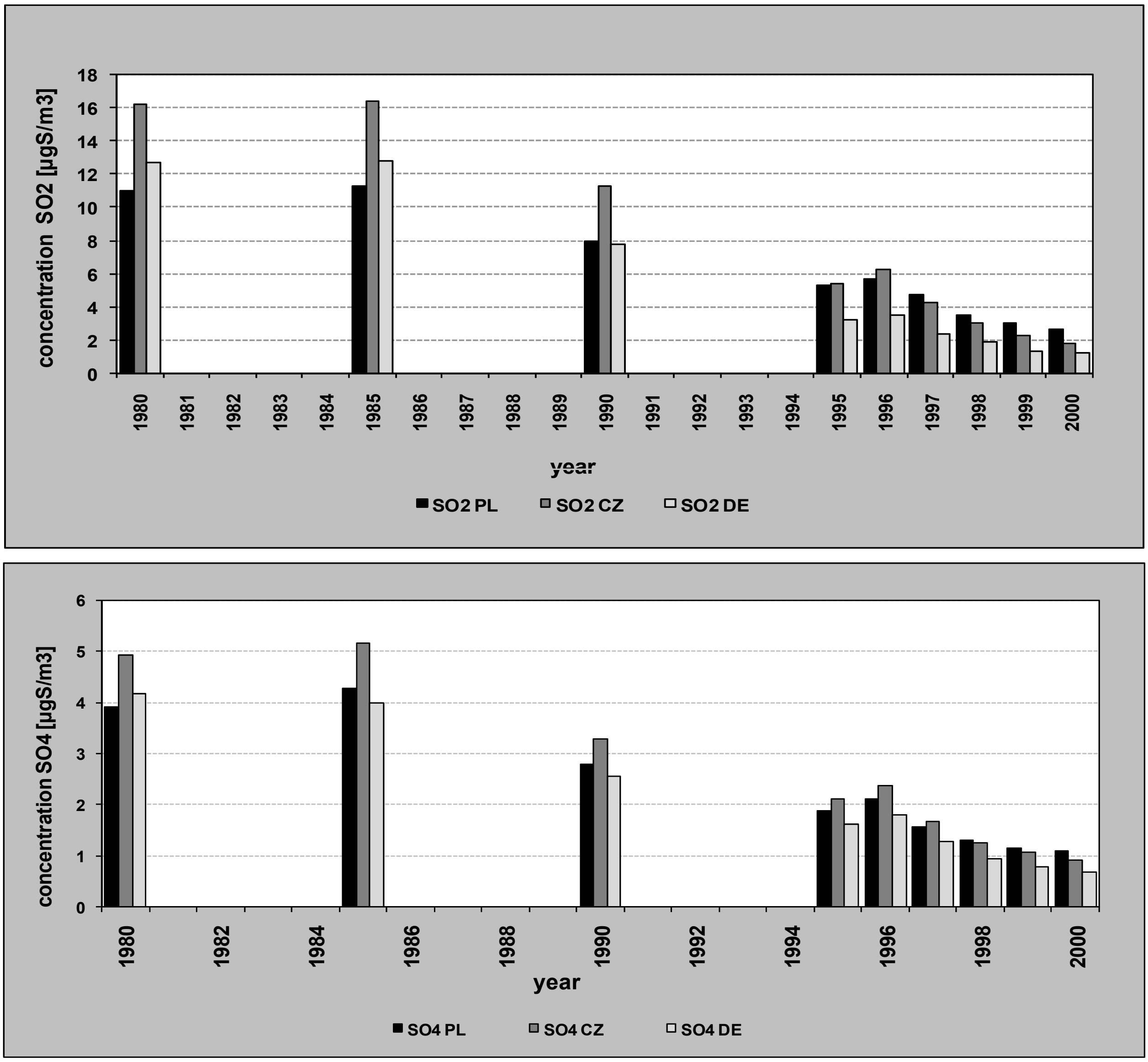

Figure 3: Average annual air concentration of SO2 and SO4 in Poland (PL), Czech (CZ) and Germany (DE) according to EMEP.

The second reason of improvement of the forest's condition is prolongation of the vegetative seasons connected with unusually warm two last decades of the 20th century. The intensity of the forest destruction was affected by specific regional climatic conditions and attributes of orography. High amounts of precipitation (over 1000 mm annualy), extreme frequency of fog and wet deposition of the pollutants (149,2 days with rime per year on Mt Szrenica) and location of the main sources of air pollution were the principal factors of the ecological disaster (Migała et al. 2002). The Sudetes are exposed to the prevailed, humid maritime air masses from the West, which enables efficient transport of air pollution from the numerous regional and European sources (Kwiatkowski 1984, Sienkiewicz et al. 1993). The most destroyed parts of the spruce-forests are situated on the main orographic barriers located in the most western part.

Contemporary progress of deforestation process

Since the beginning of the 21st century intensification of forest disaster is visible in other mountain spruce-forest areas in Poland and the area of disaster expands every year. Destruction of forests takes place currently in Central Sudetes, Western and Eastern Carpathians (Fig. 4 and 5). Unexpected diversity of forest dieback process on two different ways is clearly visible in Carpathian area during the last few years. On the higher most wind-exposed parts of the slopes, this phenomenon proceeds similarly to the “Black Triangle Region”. At the same time severe forest destruction occurs also in the lower zone of the mountains, where wet deposition of acid air pollution is marginal. The mechanism of the lower zone forest defoliation is compound and connected with high air temperature and decrease of amounts of precipitation during growing seasons with simultaneous lacking snowpack in winter months. Additionally anthropogenic tropospheric ozone can stimulate destruction of the spruce forests. The bark beetle (Ips typographus) invasion in most cases is the direct factor damaging weakened spruce forests. Identification and description of both forest dieback mechanisms is one of the most important questions for nowadays mountain forestry and creates new possibilities for the application of dendrochronological methods.

Figure 4: Typical forest dieback area in the contemporary deforestation stage in the Western Carpathians – Silesian Beskyd, 1100 m a.s.l., year 2007 (photo by M. Godek).

Figure 5: Typical forest dieback area in the contemporary deforestation stage in the Eastern Carpathians – Gorgany Mts, 1200 m a.s.l., year 2008 (photo by M. Godek).

Conclusions

A period of strongly reduced vitality of spruce, visible between the years 1965 and 1985 in all analysed trees, coincides with the most intensive phase of ecological disaster in the Sudetes. Reduction of spruce vitality started already in the sixties of the 20th century, more than 10 years before the first noticeable forest dieback. In the middle of the eighties was the time of simultaneous increase of tree ring growth dynamics and setback of macroscale forest defoliation. This regularity enables usage of dendrochronological techniques as a diagnostic tool for forecasting health condition of the threatened spruce forest areas. In the context of present island-type forest dieback in the Carpathians it seems to be possible to carry out benchmarking of the tree ring growth between spruces from both neighbouring mountain massifs and to find symptoms of weakness of forest stands, at present classified as non-threatened.

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Basal area increment trends across age classes for two long-lived tree species in the eastern U.S.

Johnson, S.E.[1] **& M.D. Abrams**[2]

[1]315 Forest Resources Building, Penn State University, University Park, PA 16802
[2]307 Forest Resources Building, Penn State University, University Park, PA 1680
Email: agl@psu.edu

Introduction

Basal area increment (BAI) is used in forest growth and modeling studies because it provides an accurate quantification of wood production due to the ever-increasing diameter of a growing tree (Rubino and McCarthy 2000). The BAI growth of individual trees typically follows a sigmoidal pattern: BAI increases rapidly from young to middle age, plateaus and remains level during a protracted period of middle age and then declines as trees become old age (Weiner and Thomas 2001). This BAI trend may be related to an increasing tree canopy during early age, a constant canopy volume during middle age, and then a physiological decline in old trees (Spiecker et al. 1996). The sigmoidal growth model using BAI may represent an excellent means for detecting post-European settlement changes in tree growth in eastern North America. BAI is often ignored in dendrochronological studies in lieu of raw or standardized ring width indices (Briffa et al. 1998).

In this study, we take a unique approach of examining BAI changes over time across all age classes from young to old trees, rather than just studying the oldest individuals of each species where a sample bias may exist (Cherubini et al. 1998, Voelker et al. 2006). Two tree species were chosen for the study: hemlock (*Tsuga canadensis*) and blackgum (*Nyssa sylvatica*). The primary objectives of the study are to examine the following:

1. Tree growth rate (including BAI) variation from young to old age classes for contrasting species.
2. The relationship between tree growth rate and maximum longevity for species and for individual trees.
3. Whether young trees are growing faster than older trees when they were at the same age vis-à-vis global change phenomenon.
4. Comparing growth trends using basal area increment (BAI) versus ring width index (RWI).

Methods

The International Tree Ring Data Bank (ITRDB) was used to compile tree ring chronologies for the two study species. Several of the contributing investigators were contacted personally to ensure that they posted complete chronologies extending from the bark to the pith of the trees recorded. Ring width chronologies of the selected species were used to calculate tree age and average yearly growth rates in basal area increment (BAI expressed as mm^2/year). Basal area increment (BAI) measurements were calculated for each tree. To calculate BAI, the diameter of an individual tree is divided by 2 to obtain the radius in centimeters. The radius is multiplied by the number Pi (3.14) to equal the area of the circle. To find the annual incremental growth for year X, the following equation is employed: X-(X-1)/(X-1), where X is the basal area at year X (last year of growth) and X-1 is the basal area of the tree measured up to the year previous to X. Basal area increments (cm^2) obtained for each individual ring of every core were then multiplied by 100 to obtain measurements in mm^2.

Cores of each species of interest previously collected in Dr. Abrams' lab were reanalyzed for age and growth rate by measuring annual growth increments on a TA Unislide Velmex machine (0.002 mm precision; Velmex Inc., Bloomfield, NY). This data was used in conjunction with the chronologies obtained from the ITRDB. These cores were taken as low as possible on each tree above buttressing, mounted on wood blocks and sanded with increasingly finer grit sandpaper (60 grit to 3200 grit in some cases; i.e., blackgum cores) in preparation for measurement with the Velmex machine. The cores were crossdated by hand using skeleton plotting to check for missing and false rings using the identification of signature years (Stokes and Smiley 1968). A skeleton plot evaluates tree ring width in relation to the rest of the rings of each tree in a stand. Signature years with consistently small or large rings are caused by an extreme climatic or disturbance event that allowed for increased or decreased growth across many trees in a stand. The identification of signature years allows for the identification of each ring to an exact chronological year. Cores were also crossdated using the computer program COFECHA (Holmes 1983), which analyzes each measured ring width series individually. COFECHA bases its analysis on a master chronology of all the cores compiled and calculates a correlation coefficient indicating how well the interannual variability in ring widths correlates with the other ring-width series. Ring width chronologies obtained from the ITRDB have been subjected to rigorous cross dating standards and checked with COFECHA. The raw ring widths recorded for remeasured and newly collected core sets were converted to BAI in the same manner as ring widths collected from the ITRDB (see above procedure).

The relationship between growth rate and age class was analyzed for each tree based on 30 year age classes for the entire life of the tree. For each age class, growth was separated into 10 year increments, and 10-year growth rates were calculated by averaging together all values of BAI in the first 10 years, second 10 years, etc. Average 10-year growth rates were calculated and standard error time series of decadal average growth were plotted and compared between age classes (Minitab 14, 2003). A repeated measures ANCOVA (Analysis of Covariance) was used to compare each tree's decadal mean growth rates both within and among age classes (SAS 9.1, 2002). Adjusted p-values were generated for each age class comparison.

Results and Discussion

Hemlock trees exhibit significantly increasing BAI growth over time in all age classes except 300+ year old trees; these trees reached a growth plateau after 200 years (Fig. 1a). Fast-growing hemlock trees fall in the four youngest age classes (90 to 210 years old), whereas slow-growing hemlock are in the four oldest age classes (210 to 300+ years old). Significant differences in BAI growth rates are seen between these younger versus older age classes. Trees in the older age classes also grew significantly slower than younger trees at the same age. Hemlock trees in the 90-120 year age class had highly variable raw ring growth over time (Fig. 1b). Trees in the 120-300 year age classes typically had flat raw growth curves, although 120-180 year old hemlock had large increases in raw growth in recent years. Hemlock trees in the 300+ age class had slightly declining raw growth over time, despite increasing BAI for the first 320 years of growth, after which BAI more-or-less plateaued.

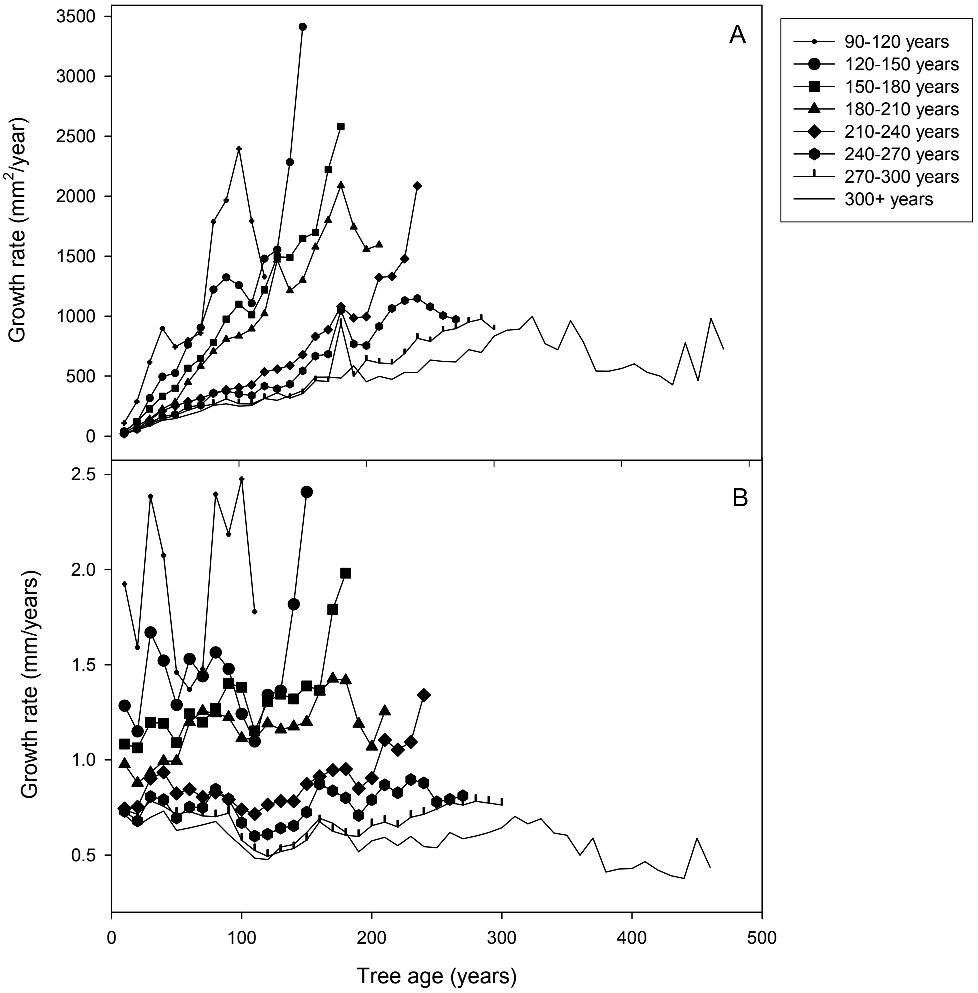

Figure 1: Hemlock decadal average growth rates in basal area increment (A) and raw ring widths (B) for each age class. Each decade indicates a 10-year period of averaged growth over all hemlock trees in the data set.

Blackgum trees in all age classes exhibited increasing BAI with increasing age, including trees over 300 years old (Fig. 2a). A growth plateau seen in the oldest trees of some other species is not evident in blackgum trees even after 400 years of age. Blackgum trees over 300 years old had the slowest growth rates of all age classes. The 30-60 and 60-90 year old blackgum display the fastest growth rates, including several growth peaks. Significant differences in growth rate occurred between disparate age classes, e.g., 30-60 versus 300+ years old. Few significant differences in growth were displayed between blackgum trees in similar age classes. Older blackgum trees grew slower than younger blackgum trees at the same age. Raw ring growth in blackgum was variable but tended to be flat over time, although trees in the oldest age classes (240+ years) had a trend of increasing raw growth (Fig. 2b).

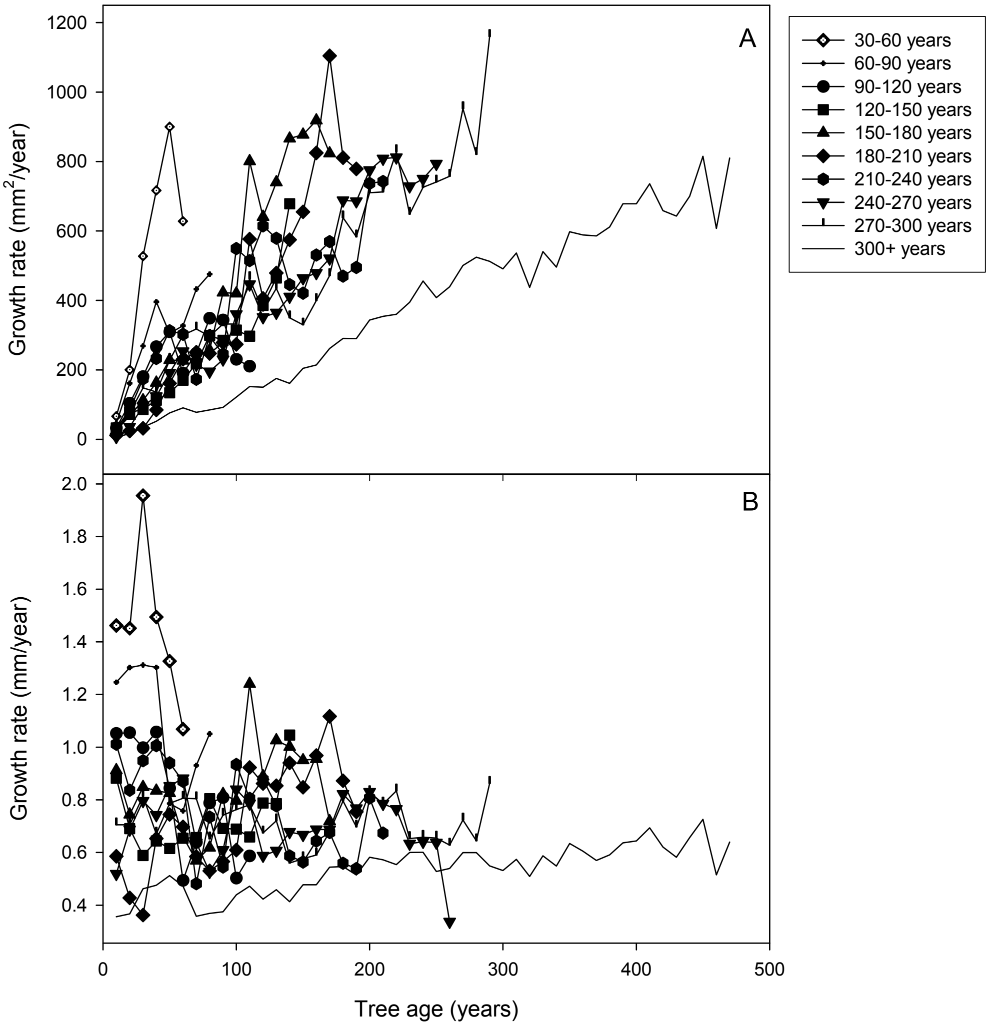

Figure 2: Blackgum decadal average growth rates in basal area increment (A) and raw ring widths (B) for each age class. Each decade represents a 10-year period of averaged growth over all blackgum trees in the data set.

Temporal variation in growth for the 20 oldest trees of hemlock and blackgum on an individual site are also investigated. Although sample sizes over age classes are not constant in this analysis, the number of trees included is sufficient to determine significant growth trends. Hemlock trees from Ramsey's Draft, VA display a decreasing raw ring width trend early on, followed by a fairly constant growth trend (Fig. 3a). This translates to increasing BAI trends over the lives of the 20 oldest trees (Fig. 3c). Calculated RWI values standardize the raw ring width chronology, flattening out increasing or decreasing trends that are present in the raw and BAI curves (Fig. 3b). Variation is indicated with the RWI graph, but general growth trends are masked. Blackgum trees from Mohonk State Park, NY, follow a similar pattern in these measurements. Raw ring widths show a decreasing pattern that level off somewhat, with a slight increase toward the end of the curve (Fig. 4a). Basal area increment values display a distinctly increasing trend over the entire life of the trees (Fig. 4c), while ring width index values are standardized to show variation around the master chronology (Fig. 4b). The results of this analysis indicate that the increasing growth trend in BAI was completely masked in the RWI data.

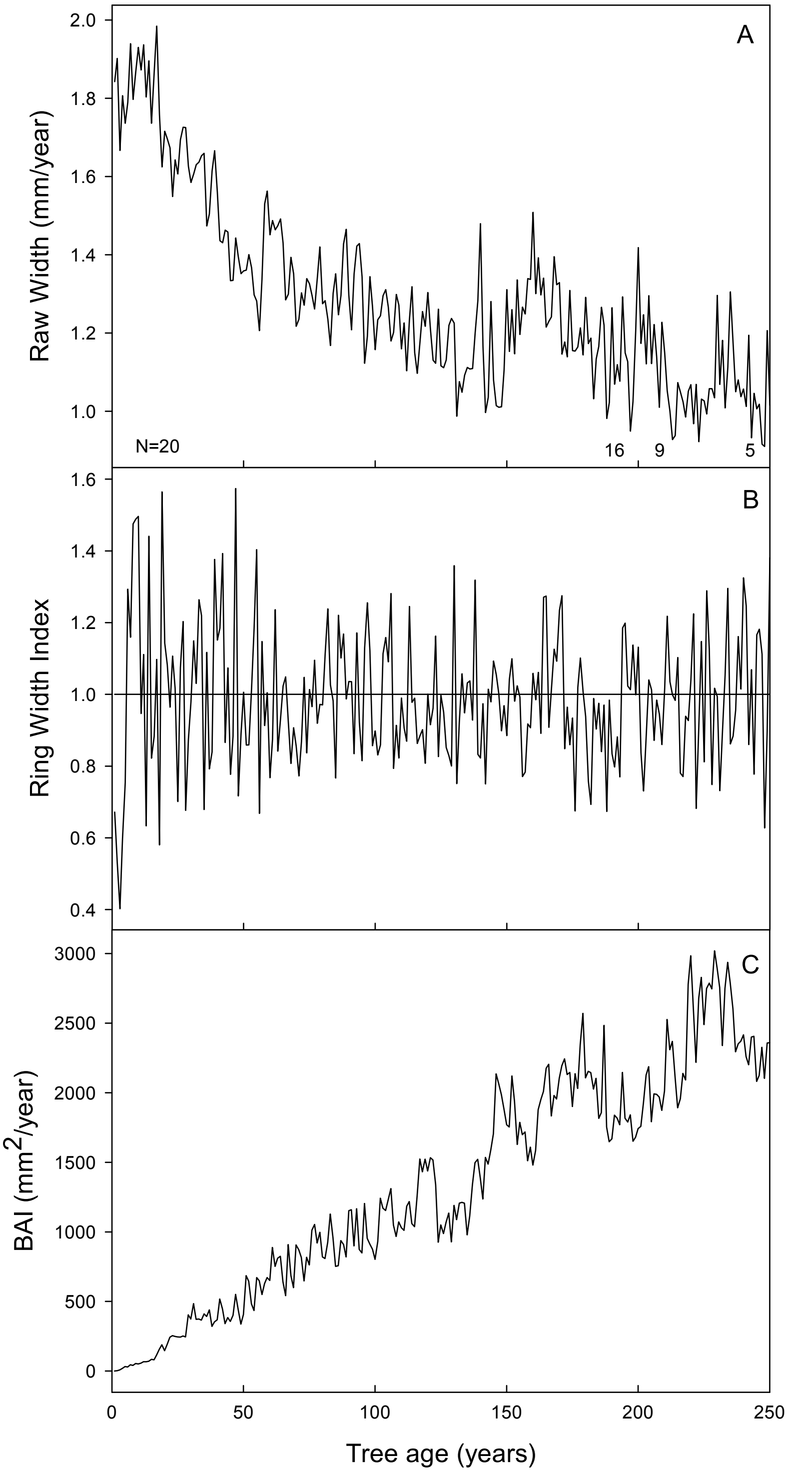

Figure 3: Ramsey's Draft, VA, hemlock average growth rates in raw ring widths (A), ring width index (B), and basal area increment (C).

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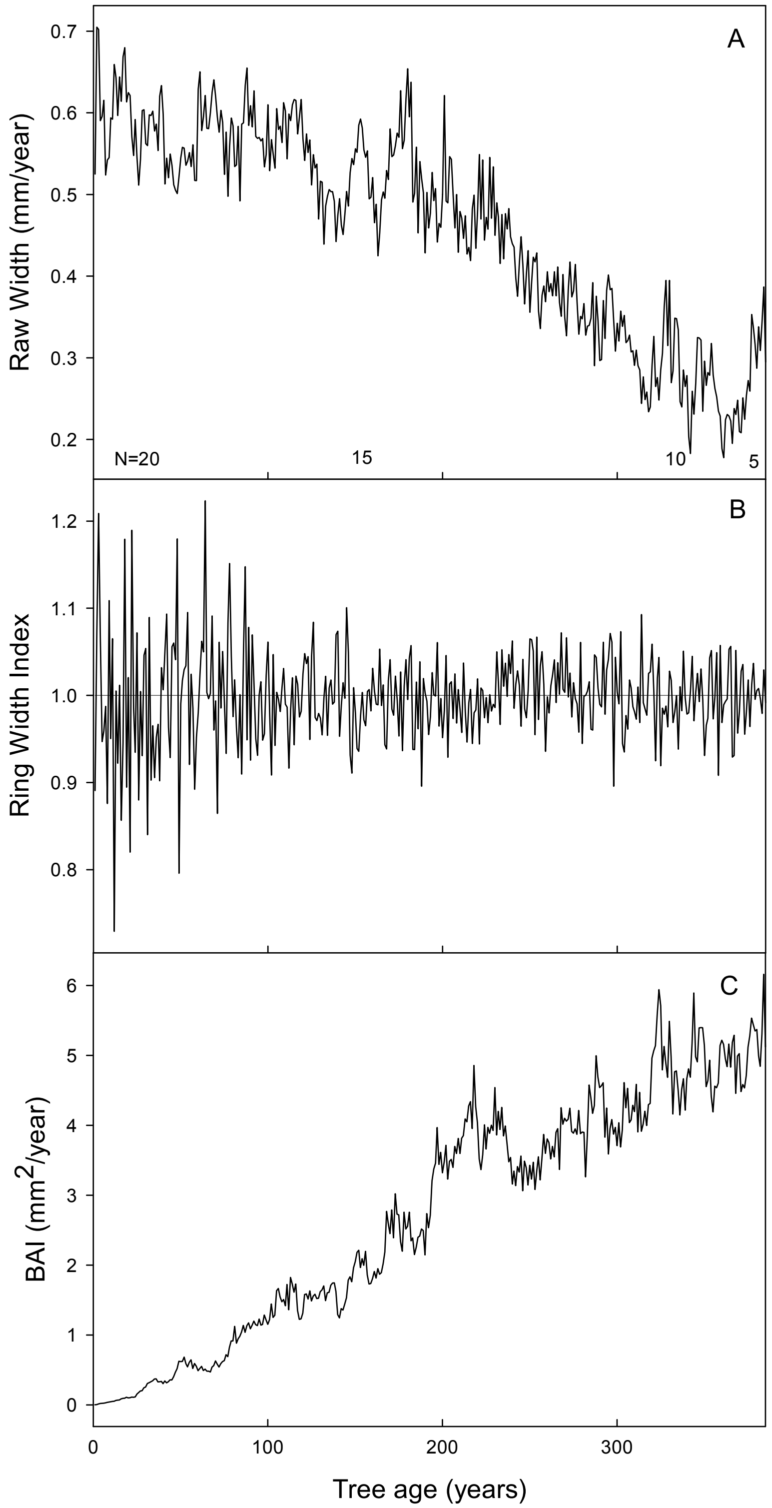

Figure 4: Mohonk State Park, NNY, blackgum average growth rates in raw ring widths (A), ring width index (B), and basal area increment (C).

The major results of this study are that 1) the majority of trees in all age classes had increasing growth (measured in BAI) throughout their life, including most of the oldest trees; 2) over the last 50 to 100 years, younger trees within a species grew faster than did the older trees when they were the same age in the past; 3) trees in the oldest age classes for each species grew significantly slower throughout their life than younger trees; 4) highly shade tolerant trees, that also include trees growing on poor quality sites, have inherently slow growth, implying a relationship between growth rate and longevity; and 5) dendrochronological studies that rely totally on RWI may be missing important growth trends that are apparent in BAI.

BAI measurements in this study consistently increased over the life of the trees, including all age classes from young to old. The increase in growth in young trees is expected from the sigmoidal model because BAI should increase as young trees produce an increasingly larger leaf canopy (Spiecker et al. 1996). However, a remarkable finding of this study is that even the oldest trees for each species continued to produce increasing BAI values throughout the life of most trees. This contradicts the sigmoidal growth model that predicts growth should plateau and then decline as middle age trees approach old age (Ryan and Yoder 1997, Weiner and Thomas 2001). The increasing BAI exhibited by both young and old trees in this study is also indicated by a quasi-constant raw ring width trend, rather than negative exponential. The latter case is expected when a constant amount of wood is distributed over an increasingly larger tree diameter. A constant raw ring width over time means that the tree is producing an increasingly larger amount of wood (BAI) each year. This trend is not indicated in RWI because of standardization of the chronologies.

Why are young trees growing faster than older trees and older trees growing faster than predicted by the sigmoidal model over the last century or more? We believe that this is most likely due to anthropogenic global change defined in the broadest sense, i.e., including both land-use history and atmospheric factors (cf. Innes 1991, Briffa et al. 1998, Voelker et al. 2006). The latter includes increased CO_2 levels, warming temperatures, increased precipitation, and changes in precipitation chemistry (Aber et al. 1989). Yearly average temperatures, atmospheric CO_2 and nitrogen levels have increased in the eastern U.S. (as well as much of the rest of the world) over the last 50 to 100 years (Körner 2000, IPCC 2007). The results of this lead to the intriguing hypothesis that the continuation of global change factors that have a stimulatory effect on tree growth may act to reduce tree longevity in the future, as fast growing trees are less likely to obtain the maximum longevity for the species.

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Natural dynamics in subalpine avalanche protection forests in the Swiss Alps

Krumm, F.[1], **Bebi, P.**[1], **Panayotov, M.**[1,2] **& H. Spiecker**[3]

[1] *Swiss Federal Research Institute WSL (SLF), 7260, Davos*
[2] *University of Forestry, Sofia, Bulgaria*
[3] *Institute of Forest Growth IWW, Freiburg, Germany*
Email: krumm@slf.ch

Introduction

Mountain forests of the Alps fulfil important protection functions against avalanches and other natural hazards. The majority of the subalpine forests in the Swiss Alps are dominated by spruce (*Picea abies* Karst.). The protection effectivity of these forests is highly variable in space and time and depends on different circumstances such as topographical settings, predominant disturbance regimes and management history.

Structures and protection effect of mountain forests are permanently changing. After centuries of overexploitation, density of most remaining forests in the Alps were very low in the middle of the 19th century, leading to increasing concerns about their protection function (Kasthofer 1822, Landolt 1960). Since then, there is a high effort to increase and permanently maintain the protection function of mountain forests. Consequently, forest-cover and forest density drastically increased during the 20th century, generally leading to improved protection against natural hazards, but often also to a dominance of more or less even aged (~100-150 years old) protection forests characterised by high densities and monotonous structures with very low regeneration. The successful reforestation efforts and regeneration problems in even-aged forest stands supported the notion that “only maintained protection forests provide enough and sustainable protection against natural hazards”. There is, however, only little knowledge about natural dynamics of subalpine, spruce dominated forests in the Swiss Alps. The goal of a new international research project is thus to determine and analyse the relevant processes occurring in subalpine spruce dominated forests without human impact.

In this paper we give a short overview on the current state of knowledge on dynamic processes in unmanaged subalpine avalanche protection forests in the Alps and we present and discuss methodical approaches to explain the natural development of unmanaged forests in the subalpine altitudinal belt with the help of newly available inventory data series and tree-ring data.

Dynamics of avalanche protection forests: What do we know?

Gravitative natural hazards like avalanches, rockfalls, or landslides appear more often in subalpine and alpine regions than in lower areas. According the second Swiss National Forest Inventory (NFI), 31 % of montane or subalpine forests exhibit tracks of snow movements, 31 % of the areas have tracks of rockfall and 16 % tracks of erosion (Mahrer et al. 1988). 15% of the forests in Switzerland have a direct protection function against avalanches, rockfall or landslides. Particularly for avalanche protection, most of these forests are in the subalpine belt. Their importance for protecting human settlement and infrastructure is increasing, especially in tourist regions and along traffic and transportation routes. As a consequence, vulnerability and damage potential below protection forests is high and the Swiss government invested within the last few decades between 120 -150 million sfr per year for “protection activities in forests”. Around 60 % (70-94 million sfr/year) were used for maintaining protection forests, regeneration, repairing damages in forests, planning actions in the protection forests and building and maintaining infrastructure in protection forests (Schärer 2004).

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Natural forest development is often described with four different stages (Barbour & Billings 1988, Oliver & Larson 1990, Peet 1999): (1) “Establishment”: Phase of regeneration, mostly initiated by large – scale disturbances; (2) “stem exclusion”: intensive competition with increasing tree – density excluding the establishment of young trees (cf. Fig. 1); (3) “Breakup”: small - or large - scale breakdown, establishment of regeneration possible; (4) “Old – growth”: no disturbances or management treatments since a longer period. The amount of dying trees and new establishing trees are more or less in balance.

For natural subalpine forests, the same stages can be described, but the relative importance of different stages may change with increasing elevation. Establishment can be so slow that by the time of canopy closure trees may already be dying from senescence-related causes. Consequently, the second and third stages - “stem exclusion” and “breakup” may be bypassed and one finds a stage in which both stand density and tree size slowly increase towards steady state conditions (Peet, 2000). Such complex natural forest structures with different layers, tree sizes and ages provide optimal protection against natural hazards (Ott et al. 1997, Motta & Haudemand 2000). They protect against different kinds of natural hazards in a sustainable way and exhibit a higher elasticity after disturbances such as windthrows and avalanches (Brang et al. 2006).

As a result of former over-exploitation and subsequently decreasing pressure of grazing and wood exploitation on large scales, many subalpine forest areas in the Swiss Alps differ from what would naturally be expected in such sites. Favourable growing conditions, providing enough light, warmth, nutrients and open soils have led to an increasing amount of young and dense forest patches in subalpine regions after land-use extensification (Bebi 1999, Brassel & Brändli 1999). Dense forest areas with more than 600 stems per hectare provide protection against rockfall and avalanches (Cattiau et al. 1995), but may be more susceptible against storm and snow break (Rottmann 1985) and require a longer period to regain their full protective properties following a disturbance. With silvicultural actions the heterogeneity and sustainable protection functions of such dense, homogenous forests in the stem exclusion stage can be influenced (Schönenberger & Brang 2004). However, the effect of such interferences differs highly according to site conditions and time of interventions. The costs of management interventions are generally so high, that they have to be prioritised according to risk considerations and expected natural dynamic of such forests without interventions (Bebi et al. 2004).

For the Alps, there is only little knowledge concerning the dynamics of subalpine forests in “self-thinning” (stem exclusion) phases. The existent knowledge is mostly based on work from outside the Swiss Alps (Peet & Christensen 1987, Korpel 1995, Veblen & Donnegan 2005). Results of dendroecological analysis and aerial photos from the European Alps suggest that the stem exclusion phase in subalpine forests does mostly happen in small scales (Cherubini et al. 1996, Motta et al. 2002). But there is still little knowledge about the time period needed for a change into favourable regeneration conditions and how this varies over different site conditions.

Near natural timberline the forest structures in the Alps and in other mountainous regions are getting more and more scattered (Arno & Hammerly 1985, Rochefort & Peterson 1996, Stützer 2002). With increasing elevation, transitions from open forest structures to closer forest structures are less frequent and slower (Bebi 2000, Rutherford 2006). The influence of temperature as a limiting factor becomes more significant with decreasing distance to the upper treeline. Consequently growth processes are slowing down and the regeneration processes of trees are strongly restricted in space and time (Ott et al. 1991, Körner & Paulsen 2004). Aggregated forests among the timberline exhibit several advantages concerning the concurrence, particularly because soil temperatures below single trees or tree cohorts are higher as below dense forest stands (Shanks 1956, Körner & Paulsen 2004). Furthermore larger amounts of snow related disturbances, like avalanches and snow-break, cause openings of the stand (Imbeck & Ott 1987, Walsh et al. 1994, Kajimoto et al. 2002).

Avalanches have a high impact on mountain ecosystems. They play important roles in shaping ecosystem dynamics, and may contribute to diversity at species and landscape level, can induce soil transport and different other types of disturbances (Luckman 1978, Rixen et al. 2007). However, avalanches also represent a source of danger to human settlements and infrastructures (Fuchs et al. 2004). Primarily subalpine forests are affected by avalanche disturbances, and in dependence of the steepness of a slope and weather conditions, avalanches may occur several times during a winter (Laternser and Schneebeli 2002). The avalanche protection function of a forest consists of impeding the release of avalanches in the forests. The most important criteria concerning the avalanche protection function of a forest are stand density (degree of coverage) and the dimensions of gaps (Meyer-Grass & Schneebeli 1992). Factors as steepness, exposition, surface structure and the rate of evergreen trees could also have an important impact for the occurring of avalanches (Schneebeli & Bebi 2004). This function is limited close to the timberline due to larger gaps between the trees or between the cohorts of trees. The avalanche protection function is also limited against avalanches starting at least 150 meters above the timberline (Schneebeli & Bebi 2004). Natural disturbances such as windthrow or bark beetle outbreaks might change the protection functions of forests immediately (Brang 2004). Dense and homogenous protection forests are generally not more sensitive against such disturbances, but they need longer to regenerate and to reach again the full protection function.

Open forest structures near timberline and monotonous formed forests of high density are thus potentially problematic forest types concerning their sustainable protection function. With increasing areas of these two forest types that haven't been managed for several decades, it is particularly important to learn more about their natural dynamics. As different driving forces seem to be predominant in these two forest types, open questions and hypotheses for the natural dynamics of subalpine avalanche protection forests have to be differentiated according to them.

A key question in open avalanche protection forests near timberline is whether they are increasing in density due to climatic factors and land-use change. These two factors might influence the forest dynamic in different ways and are often difficult to disentangle (Gehring-Fasel et al. 2007). We hypothesise that density in subalpine forests is only increasing under certain site conditions and that on very steep slopes and on sites with frequent disturbances, the forest coverage is not changing significantly. Near timberline where mainly abiotic processes cause tree mortality, self-thinning processes and competition are factors of marginal relevance. When the canopy approaches closure, trees may die from senescence related causes. “Old-growth” and “establishment” are the two phases that mostly occur under natural conditions near timberline, since the stages “Establishment” and “Stem exclusion” are essentially a function of competition, which is minimized in stressful environments.

Dense, homogenous forests in the stem exclusion stage are more driven by competition. It is an open question what finally causes tree mortality and how long this process lasts. Is it a long - term process over several decades or a quick process following some event (e.g. extreme climate situation, fine-scale disturbance). Our hypothesis is that the major reason for dying trees in subalpine avalanche protection forests within the self-thinning phase is competition. The weakest trees have competitive disadvantages such as smaller crown, less light, nutrients and warmth compared to competitors and die first. The “dying” process is a long lasting process that might take up to 100 years. Other questions of high importance in these subalpine forests in the stem-exclusion stage are: On which scale do disturbances occur? How do different site conditions and former management history affect their natural development? How fast do disturbances and subsequent regeneration processes occur without human interventions?

Methodical Approaches

To examine the development and dynamics of subalpine spruce dominated forests, two different methodological approaches on different spatial and temporal scales which are complementary to each other were chosen: (1) the analysis of inventory data from three periods of the Swiss National

Forest Inventory and (2) the assessment and dendroecological analysis of field data on selected plots. Purposes of and differences between the two methodological approaches are summarized in table 1.

Table 1: Comparison of the two complementary approaches to analyse the dynamics of subalpine avalanche protection forests

Analysis of NFI data	**Dendrochronological analysis of selected forests**
Quantitative analysis of about 150 NFI plots with the goal of investigating differences in forest development in dependence on silvicultural management actions.	Qualitative, more detailed analysis of a selection of sites. Focus is set on "single tree-dynamics")
Focus on the last 20 years (time span of the three inventories). Comparison of different variables such as steepness, grazing, avalanches and rockfall	Investigation from the originating of the site, age of the trees – long - term development. Dynamical chances since originating.
Dying processes – examination over a larger scale.	Dying processes consideration on a high resolution.
NFI data contains information about small scale disturbances	Role of small - scale disturbance regime – small gaps, tree development in small gaps.
	Analysis and evaluation of microclimatic and regional influences

Analysis of data from three complete finished Swiss National Forest Inventories.

The Swiss Forest Inventory (NFI) obtained data from three inventory periods, NFI 1 1983-1985, NFI 2 1993-1995 and NFI3 2004-2007. On the basis of this data we identify forest areas in the whole Swiss Alps fulfilling our requested criteria of land-use and site conditions (see Fig. 1). 77 of these forests, selected from the NFI sample (1 km grid over Switzerland, for details see Brassel & Brändli, 1999) are in the self-thinning phase (stem exclusion). This selection of NFI-plots allows us to compare the development of unmanaged forest areas with comparable subalpine forests and to further analyse them with GIS and statistical methods.

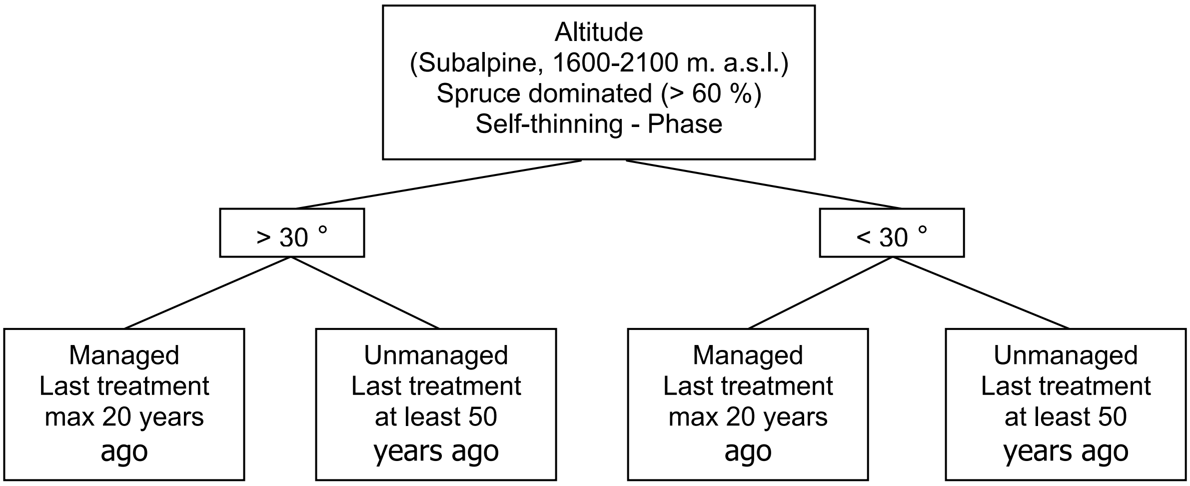

Figure 1: Selection criteria for evaluating NFI data. Number of selected forests n=77.

The basis of our analysis is the situation during the assessment of NFI 1 with equal numbers of plots for different treatments. We then examine the development of the forests from NFI1 to NFI2 and NFI3 concerning stand density, proportion of dead trees (standing and lying) and the dimensions of subsequent disturbances. Preliminary analysis show that various site factors exert a strong influence on structure and development of the examined subalpine forest stands. For example, sites with signs of avalanche activity have lower basal areas per hectare than sites without signs of avalanche activity (Fig. 2).

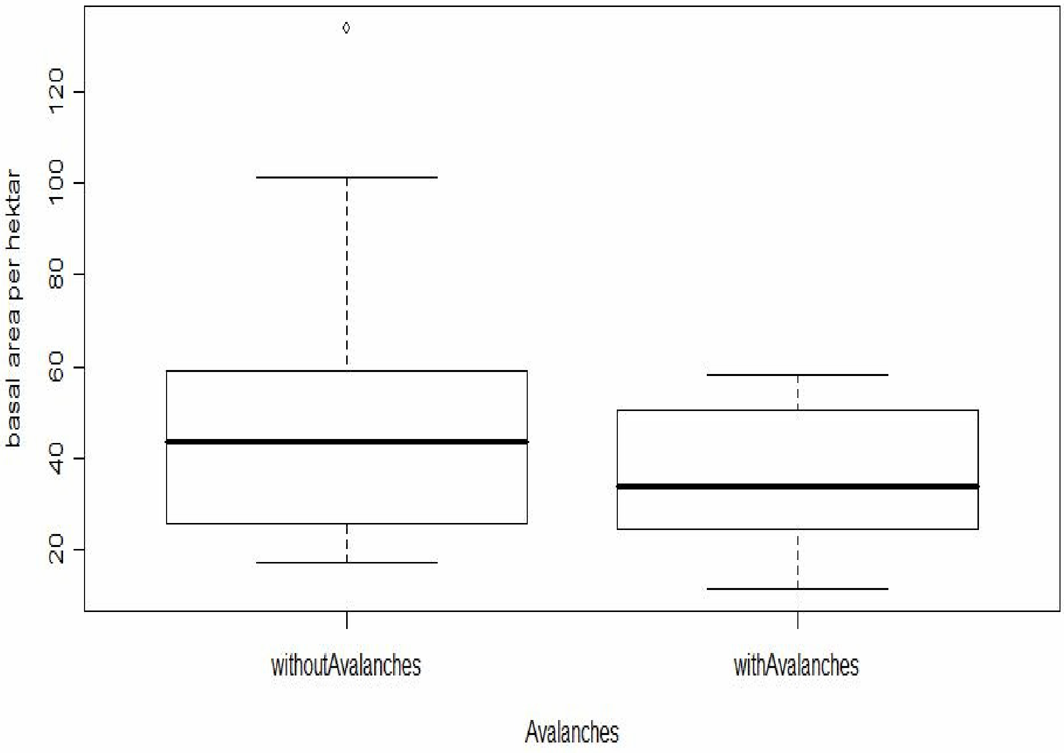

Figure 2: Basal area per hectare in unmanaged (at least for 50 years) forests. Without the influence of avalanches (left) and with avalanches (right)

Dendroecological analysis of selected "self-thinning" plots in the Swiss Alps

Based on the NFI data and the criteria described above, we locate representative plots for the Swiss Alps and study them with dendrochronological methods concerning stand structure, stand dynamics, history and age structure. Additional parameters, such as the stand density index, the degree of coverage, exposure, steepness of the slope, altitude, crown height, tree height and the diameter in 1.3 m, will be included as co-variables in the analysis.

In each plot we select areas of 22 * 22 meters, where every tree with a diameter >= 10 cm, (dead and alive, standing and lying) will be cored twice. In order to determine the age of the trees (e.g. obtain as many year rings as possible), we take one core from the bottom, from downside the tree. The second core is taken from a height of 1.3 m parallel to the slope and provides information about year ring widths excluding reaction wood for getting information about the competition and dynamics of every single tree. Additionally we assess the structure of the whole site by exhibiting 10*10 meters plots. In 5 such 10*10 plots we measure diameters of every tree > 6 cm, count the regeneration and put them into different age classes.

The year ring widths will be measured in the Laboratory of the Institute of Forest Growth in Freiburg (Germany) and we will analyse the year ring samples with standard methods (Stokes & Smiley 1968) concerning the age structure and the dynamic of the forests. The effects of disturbances will be related to differences in growth to the forest structure by using statistical analysis.

Outlook

Our research questions and hypotheses concern dense subalpine forests, and open forests near timberline. These are different forest types that require different methodical approaches. The two described methods enable us to get quantitative information about the requested forests over the whole Swiss Alps. We are also able to examine forests within the stem exclusion-stage on a high resolution and on small scales. The dendroecological method allows us to reconstruct the history and the dynamics of every single stand.

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Dendroecological studies on Bosnian Pine (Pirin Mtns., Bulgaria)

Scheithauer, J.[1], Grunewald, K.[1], Helle, G.[2], Günther, B.[3], König, J.[3] & A. Gikov[4]

[1]*Landscape Research Centre Dresden, Am Ende 14, 01277 Dresden, Germany*
[2]*Research Centre Jülich, Institute of Chemistry and Dynamics of the Geosphere, Institute 3: Phytosphere, Leo-Brandt-Str., 52425 Jülich, Germany*
[3]*University of Technologies Dresden, Institute of Forest Utilization and Forest Technology, Pienner Str. 19, 01737 Tharandt, Germany*
[4]*Bulgarian Academy of Sciences, Space Research Institute, Moskovska Str. 6, Sofia, Bulgaria*
Email: joerg@scheithauers.de

Introduction

The Bosnian Pine (*Pinus heldreichii* Christ. or *Pinus leucodermis* Ant. respectively), found at the timberline in the Northern Pirin Mountains, is a conifer growing up to 1000 years. Generally, this species only occurs on the Balkan Peninsula and in the southern part of Italy (Morgante & Vendramin 1998). In the context of the currently enforced debate on global climate change, the reconstruction of the modern landscape development in the Bulgarian Pirin Mountains constitutes an important element for the understanding of the current climate dynamics in Southeastern Europe. Located at the transition zone from temperate to Mediterranean latitudes, the high mountain ranges of Pirin are strongly sensitive to climatic changes (Beniston 2003). Tree-rings of coniferous trees at extreme sites have proven to be reliable and valuable archives for climate signals, especially for regions where there are no direct measurements of temperature and precipitation available or where data records are short in time or fragmentary. Among coniferous trees pine species usually serve as the dominant climate archive. On the one hand they prevalently represent the upper timberline in the Mediterranean region, on the other hand they rank among drought sensitive species (Körner et al. 2005, Martin-Benito et al. 2008, Oberhuber et al. 2008).
Mainly since the 1990s the study region is subject to analyses of landscape history and climate change utilising different methods. Geoarchives like glacierets, moraines, soils and lake sediments serve proxy data archives for reconstructions of the Holocene development at the subalpine level (Grunewald et al. 2006, Läßiger et al. 2008, Stefanova et al. 2006). Recently, the analysis of highly resolved climate data (Grunewald et al. 2008) and annual tree-rings of Bosnian Pines at the timberline ecotone are established within the network of proxy data to better understand the climate and landscape dynamics (Grunewald & Scheithauer 2008a). This article presents first results of a dendroecological study in the northern Pirin Mountains, Bulgaria. Firstly, we aimed at the development of statistically robust ring width chronologies of *Pinus heldreichii*. Secondly, we compared the ring width chronologies with the available climate station data and established climate-growth relationships allowing the assessment of site specific effects and climate sensitivity of the Bosnian Pine.

Materials and methods

Study site

The Pirin Mountains are located in a tectonically active area between the Struma and Mesta Valley near the Greek and Macedonian border in the south-western part of Bulgaria (Grunewald et al. 2007). The mountain range raises up to approx. 3,000 m a.s.l. and tops its surrounding basins and valleys like a horst. Marble, granite, gneiss and schist characterise the Pleistocene intensively shaped mountains. The zone between the upper timberline and treeline, mostly situated between 1,900 and 2,250 m a.s.l., is characterised by the two subendemic tree species, Macedonian Pine (*Pinus peuce* Grisebach) and Bosnian Pine (*Pinus heldreichii*). While the Macedonian Pine determines the silicate sites, the Bosnian Pine dominates the carbonate rock.

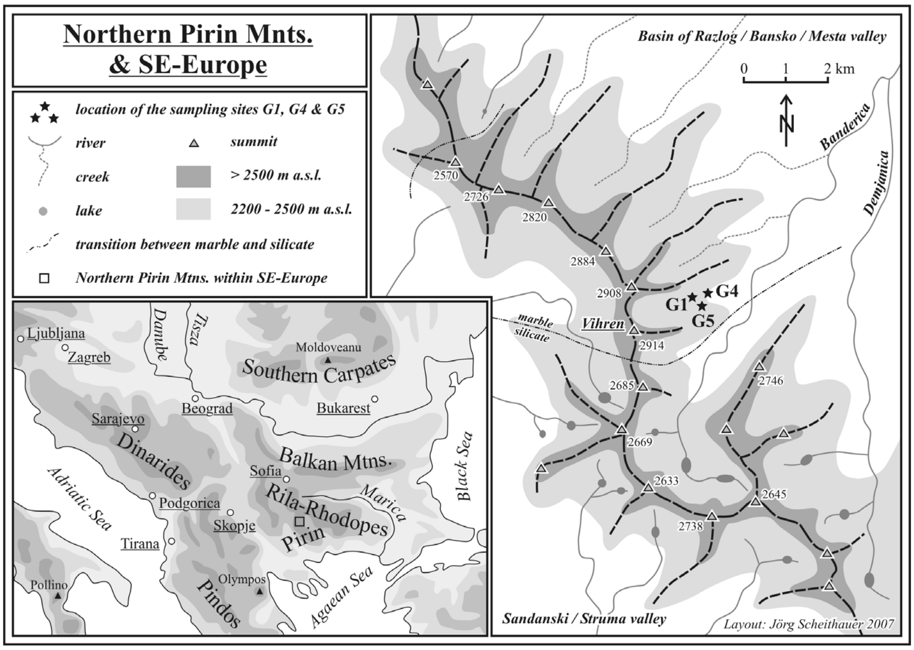

Figure 1: The mountains in South East Europe (small map) and the positions of the three sampling areas in the northern Pirin mountains (major map).

The study and sampling area is located in the northern part of the Pirin Mountains (Fig. 1), in the Banderica Valley near the 2,914 m a.s.l. high marble peak Vihren. Three sites with divergent stand and age structure as well as different morphologic and pedologic properties have been chosen and labelled G1, G4 and G5 (Tab. 1). In the context of dendroclimatology, G1 should be the most valuable site, as it extends on an approx. 500 metre long, south-exposed rocky slope. The Bosnian Pine is the sole tree species growing at this site. The appearance of the investigated, potentially nearly 1000 year old trees reflects the harsh conditions at the timberline ecotone accordingly: windswept, wind and ice scoured, partly dead crowns, torned trunks and spiral grain with traces of rockfall and lightning. In contrast, G4 and G5 serve as comparison sites with moderate and sheltered conditions respectively, to research the dendroecology of the Bosnian Pine. Besides, these sites feature occurrences of Macedonian Pine in more or less closed groups, which have been sampled as well, but will not be discussed in this context.

Table 1: Characteristics of the sites (tree height to ring width: median, in brackets minimum and maximum).

Sampling site	G1	G4	G5
Altitude (in m a.s.l.)	2,100 - 2,235	2,005 - 2,055	2,100 - 2,120
Exposition	ESE - SSW	E - ENE	NNE - N
Slope (in °)	≈ 45	≈ 25	≈ 20
Soil type	Histosols	Rendzic Leptosols	Rendzic Leptosols
Mean age of trees	352.6	193.4	200.4
Tree height (in m)	9,9 (7 - 14)	15,3 (9 - 22)	14,7 (10 - 16)
Breast height diameter (in m)	0,8 (0,5 - 1,0)	0,7 (0,3 - 1,25)	0,5 (0,4 - 0,7)
Ring width (in mm)	0,6 (0,06 - 2,8)	1,1 (0,05 - 4,9)	0,9 (0,08 - 4,0)

Sampling, dendrochronological analyses and statistics

The three chronologies include the measurement series of 116 single samples from 58 trees. Generally, cores were taken at breast height or above using an increment borer and avoiding compression wood. In addition, 13 stem discs at G1 were cut from stumps with a chain saw. The pith and therefore the cambial age could not be obtained for several individuals due to the length of the standard increment borers (400 mm). Initially, the tree-ring width was measured in a conventional manner by using the LINTAB (RinnTech) and TSAPWin version 0.55 (see Rinn 2005) at an accuracy of 1/100 mm. With the assistance of the TSAPWin software it was possible to cross-date all tree-ring series.

The individual ring width series were examined with the statistical quality control software Cofecha (Holmes 1983, Grissino-Mayer 2001). Thereby, missing or false tree-rings and hence segments with flawed cross-dating could be identified. The descriptive statistics finally reflect the quality of the individual series and of the sampling group. The chronology development itself was realised with the help of the Arstan software (Cook 1985), which is a programme for standardisation and tendency adjustment of the individual tree-ring series as well as for the development of a standard chronology and residual chronologies (without autocorrelation). A negative exponential function was used for the first detrending of the raw series removing the low frequency non-climatic growth trend. For a second detrending, a cubic smoothing spline function (66 years) was applied in order to amplify the high frequency climatic signal. The quality of the chronology was tested by calculating the Rbar (average correlation between all series) and the EPS (expressed population signal). The EPS parameter quantifies the variability within all ring width series at the sampled site as proportion between common variance of trees and total variance (signal + noise) and should be > 0.85 (Wigley et al. 1984). The software "Corina" developed by the Cornell Tree-Ring Laboratory was used for continuative statistical tests to help correcting flawed segments and to calculate pointer years (Brandes 2007). Pointer years are characterised by simultaneous positive or negative tree-ring growth compared to the previous year reflected by at least 75% of all investigated trees.

Climate data and climate-growth relationships

Two climate stations, Bansko and Musala were considered (Fig. 2). At both stations monthly temperature data were gained for the period from 1936 to 2006 and precipitation data for 1955 to 2005, accordingly. Bansko station lies approx. 12 km away from the study area in the town of Bansko and hence at the foot of the Pirin Mountains (936 m a.s.l.). The second station is located in approx. 45 km linear distance at peak Musala in the neighbouring Rila mountain range. With 2,925 m a.s.l. the Musala is the highest mountain of the Balkan Peninsula. To determine a climate-growth relationship of *Pinus heldreichii*, the standard ring width chronology was regressed against the monthly parameters temperature and precipitation using the software package DENDROCLIM2002 (Biondi & Waikul 2004). Pearson correlations and response functions were calculated by applying principle components analysis. Bootstrapped confidence intervals were calculated to assess the significance of both. To study changes in monthly climate response between October of the previous year and September of the current growth year, moving interval correlation was established with a base length of 24 years according to the available time periods of climate parameters and stations.

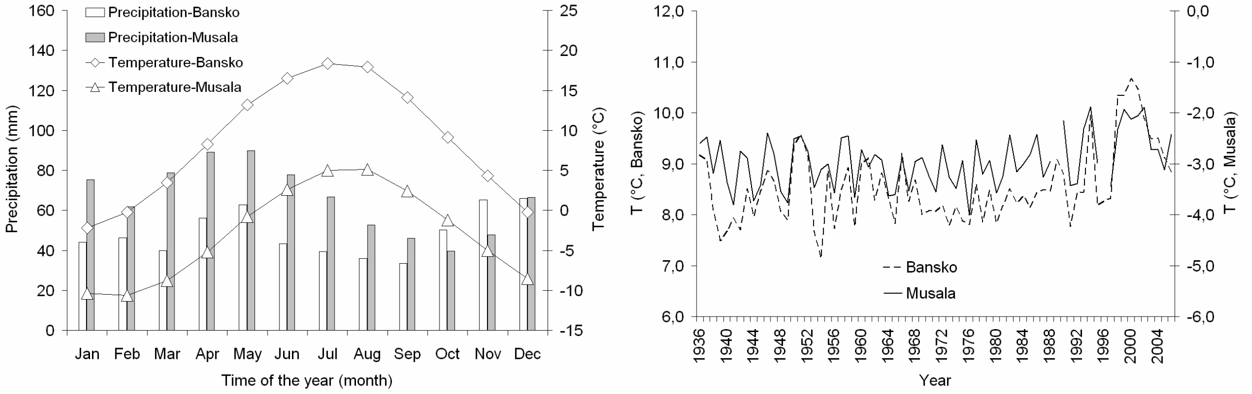

Figure 2: Climatic features (temperature, precipitation) of the stations Bansko and Musala.

Results and discussion

Ring-width chronologies

The tree ring series were verified with Cofecha separately for each of the sampled sites and finally chronologies were generated with Arstan (Fig. 3). The Bosnian Pine ring width chronology that goes back 722 years could be established at site G1 (Grunewald & Scheithauer 2008a). The age trend was successfully eliminated by detrending whereby the high frequent interannual climate signal was intensified. The chronologies for G4 and G5 are shorter. Here the drillings often reached the pith. Moreover, in the G5-series it becomes obvious that a local event (e.g. fire) destroyed nearly the whole stand. Possibly due to the stand dynamic, numerous A flags are significant (indicates the calculated correlation for segments fell below the 99% confidence level). Nevertheless, the Cofecha quality parameters as well as the Arstan parameters show the chronologie´s robustness (Tab. 2).

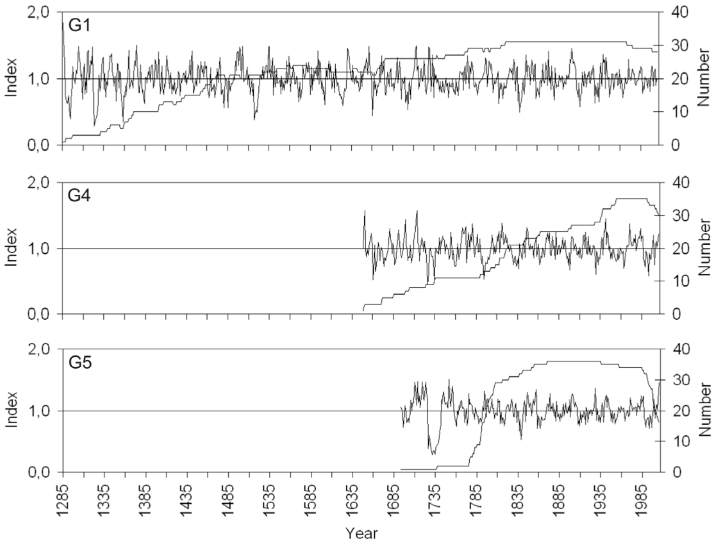

Figure 3: Standard chronologies G1, G4 and G5 (index, twice detrended) and number of cores.

Table 2: Average descriptive statistics from all ring width series (Cofecha: No. of dated series, mean length of series, Arstan: means, in brackets minimum and maximum values from 50 years moving intervals).

Parameter	G1	G4	G5
No. of dated series	45	35	36
Time span of master dating series	1285 - 2006	1648 - 2005	1693 - 2005
Series intercorrelation	0.67	0.64	0.51
Sensitivity	0.23	0.19	0.21
Segments, possible problems	3	9	36
Rbar	0.48 (0.38 - 0.60)	0.31 (0.21 - 0.52)	0.30 (0.24 - 0.41)
EPS	0.95 (0.89 - 0.97)	0.83 (0.73 - 0.92)	0.94 (0.92 - 0.96)
Standard deviation	0.18 (0.11 - 0.24)	0.24 (0.15 - 0.30)	0.20 (0.17 - 0.24)

Beyond the partial characterisation of the chronologies (Tab. 2), statistical comparison among each other was carried out. Considering the total length of the series, the correlation between the chronologies is rather weak (r = 0.39 ... 0.51). Close relations were observed (r = 0.67 ... 0.87) for the period, during which the climate-growth-analyses were realised (1936 - 2005). Whereas regarding the pointer years of the period which is relevant for the climate data, differences between the sites were observed (Fig. 4). The G4-series show a total of 33 (18 positive and 15 negative) and therefore the most pointer years between 1936 and 2005, whereas for G1 a total of 26 (13 positive and 13 negative) and for G5 only 20 pointer years could be determined (11 positive and 9 negative). In addition, there are logically, statistically significant correlations between the occurrence of pointer years and the established chronologies, especially after eliminating the autocorrelation (e.g. positive pointer year and positive index in the residual chronology). Basically it can be stated that positive or negative pointer years simultaneously occured at all three sites in several years only. This fact indicates the storage of different climate signals depending on site and stand conditions.

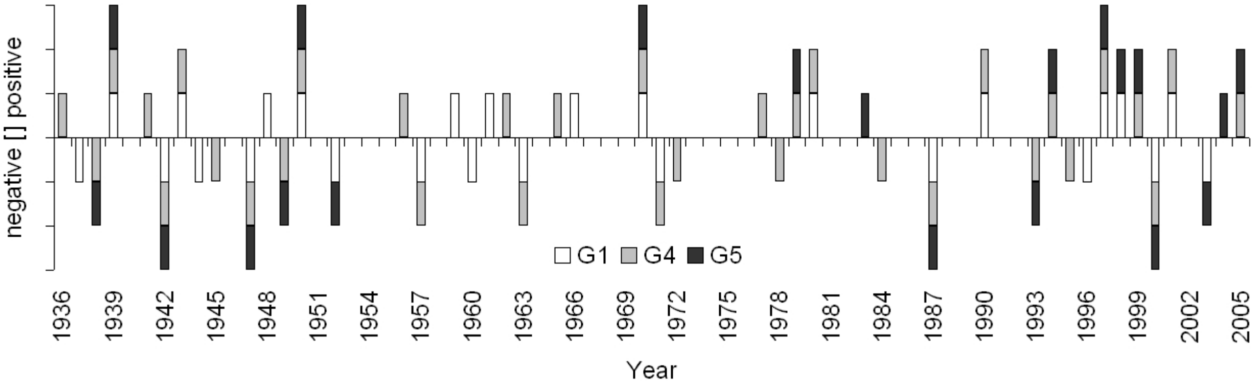

Figure 4: Pointer years in the tree-ring width series of G1, G4 and G5 for the period 1936 - 2005 (comments: y-axis units display “existence” or “non-existence” of a negative or positive pointer year with a bar; period corresponds with the measurements of climate data).

However, at present first correlations can already be established between tree-ring width and influencing (exogenous) factors. Perennial ring-width growth increases or decreases at the timberline ecotone correlate with local site conditions and events as well as with local to regional, particularly climate effects or anthropogenic impacts. Beside in situ natural processes (e.g. rockfall, land slide), anthropogenic factors (slash-and-burn for grazing, wood cutting) can be responsible for the divergence between several trees and ring width series respectively at the sampled sites. For instance, it is known that the Aromuns, nomadic and halfnomadic shepherds and goatherds, also used the Pirin Mountains in summer for long-distance grazing over many centuries. In addition, the wood of the Bosnian Pine in the range of the investigated timberline was manufactured in considerable amounts in the saw mill in Bansko until 1944.

Additional to site influences, extremely cold or dry but also very mild and wet years as well as late frost events and insects calamities become locally effective and be reflected in the entire sampling group as pointer years (Schweingruber 1993). Touchan et al. 2005 could deduce periods with water deficiency or water surplus from Turkish *Juniperus excelsa*-chronologies. Significant positive or negative changes in growth can be determined accordingly in the ring width series of the Bulgarian Bosnian Pine (dry years 1608, 1675, 1907: negative pointer years, wet events in 1428, 1503, 1629/30, 1914: positive pointer years). A similar reference can be established for individual pointer years and the drought limited growth of the *Pinus nigra* in the Greek Taygetos-Mountains respectively (Brandes 2007) and for most positive pointer years between 1881 and 1959 for the Aegean (Hughes et al. 2001). In this context, even the chronology of *Pinus leucodermis* from Northern Greece (Olympos Oros, WSL Dendro Database, Switzerland. www.wsl.ch/dendro) closely correlates with the series from Pirin Mountains (correlation with master 0.64). The variability of the analysed segments is largely synchronous (no B flags in Cofecha, indicates higher correlations within segments -10 / + 10 years).

Climate-growth relationships

Based on the chronologies comparison, it is stated with regard to the growth characteristics of the Bosnian Pine that the climate-growth-relation varies according to site conditions (sunny or shady slope) or that either temperature or precipitation should have a limiting effect. The statistical investigation lead to different findings with regard to the temperature impact. On the one hand, there are differences between the data series from Bansko and the Musala despite a close correlation of the annual values (r_R = 0.72, see above). Whereas the temperature variability between April and July in Bansko is in negative relation to the ring width growth at G1 (G4, G5 only June and July, Fig. 5, upper graphs), hence high temperatures during the vegetation period entail a thin tree-ring, rather mild winters at Musala promote growth. This would mean that the tree-ring traces the temperatures at the peak as climate signal of the winter months, whereas the more warm and dry influenced Bansko is characterised by a kind of heat limitation. On the other hand, the summer temperatures could barely act growth-resistant at the theoretically thermal-determined timberline and treeline.

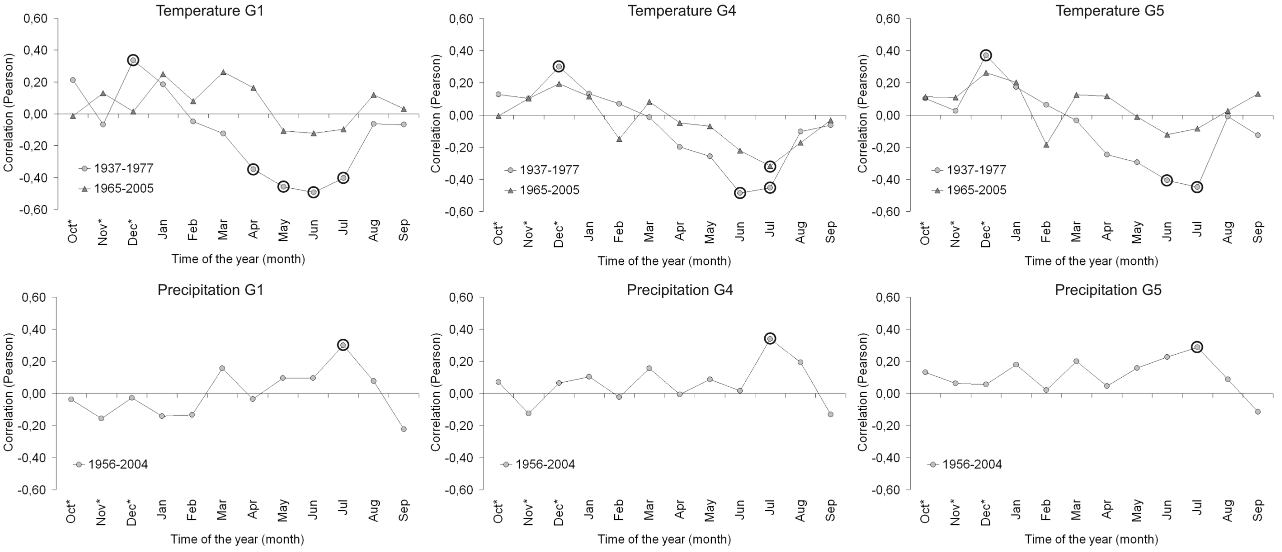

Figure 5: Temperature and precipitation from station Bansko in relation to ring width at the three sampled sites G1, G4 and G5 (significant correlations at the 0.05 level are marked with a bold ring).

Interestingly, the Bosnian Pine behaves similarly - with regard to the Bansko climate data - at the three investigated sites. The expected temperature limitation in summer at the G5-north slope was not observed. The number of months with statistically significant impact on the ring growth simply declines from G1 towards G5. Nevertheless, as the result a moisture limited growth should be found at G1. The statements correspond with the results of Brandes (2007) and his discussion on a climate-ecological timberline in the Greek high mountains. This assumption is also confirmed by the relation to the monthly precipitation sum because the data sets of both stations are significantly positive correlated with the ring width in July (e.g. Bansko in Fig. 5, lower graphs).

Furthermore, the temperature series for the period 1937-2005 show comparatively weak correlations with the ring width. In contrast, the periods 1937-1977 and 1965-2005 are more closely correlated, however in different months. A comparison with the last 40 years of the series showed little relations within the 0.05-significance level. Instead, the growth of the tree-ring width is closely related to summer temperatures in the years 1937-1977. If one considers the analysed moving intervals for the total series length (base length 24 years), a change in the response of the climate-growth relationship becomes apparent. This means for Musala a shift from a positive last year's impact to a winter and spring-time impact as well as a negative June and July temperature impact. Referring to Bansko, the summer and partly last year's November have an almost limiting effect during the entire observation period.

The tree-ring width as well as the occurrence of pointer years and the annual number of trees with a conform growth tendency respectively correlate with climate parameters. There were particularly negative pointer years in winters (December, January) with low temperatures and early summers (May, June) with high temperatures. Interestingly, this impact is similarly stored in all chronologies.

Conclusions

The results on dendroclimatology provide an insight into the potential of the Bosnian Pine and its chronologies in the Northern Pirin Mountains. First conclusions can be drawn from the chronology and site comparison respectively as well as the climate-growth-analysis. On the one hand, the width growth is humidity limited. On the other hand, the tree-rings similarly reflect high summer temperatures as a negative impact factor at sunny south flanks as well as at shady north slops. At the same time, mild winters have a positive effect. The growth period lasts, like at Mt. Pollino in Italy (Todaro et al. 2007), at the south-exposed site G1 from about the beginning of May until the end of July / beginning of August. In contrast, the cambial activity and cell growth period is likely to be shorter at G4 and G5 although both sites lie slightly lower and above all more sheltered. Temperatures rise however later above 0 °C in spring at a north-exposed site. Vice versa, an earlier influence of lower temperatures can be expected in summer. Consequently, wider tree-rings rather reflect a younger age of the investigated trees than better morphological and pedological conditions. Moreover, it is observed that the mean ring width (average raw data series) has increased over the last 50 years despite increasingly drier and warmer conditions in Southwestern Bulgaria. Although the Bosnian Pine forms thinner tree-rings in dry years in comparison with wet years, it tolerates relatively well the sparse conditions. It is assumed that there will not be any competition for the Bosnian Pine by tree species of the upper montane level zone during the course of shifting of vegetation zones towards the summit, which means that the *Pinus heldreichii* would be a winner of climatic changes (Grunewald & Scheithauer 2008a).

Next, series of the earlywood and latewood density as well as the stable isotopes were also measured ($\delta^{18}O$, $\delta^{13}C$) which show a more robust climate proxy than the tree-ring width (Helle & Schleser 2004). They are currently analysed and have to yet be compared with other studies on Bosnian Pine and on climate change in the Mediterranean area. Furthermore the phenomenon of increasing ring width during the last decades will be ensured with climate data and other proxies. Having carried out additional statistical analyses and applied adjusted methods (Cook & Kairiukstis 1992, Naurzbaev et al. 2004, Esper et al. 2008), the climate reconstruction for the Pirin Mountains will finally take place.

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Effect of resin tapping on radial increments of Scots pine (*Pinus sylvestris* L.)

Tomusiak, R. & M. Magnuszewski

Department of Dendrometry and Forest Productivity,
Faculty of Forestry, Warsaw University of Life Sciences, Poland
Email: rtomusiak@wl.sggw.pl

Introduction

Resin – a valuable gift of nature – is a hydrocarbon secretion of many plants, particularly coniferous trees: pine, spruce, larch and others. Pine resin is mainly composed of rosin (70%) and turpentine (22%) as well as some amount of water (Grochowski 1984). Both rosin and turpentine are chemicals which are widely used for industrial purposes. Rosin is used in the production of adhesives, paper sizing agents, printing inks and detergents. Turpentine is usually the raw material for varnishes, perfume, disinfectants and cleaning agents (Coppen & Hone 1995).

Due to its numerous applications pine resin is an important non-timber forest product (Wang et al. 2006). China is the world's leading producer of rosin, the rosin industry involves there more than 250,000 people. During the 1990s China exported a total of 200,000 t of rosin to over 40 countries annually, which was app. 50% of rosin traded in international markets all over the world (Liu 2001)

Before Poland started to import cheaper resin from China, Ukraine and Brazil, the process of acquiring of this substance, called resin tapping, was a branch of the forest management and economy, performed by the State Forest Administration and categorized as one of the non-wood forest products and services. It took place from 1920s till 1994. Species which was most frequently used for that purpose is the Scots pine (*Pinus sylvestris* L.) (Głowacki 2004)

According to the Polish method of resin tapping diagonal incisions on the tree stem should be made up to the height of 3.0 m. These incisions left finely-carved fishbone scars visible on stems even many years after the process was given up. According to the regulations of the Polish State Forest Administration resin tapping could be performed only in the forest stands, where cuttings were planned at the latest in 6 years (Instrukcja 1956). However, there are still many stands in Poland, where no cuttings were performed after the process of resin tapping was finished.

Resin tapping, causing a wound on tree tissue, may influence the tree growth, especially the forming of tree rings. Studies on economic aspects of resin tapping and resin yield were carried out in many countries (e. g. Głowacki, 1983, Nanos et al., 2001, Wang, 1993, Zhang 1990). The research on influence of resin tapping on tree growth was performed significantly more rarely (e. g. Grochowski 1984, 1990, Jezierski 1930, Li 1991). Moreover, the results of various investigations differed from each other as well as they presented opposite opinions. Analyses of these results show that the investigations of influence of resin tapping on tree growth are often not comparable (e. g. due to different species and different resin tapping methods).

The aim of this work was to evaluate the influence of resin tapping on radial increments of Scots pine trees, tapped with the Polish original method.

Material and Methods

The study area is located in the northern part of Poland, in Lidzbark Forest District. It is a 148 year old Scots pine (*Pinus sylvestris* L.) stand, growing on a rich site (fresh mixed forest). Average diameter at breast height (1,3 m above ground) is 40 cm, average height 32 m. There is some admixture of Norway spruce (*Picea abies* L. Karst.) and hornbeam (*Carpinus betulus* L.) in the stand. Against the rules of the Polish method of resin tapping (Instrukcja …, 1956), the stand wasn't cut after the process was finished. There are many such pine stands in Poland, which were first used for resin extraction and which weren't harvested thereafter. In the studied stand the

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process of resin tapping was carried out in mid-1960s. There are still numerous Scots pine trees with old tapping scars (Fig. 1). 40 years after the tapping was finished they seem to be vigorous.

Figure 1: Scots pine stand with resin tapped trees. (Photo: Michał Magnuszewski, 2006)

The tree ring samples were taken with an increment corer from two heights on a tree stem: 1,3 m and 3,3 m. On the tapped trees some parts of bark and woody tissue was removed, which caused a long wound on a stem, the so called "tapping face" (Fig. 2). Cores were taken only from the non-wounded part of a stem, called "life belt". The scars were not longer than 3 meters, so the extracted cores at the height 3,3 m were always above the scar.

Figure 2: Tapping face and life belts on the Scots pine stem – 40 years after resin tapping process was finished. (Photo: Michał Magnuszewski, 2006)

Altogether, 71 cores were obtained: 35 from the tapped trees and 36 from the non-tapped trees (as a comparative research material from the same stand). The empirical material consists of four groups of samples:

- tapped trees, coring height 1,3 m
- non-tapped trees, coring height 1,3 m
- tapped trees, coring height 3,3 m
- non-tapped trees, coring height 3,3 m.

Because all groups of trees grow in the same place it is expected that possible differences in the tree ring characteristics will be an effect of some factors diversifying their growth. In the analysed case, the resin tapping which was performed in the stand from 1965 to 1970, is supposed to be one of this factors.

The increment cores were first dried and than the ring-width series were measured using a digital positioning table (accuracy: 0.01 mm) and the corresponding software “Przyrost”. The tree ring analyses were performed according to the standard dendrochronological methods (Cook 1990).

For each of the four analysed groups of sequences chronologies were constructed. Values and variability of the increments for each group were evaluated and were than compared to each other. Analyses were carried out for the period 1900-2006 as well as for the periods: before (1900-1965) and after the process of resin tapping (1966-2006). Comparison of chronologies was based on Student’s t-value.

Results and discussion

The comparison of breast-height chronologies shows a significant difference between the tapped and non-tapped trees (Tab. 1). Average value of the tree ring width in the first group is 1,42 mm; in the second: 1,20 mm, with similar variability.

Table 1: Characteristics of the chronologies from breast height, 1,3 m (mm).

Group of trees	Average TRW	Standard deviation	Minimum TRW	Maximum TRW
Whole chronology				
Tapped	1,42	0,44	0,63	2,70
Non-tapped	1,20	0,43	0,47	1,89
Period before the resin tapping (1900-1965)				
Tapped	1,23	0,29	0,72	1,92
Non-tapped	1,29	0,32	0,78	1,89
Period after the resin tapping (1966-2006)				
Tapped	1,71	0,48	0,63	2,70
Non-tapped	1,05	0,27	0,47	0,53

When comparing some characteristics of both chronologies in the two periods, it is evident that before the resin tapping process was started (1900-1965) growth of both groups of trees was very similar (Tab. 1). After the year 1965 it changed rapidly (Fig. 3) and the annual radial increments of the tapped trees increased in that period significantly. The average value of the tree ring width increased to 1,71 mm (Tab. 1). The chronology curve of the tapped trees shows higher values of ring widths than the comparative trees since the year 1971. In the Polish method of resin tapping trees are notched for six years; what is very stressing for a tree. The observed, significantly higher tree ring widths after the resin tapping process in comparison with the non-tapped trees can be tree's reaction to the lack of cambium in a part of the stem's circumference. The size of the wound ("tapping face") on the stem varied between the trees. Depending on the DBH and conditions of a tree there could be one, two or even three wounds around the stem (different intensity of resin tapping). The wound was always without cambium, so the annual growth of a tree could take place only in the non-wounded part of a stem, in the life belt (Fig. 3). The results described above refer to the tree ring samples extracted from the height of 1,3 m on the stem; in the group of the tapped trees they refer to the "life belt".

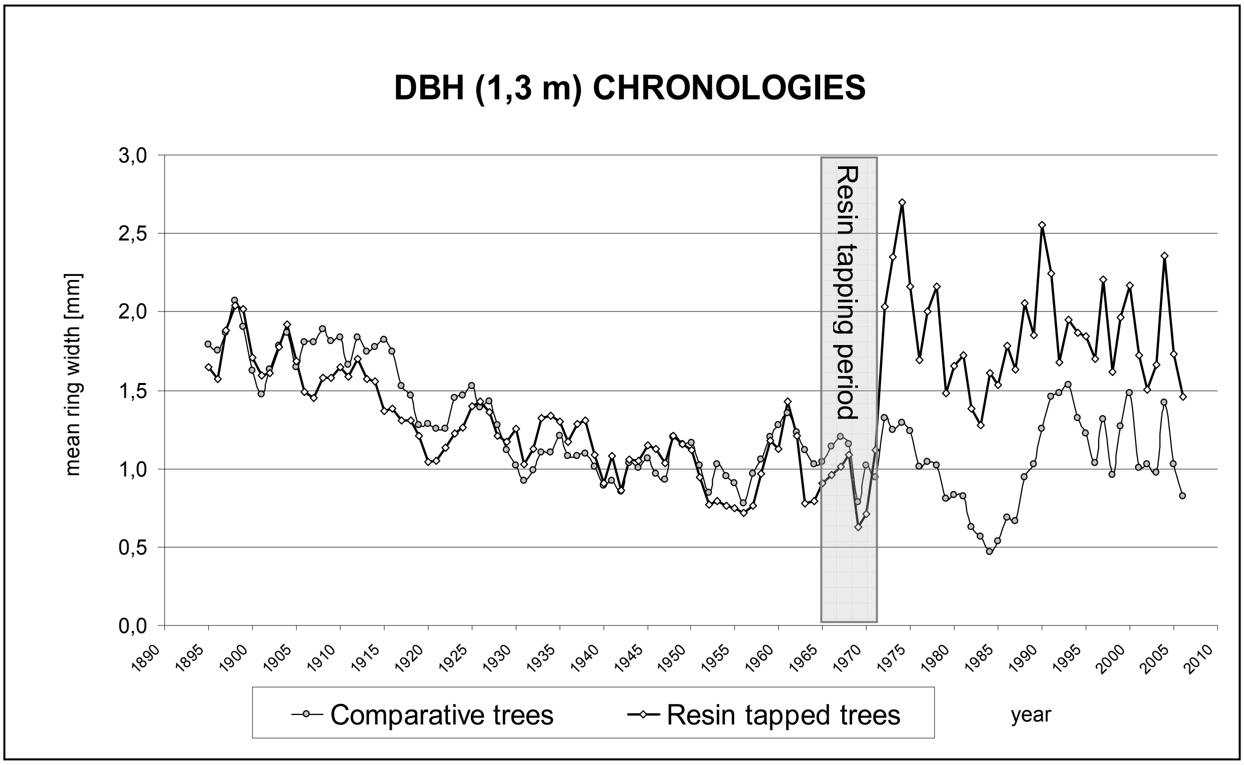

Figure 3: Breast height (1,3 m) chronologies for tapped and non-tapped Scots pine trees – raw values (mm).

A different situation can be observed on the height of 3,3 m above the ground. Average value of the tree ring width during the whole period of reconstruction is higher on tapped trees (Tab. 2). It shows also higher variability.

Table 2: Characteristics of the chronologies from the height 3,3 m (mm).

Group of trees	Average TRW	Standard deviation	Minimum TRW	Maximum TRW
Whole chronology				
Tapped	1,15	0,74	0,32	3,94
Non-tapped	0,86	0,30	0,29	1,55
Period before resin tapping (1900-1965)				
Tapped	1,50	0,76	0,66	3,94
Non-tapped	1,00	0,28	0,45	1,55
Period after resin tapping (1966-2006)				
Tapped	0,61	0,17	0,32	0,97
Non-tapped	0,63	0,18	0,29	1,00

It could be supposed that it is an effect of the resin tapping, but if we perform analysis regarding the two periods “before” and “after” the resin tapping, we can see rather surprising results (Fig. 4). In the period 1966-2006 there are no statistically significant differences in the tree ring widths between the tapped (average 0,61 mm) and the non-tapped trees (0,63 mm). It means that there is no noticeable effect of resin tapping on tree growth on the height 3,3 m (at least 0,3 m above the wound on the tapped trees).

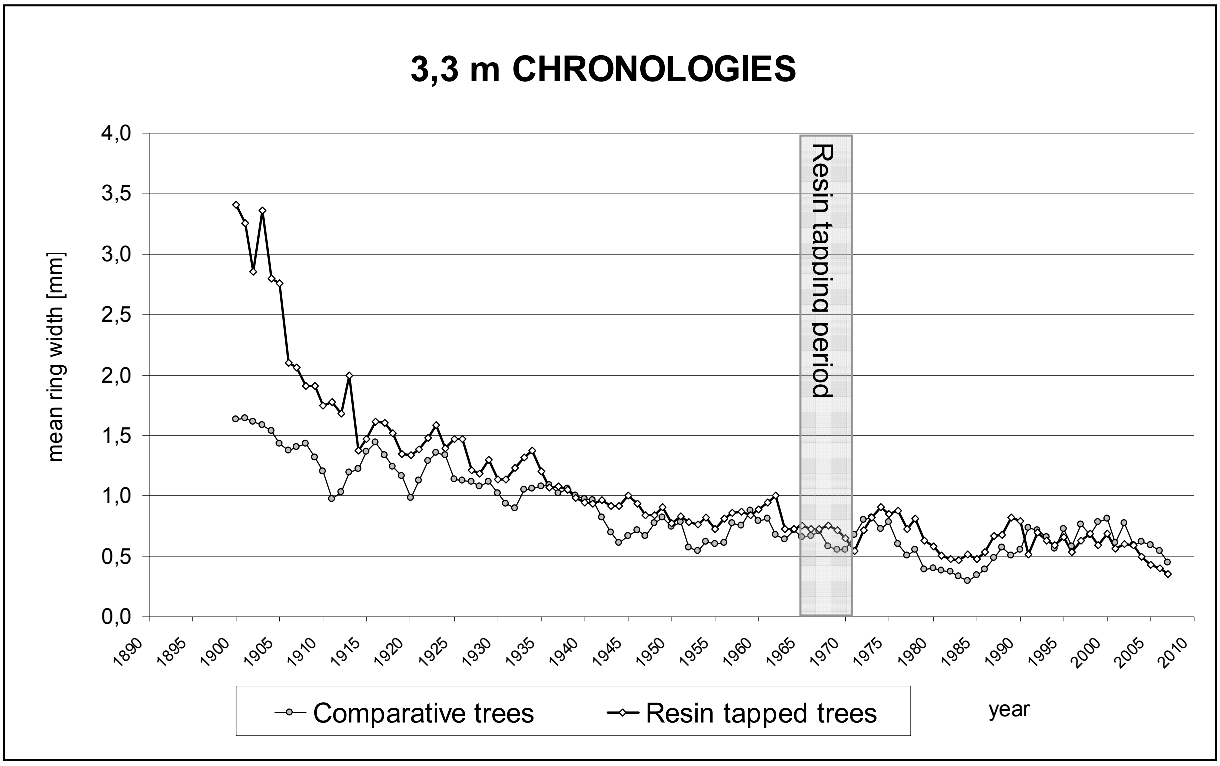

Figure 4: Tree ring chronologies from the height of 3,3 m for tapped and non-tapped Scots pine trees – raw values (mm).

It is difficult to explain why the tapped trees have higher tree ring widths in the period before the resin tapping process: 1900-1965 (Tab. 2). The possible answer could be that some weak and less vigorous trees were not selected for the resin tapping process, but it is against the regulations (Instrukcja, 1956), which say, that all trees in the stand should be used for this purpose.

It should be mentioned that the effect of resin tapping on radial increments is one of many possible changes of tree characteristics. Although resin tapped trees seem to be vigorous, more careful observation of their stems show many fungal infections as well as the rot caused by them. 40 years after the process of resin tapping was finished the tapped trees are less stable than the comparative ones (Fig. 5). They have also significantly lower technical properties of wood.

Figure 5: Broken and rotten stem of a resin tapped Scots pine. (Photo: Michał Magnuszewski, 2006)

Conclusions

The study revealed significant differences in the annual growth response at the breast height between the tapped and the non-tapped Scots pine trees. It allows the assumption that resin tapping positively influences the radial increments at 1,3 m. It takes place only in the "life belt"; the “tapping face” (scar) has no increment after the process due to the damage of cambium. Wider tree rings recorded in the “life belt” seem to be some kind of tree reaction for the lack of woody tissue in a part of the stem. The same phenomenon is very common at burned but surviving and living trees where only a part of the bark and cambium were destroyed by fire.

The comparison of tree ring width pattern (raw values) of the tapped and non-tapped trees at the height of 3,3 m shows no significant difference. It means that there is no significant effect of resin tapping on radial growth on the height above the scar (at 3,3 m).

The study shows that an effect of resin tapping on radial increments of Scots pine is very local on the tree stem. It takes place only on that part of the stem, where the “tapping face” is located, what means the height of about 0,1-3,0 m.

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An abrupt growth release as an indicator of past disturbances in a spruce forest in the High Tatras

Zielonka, T.[1], Holeksa, J.[1] & P. Fleischer[2]

[1] *Institute of Botany Polish Academy of Sciences, Lubicz 46, 31-512 Kraków, Poland*
[2] *Research Station, State Forest of Tatra National Park, Tatranská Lomnica, Slovakia*
Email: T.Zielonka@botany.pl

Introduction

The development of methods used in dendrochronology especially during the last decades enables the application of information contained in tree-rings to study the dynamics of forest stands and the reconstruction of their history (Bergeron et al. 2002). An abrupt growth release in trees is used for the identification of disturbances in the past. In closed canopied forest, trees which survive a disturbance may increase their radial growth due to decrease of competition for space, light nutrient and water (Lorimer 1985; Lorimer & Frelich 1989; Nowacki & Abrams 1997). Many methods were developed to detect the moment of disturbance event and to measure its severity (Rubino et al. 2004). An increase of growth rate in comparison to growth rates in previous years with different thresholds were used in many studies (Schweingruber et al. 1990; Kienast & Schweingruber 1986). Other methods are based on comparison of adjacent periods of growth using running mean calculations. An increase in mean growth over periods of preceding and subsequent years may indicate a severity of disturbance when its value exceeds a given threshold (Lorimer & Frelich 1989; Nowacki & Abrams 1997). These methods were broadly used for reconstruction of forest history and to determine a frequency and severity of disturbances. Past disturbances regime significantly influences the structure, species composition and processes like mortality and regeneration. Thus, the knowledge of disturbance history might be helpful to explain the current state of forests and to improve management, conservancy and restoration of forests stands. In this study we used a dendrochronological method to reconstruct a history of forests in the Tatra Mts. (Western Carpathians) which are known to be affected by severe windthrows. We hypothesized that past disturbances in this region influenced the radial growth of spruce trees.

Methods

Study site

The study plot was located in the Slovakian High Tatras in an area affected by the severe windthrow which took place in November 2004. In the tree layer Norway spruce (*Picea abies* L. (Karst)) prevails with an admixture of Scots pine (*Pinus sylvestris* L.) and European larch (*Larix decidua* Mill). The ground vegetation is dominated by *Vaccinium myrtillus*, *V. vitis-idaea*, *Calamagrostis villosa* and *Homogyne alpina*. The average annual temperature is 4.7^{0}C and the annual average precipitation is 864 mm. Except for the windstorm event in 2004 the area was also affected by windthrows of high and moderate severity known from historical sources during the 20th century (Koren 2006).

Collecting data and analyses

On the area of 100 ha, 67 cross-sections were extracted from the stumps which were left after clearance of the windthrow. To obtain the possible longest time series of tree rings stumps representing the oldest generation of spruce trees were selected. The chosen stumps were distributed evenly throughout the whole 100 ha area. All discs were dried and polished and then tree-ring widths were measured with LINTAB and TSAP measurement system. The quality of measurements was verified with COFECHA (Baillie & Pilcher 1973). An abrupt release signal was detected for all trees with the method proposed by Nowacki & Abrams (1997) - a percent growth change (%GC) according to the formula:

%GC = [(M2 – M1)/M1] x 100

%GC = percentage growth change between preceding and subsequent 10 years mean, M1 = preceding 10 years mean, M2 = subsequent 10 years mean.

%GC was calculated for each ring-width of all trees except 10 first and last rings in time series. To detect an abrupt growth releases two thresholds for the %GC were used – 50% and 100%. As a year of possible disturbance event we treated the year when the highest value of %GC appeared and exceeded the threshold values. Number of trees containing a respectively release signal were plotted in a time scale and were compared with historical records of severe windstorms. To verify whether the intensity of release depends on tree age or not, all %GC values over 50% were correlated with the age of tree in the moment of appearance of the event. The same highest %GC values were correlated with a prior growth. To calculate the prior growth, width of 10 preceding rings were averaged. For calculation of these correlations, data were transformed first to obtain the normal distribution.

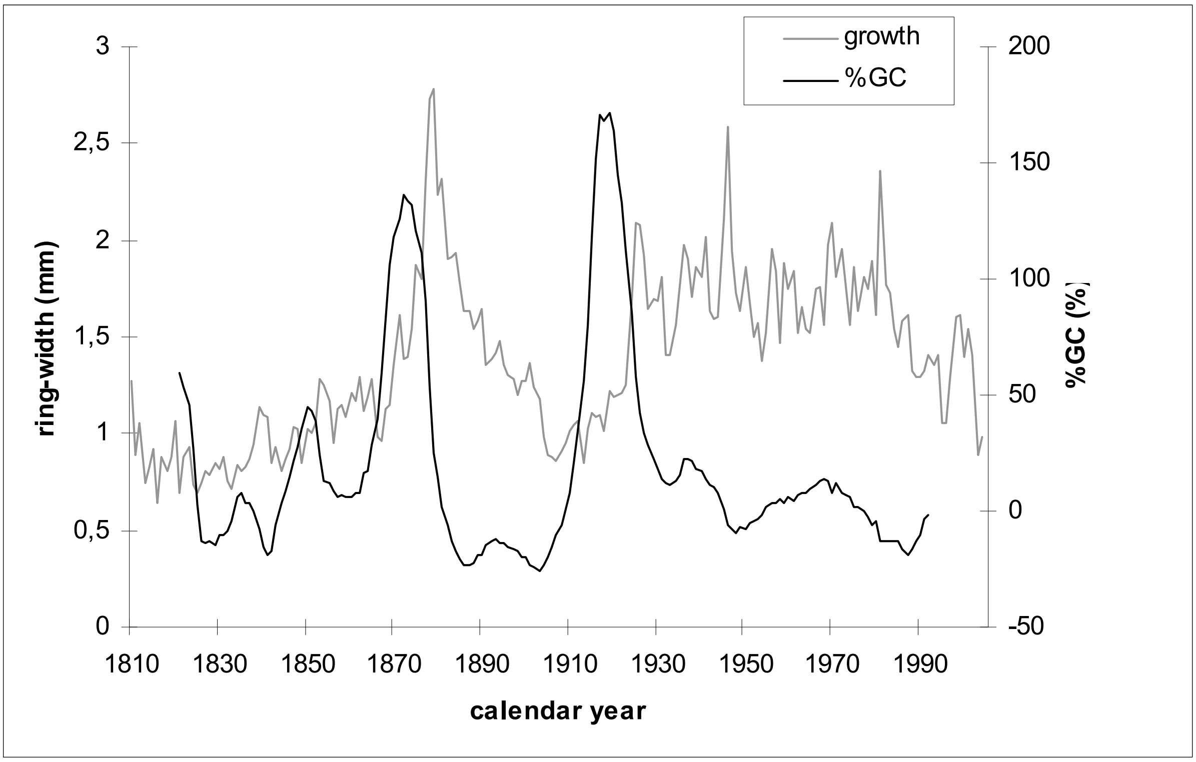

Figure 1: Average growth (grey line) and %GC (black line) for sampled trees.

Results

There were two periods of intensive growth acceleration detected with an average %GC (Fig. 1). An average %GC increased over 100% around 1870 and was preceded by a slow growth period with an average growth of approximately 1mm/year. After 1870 the average growth increased abruptly, however for a short period, to over 2.5 mm/year. Next increase of %GC began around 1915 and was also preceded by growth depression (Fig. 1). The average growth increased at the same time to values of ca. 2 mm/year. Since this time the average %GC did not increase significantly, and the growth rate started to decrease gradually since 1980s. %GC values calculated for individual trees shows a similar pattern (Fig. 2).

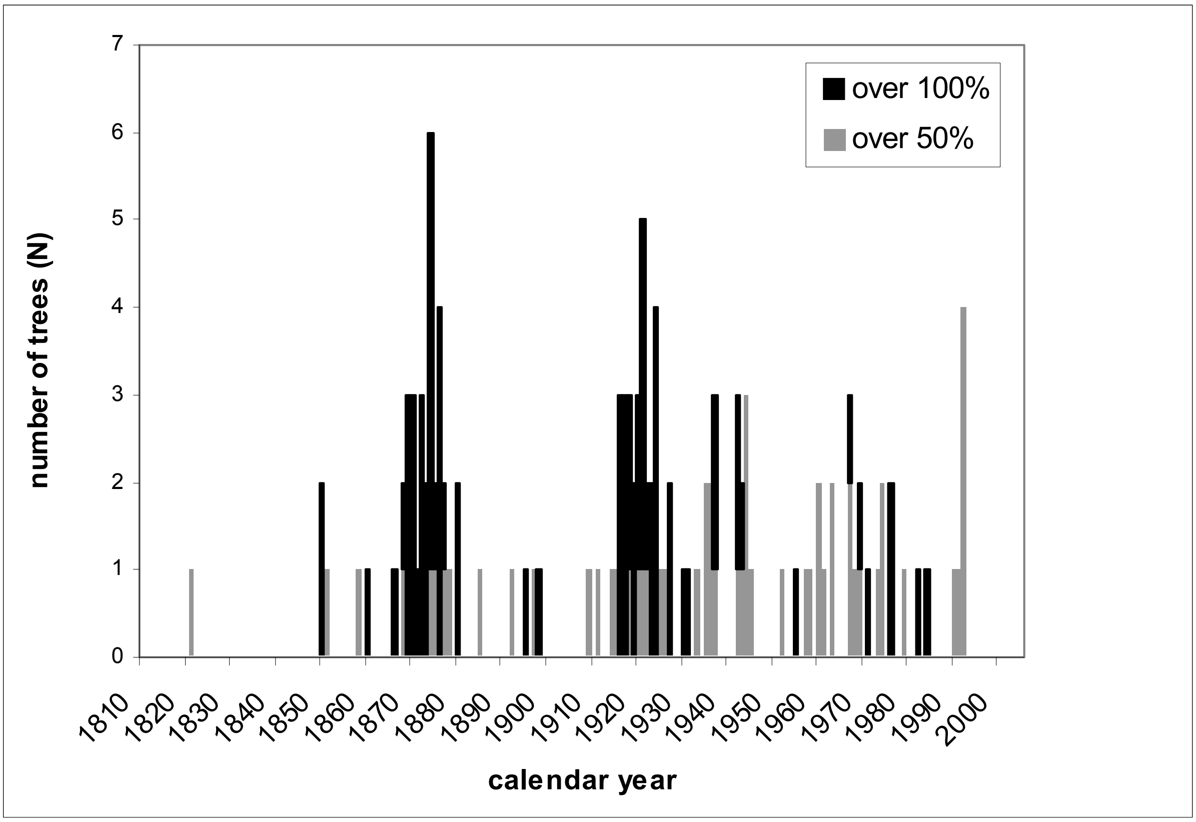

Figure 2: Number of trees with a recorded release reaction - %GC exceeding 50% (gray bars) and 100% (black bars).

First trees started to increase their growth abruptly in 1868 and during subsequent 10 years 70% of spruces recorded a reaction over 100 %GC. Another 12 % showed a smaller reaction between 50 – 100%GC. In the period 1916 – 1924, 36% of all trees showed a reaction over 100%GC and another 6% a reaction between 50 – 100 %GC. Except these two distinctive periods 13% of trees showed a reaction over 50% in 1942 – 1945, and in case of three individuals the reaction was over 100%GC. After this time only single trees showed an increase of %GC above respective thresholds. In some time series, %GC values exceeded a threshold of 100% many times. The highest value of %GC was almost 3000% and in case of 12 individuals %GC exceeded 500% (Fig. 3, Fig. 4.). This shows a very high intensity of growth reaction. %GC was significant negatively correlated with tree age and prior growth (Fig. 3, Fig. 4.). The correlation was stronger for prior growth ($r = -0.65$, $p<0.005$) then for the tree age ($r = -0.35$, $p<0.005$).

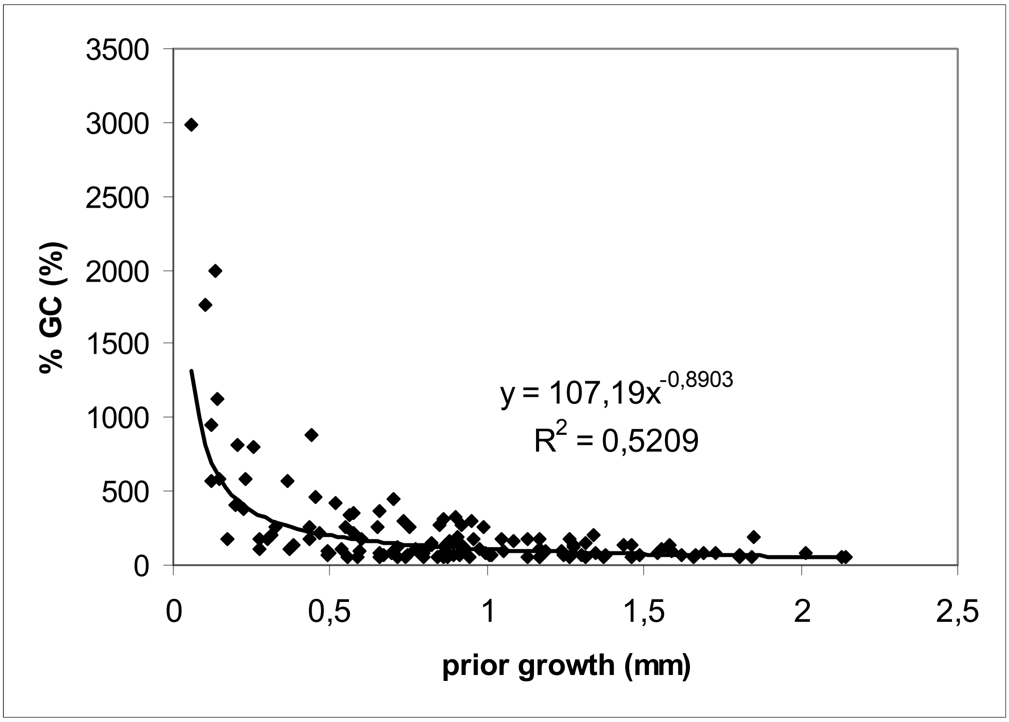

Figure 3: Relationship between %GC values and prior growth (r = -0.65, p<0.005).

Figure 4: Relationship between %GC values and tree age (r = -0.35, p<0.005).

Discussion

Release pulses observed in studied spruce trees overlaps with records of severe windstorms which are documented in historical sources. Severe windstorms were noted in 1915, 1919, 1941, 1971, 1981, and were responsible for serious losses of the timber volume (Koren 2006). The abrupt growth release initiated around 1915 might be explained by the windthrow recorded for this year. This reaction in spruce trees was extended until 1927, what may indicate that windthrow in 1919 might have strengthened the reaction of survived trees. After 1941 a growth release was noted for a smaller number of trees, but still some of them showed growth release exceeding 100%. The other period of the intensive increase of growth began in 1868. Historical sources do not reach the 19th century so it was not possible to relate this event with confirmed disturbance. Intensive reactions of trees in this period indicate a severe disturbance event, probably like this one in the 20th century caused by a windthrow. Additionally high values of %GC observed in a portion of trees indicate a high severity of noted disturbances. Such intensive and abrupt change in growth pattern of trees which survived must have been related to the dramatic environmental change and suggests that the stand was considerably thinned due to windstorm. Our results shows different pattern, than observed at forests of Central Europe. Studies in mixed stands usually show a high variation of frequency of wind disturbances (Splechtna et al. 2005). Low and moderate severity of wind disturbances and frequent and asynchronous release signals in individual trees indicate rather small-gap phase processes (Nagel & Diaci 2006) (Nagel et al. 2007) then infrequent disturbances of high severity, like in our study. Similar dendroecological reconstructions from the Alps showed additionally a high contribution of human activity in the past besides natural disturbance factors (Motta & Nola 2001). According to the historical sources the Slovakian High Tatras were prevented from intensive logging. In the 19th century the area was sparsely populated and since 1949 it was protected as a national park. Our study confirms that the intensity of growth acceleration induced by disturbances depends on the prior growth. Trees of slow growth and suppressed trees react more intensively to an improvement of growth conditions (Lorimer & Frelich 1989; Black & Abrams 2003). However, the intensity of growth acceleration depends also on the tree age. Younger trees have a higher potential to react with high growth acceleration to disturbances then older individuals.

We conclude that with the use of dendrochronological methods it is possible to reconstruct a forest history in the long time scale which exceeds many times the possible period of direct observation, e.g. in permanent plots. A long scale of observation seems to be important especially in case of detecting disturbances of low frequency like those, which appear in some regions of the Tatra Mts. Forest history, obtained from dendrochronological reconstructions increases our knowledge of forest dynamics and about processes within tree populations. Such knowledge may improve management, conservancy and restoration of European forests.

Acknowledgements

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SECTION 4

GEOMORPHOLOGY

Dendrogeomorphological records of trail erosion

Buchwal, A.

Institute of Paleogeography and Geoecology, Adam Mickiewicz University
Dziegielowa 27, 61-680 Poznan, Poland
Email: kamzik@amu.edu.pl

Introduction

Trail construction on forested mountain slopes is a cause of accelerated erosion which is an effect of exposing the soil surface. The erosion risk on slopes is increased by removal of the plant cover and by soil compaction, which drastically reduces infiltration rates. Both natural morphogenetic processes and human activity, mainly trampling, are responsible for root exposure on the trail surface. Those lateral roots can be used for dendrogeomorphological analyses. Changes in the root morphology and especially in its anatomy offer a great opportunity to situate erosion processes in time. Considerable improvement of dendrogeomorphological techniques enables to distinguish even the character of the exposure process (continuous denudation or erosive events) (Gärtner et al. 2001, Gärtner 2003, 2006). Dendrogeomorphological approach has been already developed to estimate the processes and their rates within the mountain trails in the Guadarrama Mountain Range (Bodoque et al. 2005, Rubiales et al. 2008) and in the Central Italian Alps (Pelfini & Santilli 2006).

The study focused on the analysis of anatomical variations in the annual growth rings of exposed roots of spruce (*Picea abies*). Samples were taken along the trail on Mount Babia in the Polish flysch Carpathians. The aim of the study was to reconstruct denudation processes with the help of wood anatomical features of exposed roots of spruce.

Study area

The Babia Gora massif is a mid-mountain range located in the Western Carpathians, Southern Poland. The maximum elevation reaches over 1,700 m a.s.l. (Mount Babia - 1,725 m a.s.l.). The massif consists primarily of flysch conglomerates. The highest parts, which are built of sandstones, show traces of a periglacial climate (Jahn 1958).

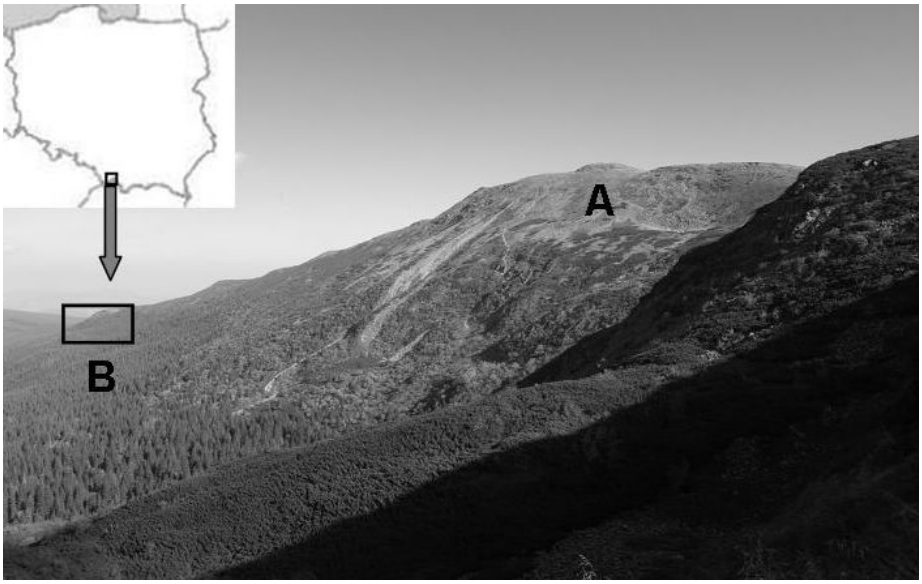

Figure 1: Study area. A - northern slope of Mount Babia (1,725 m a.s.l.) in the Flysch Carpathians; B - investigated trail area.

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The massif is asymmetric with a steeper northern slope, which is highly prone to landslides (Fig. 1). The significant relief energy of the northern slopes of Mount Babia leads to active geomorphological processes that are considerably accelerated by human activity, which now, after the establishing of the Babia Gora National Park (BGNP) consist mainly of tourism and very restricted timber harvesting. Due to the altitude of the surrounding mountains, which is about 350 m lower, the study area receives higher precipitation. The average amount of annual precipitation is 1,500 mm; high-intensity storms occur mostly during the summer. The area is forested predominantly with spruce (*Picea abies*). Since 1954, the area has been under protection (BGNP) and in 1977 the site was designated as UNESCO-Man and Biosphere Reserve. The area is visited on average by 70,000 tourists annually. This number is considerably lower as for example in the Tatra Mountains, which are visited by almost 3 million tourists per year. Nevertheless, problems of trampling and local damage also exist in BGNP.

Figure 2: Exposing of the roots within the trails is a very common situation. Each of them show a high injury grade and growth variations. Disc samples from the middle part of exposed roots from the trail surface were taken for the dendrogeomorphological analysis.

Studies were carried out on the Perc Przyrodnikow (Naturalists Path) trail. This short path (1,700 m) combines two long-distance transversal trails and climbs from 1,100 to 1,367 m a.s.l. This makes the path quite steep and in many parts the trail directly follows the slope gradient. The trail was constructed in 1927 by the Tatra Association, but no specific road design was used. Since that time its surface has never been replaced under a renovation scheme. This situation is advantageous for a dendrogeomorphological survey.

Methods

The research rested on two approaches. A field study involved geomorphological mapping and sampling of lateral roots covering the trail surface. Disc samples from the middle part of exposed roots were taken for further analysis by using a hand saw. The main part of the field mapping included a precise documentation of the position of the exposed roots relative to the recent soil surface. Data were collected using special inventory forms. An additional detailed photographic documentation was made.

In total, 18 roots samples (each 10 cm long) were collected in the field, but after a macroscopic analysis only 14 of them were taken for further investigation and were used for exposure dating purposes. Discs were sanded with a 400-grain or higher belt sander to prepare the wood surface for macroscopic analysis. From those prepared discs, micro-sections of 15 µm thickness were taken by using a sledge microtome. The slices were then stained with Safranin and fixed in Canada balsam.

Most of the laboratory work was carried out in Davos Laret during the “7th International Winter School on Wood Anatomy of Tree-Rings” and in the Department of Geomorphology of the Jagiellonian University, Poland. Micro-photographs were taken from the slides for digital cell size measurements. To process them, the software Image-J was used.

The anatomical reaction of conifer roots after their exposure is partly known (Gärtner et al. 2001) and the methodology was adopted from Schweingruber (1978) and Gärtner (2003). In addition, scars and the occurrence of compression wood were taken into consideration. The occurrence of scars and traumatic resin ducts was dated.

Preliminary results

It has currently been proved that both rapid and continuous exposure precedes anatomical changes in roots. After exposure, a considerable rise in the number of cells in a tree ring and a strong delimitation of early and late wood cells can be observed. This anatomical structure is typical of a stem but not of a root, which normally grows buried in the soil. After exposure, cell wall thickness increases, especially in late wood. Changes in cell growth begin when a part of the root is located near the soil surface, therefore the size of early wood cells must be considered since it is an indicator of root exposure (Gärtner 2006).

The exposure of roots progresses both due to natural geomorphological processes and human impact, such as trampling. A high-intensity runoff on a trail surface can be observed during heavy rainfalls which intensifies erosion. After exposure, the roots can be reburied at a shallow depth again. On rather flat parts of trails, the exposure rate may be lower as in steeper sections. Recovering can again be triggered by both natural processes and trampling. During the cold seasons, when the surface is free of snow cover, soil surface uprising is initiated by needle ice, which can easily expand on a bare trail surface and roadcut sides.

Simultaneous growth variations were detected in the analyzed roots. Increased root exposure occurred during the years 1963-1967, 1980-1981 and especially in the year 1984. Three out of the fourteen samples located in different parts of the trail showed that exposure occurred in 1984, two samples indicated exposure in 1954.

The main results obtained about the record of root exposure on the trail surface were:

1. Most of the analyzed root exposure dates are attributed to the summer season. Root exposure was probably triggered by frequent heavy summer storms and was intensified by trampling, which is documented in a greater number of rows of resin ducts (Figure 3).

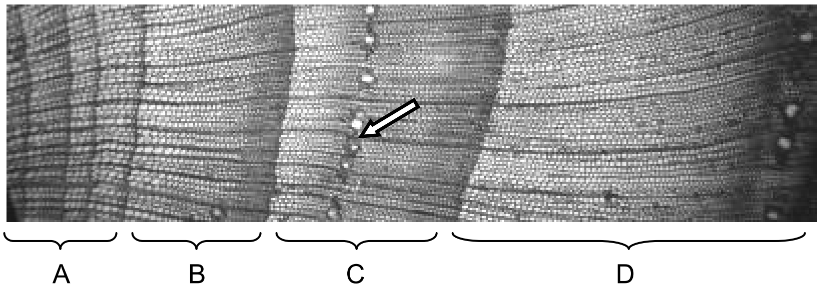

Figure 3: Micro section of an exposed Picea abies root taken from the trail:
A - typical growth pattern of buried root (narrow rings and dominance of early wood cells within each ring; one or two rows of late wood cells terminate each ring);
B - growth variation for the root growing near the soil surface (increase of late wood cell formation, increase of ring width);
C - ring showing the year of root exposure. The high mechanical stress, which in this case was witnessed by a scar caused by trampling, was responsible for the final root exposure. The response to the injury resulted in the production of a tangential row of resin ducts (white arrow);
D - typical growth pattern of an exposed part of a root on the trail surface (decrease of the early wood cell size and increase of early wood cell numbers; tangential rows of resin ducts show the reaction of continuous root re-treading).

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2. Thirteen out of the fourteen analysed roots show a considerable number of tangential or even traumatic rows of resins ducts (TRD) in the year of exposure and in consecutive years, which corresponds to mechanical stress on the roots. This is interpreted as a response of human induced denudation processes, which leads to root exposure.
3. Scars with resin pockets indicate a high injury grade, which was found in nine roots. Furthermore the sequences of scars were indicated. Most of them might be trampling scars.
4. Due to the continuous use of the trail and re-treading, the exposed roots form mostly wedging rings instead complete rings. Only one sample did not show this reaction.
5. None of the studied roots showed indications of rapid exposure. This fact might indicate that soil compacted by continuous treading is less susceptible to water erosion.
6. Before exposure, when a root is situated near the surface, false rings start to occur, which might make tree-ring recognition difficult. After exposure, an anomalous increase in tree-ring width is usually observed as well as the development of compression wood.

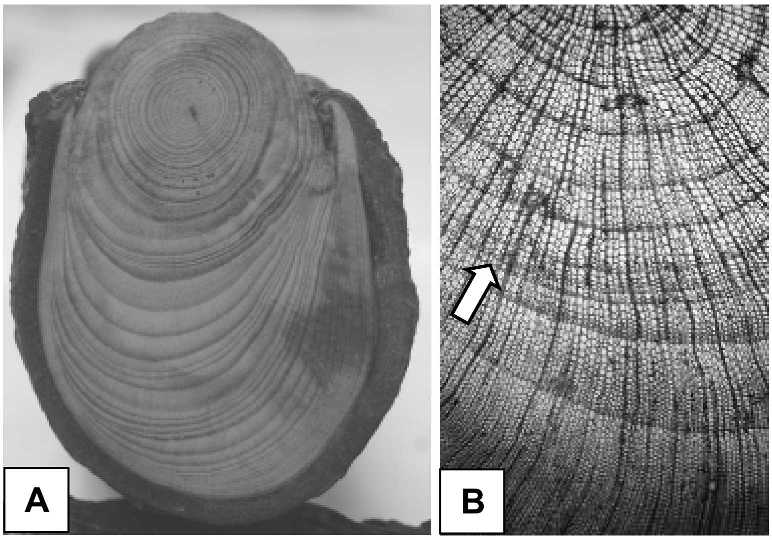

Figure 4: All root samples taken from the trail surface have shown severe cambial damages, which are a response to continuous trampling. Therefore ring recognition might be sometimes difficult due to occurrences of wedging (A) or false rings (B).

Discussion

The study shows the usefulness of the dendrogeomorphological method for dating of root exposure along a footpath surface, but possible sources of errors must be taken into consideration. Because the roots were often heavily damaged due to mechanical stress, ring recognition was difficult in some samples. The structure of wedging and false rings must be carefully analysed along the whole root circumference, therefore complete discs need to be collected from roots rather than only increment cores. Nevertheless, real dates for tree rings in roots might differ slightly from the assigned dates due to ring counting by +/- 1 or 2 years. Due to usual practice the author regards this approximation as being of acceptable accuracy.

For further studies it will be very helpful to obtain a reference chronology from the stems of the injured trees from which the root samples were taken. To make the analysis reliable, experimental studies of both partly exposed and covered roots shall be conducted in the future. It would also be interesting to investigate the relationship between root exposure, erosion rates and precipitation regime parameters. The dendrogeomorphological approach offers a great opportunity to quantify trail erosion, within a certain bandwidth of underestimation or overestimation of erosion rates. There are some factors which can results in an underestimation of erosion rates, such as soil compaction and roots leaning towards the soil surface due to treading. For precise erosion rate estimation, a statistically significant number of samples must be analysed.

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Dynamics of large woody debris and wood dams in mountain Kamienica Stream, Polish Carpathians

Kaczka, R.J.

Faculty of Earth Sciences, University of Silesia, Poland
Email: ryszard.kaczka@us.edu.pl

Introduction

Fallen trees and their fragments (large woody debris, LWD) stored in the channels of mountain streams exert an important influence on the ecological and geomorphological functioning of the watercourses which depends on stream size, the amount LWD as well as the species composition and management of riparian forests (Gurnell et al. 2002). LWD creates habitats and provides organic matter for aquatic organisms (Bilby & Bisson, 1998), it creates physical obstructions to flow and forms wood dams (Nakamura & Swanson 1993, Buffington et al. 2002). This study aimed at determining the time of delivery of large wood pieces to the channel of Kamienica Stream and assessing the longevity of wood dams occurring in the channel.

Material and Methods

Kamienica is an almost unmanaged mountain stream draining a forested catchment in the Gorce Mountains National Park, Polish Carpathians (Fig. 1A). The research was conducted in a 7.9 km long section of the upper reach of Kamienica, where it is a fourth-order stream with mean channel gradient of 0.052 m m^{-1} and about 10 m in width on average. Bank erosion (Fig. 1B) and windthrow were identified as principal processes controlling wood delivery to the stream.

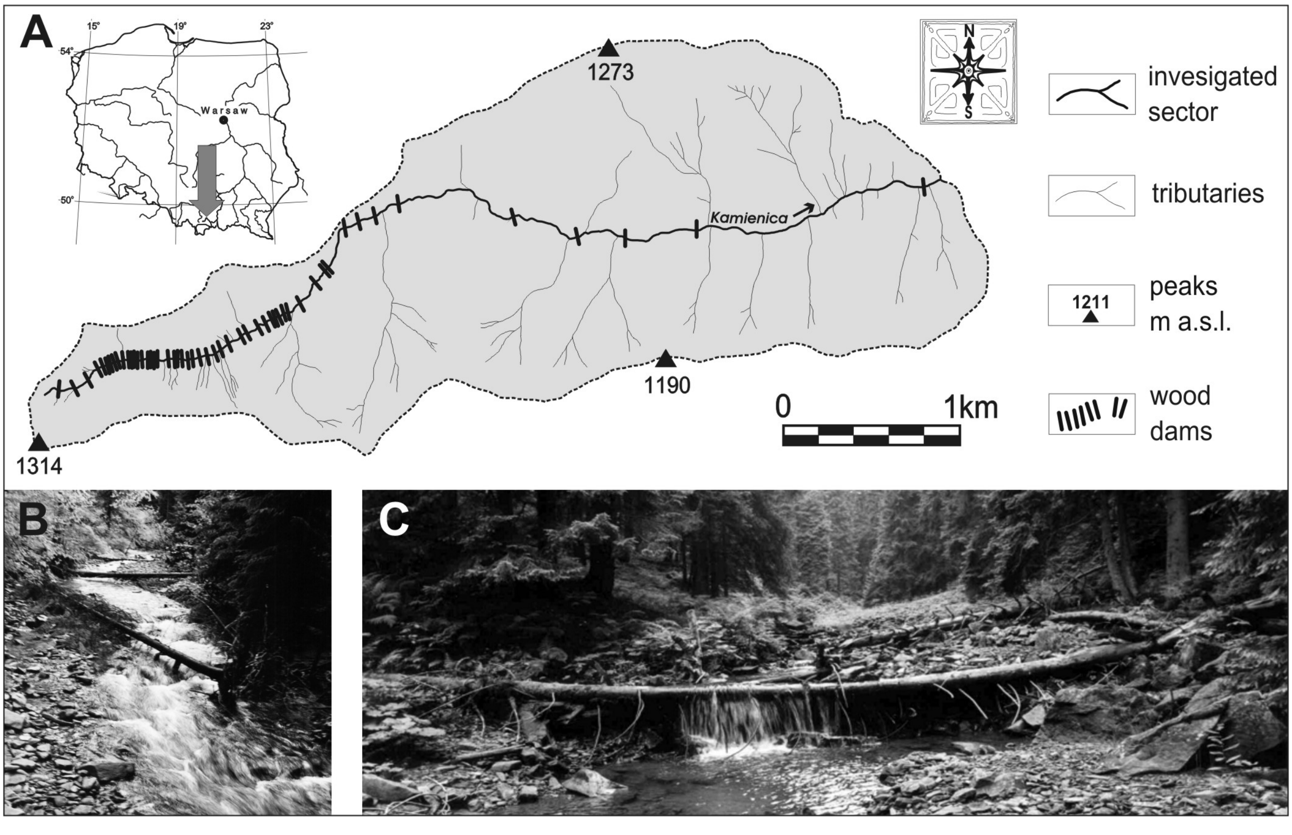

Figure 1: Location of the investigated reach of Kamienica Stream (A). In-channel wood recruited as a result of bank erosion (B). Wood dam formed by a piece of wood spanning the channel and causing a step in the water surface profile (C).

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All in-channel LWD, i.e. wood pieces of minimal length of 1 m and with a diameter of at least 0.1 m in the half-length (Piegay & Gurnell 1997, Gurnell et al. 2000), as well as wood dams were mapped and measured. The age structure of LWD was determined by dating 10% of randomly chosen logs. Depending on wood condition, cores or discs were taken from each tenth consecutive piece of LWD, starting from the beginning of the studied stream reach. A majority of logs (86%) were recruited from Norway spruce (*Picea abies* L. Karst) growing in the riparian forest. Logs in the late stage of wood decay or originating from deciduous species were omitted and replaced by the subsequent log. In total, 170 in-channel logs were sampled.

The longevity of wood dams (Fig. 1C), i.e. groups or single pieces of wood spanning the channel and causing a step in the water surface profile (Gregory et al. 1985), was determined. Only dams initiated by *in situ* key-member log (log which was not transported after recruitment) were selected for dating as the age of dams created by transported wood can differ from the year of recruitment of the key-member log. Forty one of the 71 mapped dams met this condition and were sampled. Standard dendrochronological methods of dating were employed to determine the age of LWD and wood dams using a previously existing spruce chronology from the Gorce Mts (1850-2002) (Büntgen et al. 2007), updated to 1785-2007. One hundred twenty pieces of LWD and all 41 dams were successfully dated. The main problem with dating was related to the condition of wood and the number of rings (65 on average ±SD18). The growth reduction of 1978-1983 that was caused by an outbreak of a defoliating insect, the web spinning sawfly *Cephalcia abietis* (Jachym 2007), provided a useful pattern to cross-date more recent samples. This strong ecological signal was detected only once over all analysed 222 years long period (Fig. 2). Those pointer years reinforced the confidence in dating of short tree ring series.

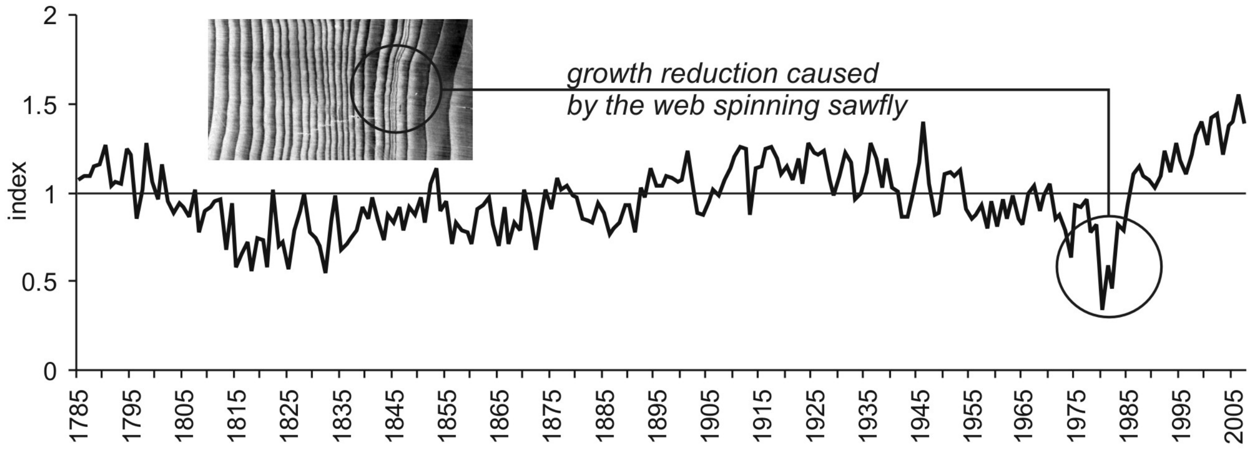

Figure 2: Spruce chronology for the Gorce Mountains, composed of 104 samples spanning the years 1785-2007 (after truncation at < 5 series). The marked growth reduction of 1978-1983 formed during a web spinning sawfly outbreak.

Results and discussion

Large woody debris and dams characteristics

1649 logs with the total volume of 674 m^3 were mapped in the study reach. The average log length equalled 7.6 m ±6.4 (SD) and log diameter amounted to 0.2 m ±0.09 (SD). The presence of such amount of wood, in addition to the size of wood pieces, strongly influenced the morphology of the channel. The distribution of LWD along the analysed stream reach was relatively uniform, whereas wood dams were rather concentrated in its upper part (Kaczka 2003). The structure and number of the wood pieces forming dams did not vary along the reach. The dams composed of greater number of logs were usually higher and more stable (Fig. 3). On the basis of the frequency (9 per km of stream course) and size of dams (0.65 m^3) accompanied by other wood accumulations, Kamienica is recognised among mountain streams in Europe as the stream with the largest number of wood structures (Hering 2000, Kaczka 2003, Comiti et al. 2006).

Figure 3: Wood dam composed of 7 logs. Dams consisting of a great number of logs are usually higher and more stable. The arrow points to a key-member log of the dam, i.e the log which initiated the dam.

Age structure of LWD

The dated logs were delivered to the channel in the years 1943-2000 (Fig. 4A) and half of them were delivered between 1980 and 2000. Logs older than 40 years were rather scarce (8.4%). More common were logs delivered in the 1960s-1970s (41.9%). The peaks of recruitment intensity occurred in 1975 and 1997 (11,5% and 8.4% of all logs, respectively).

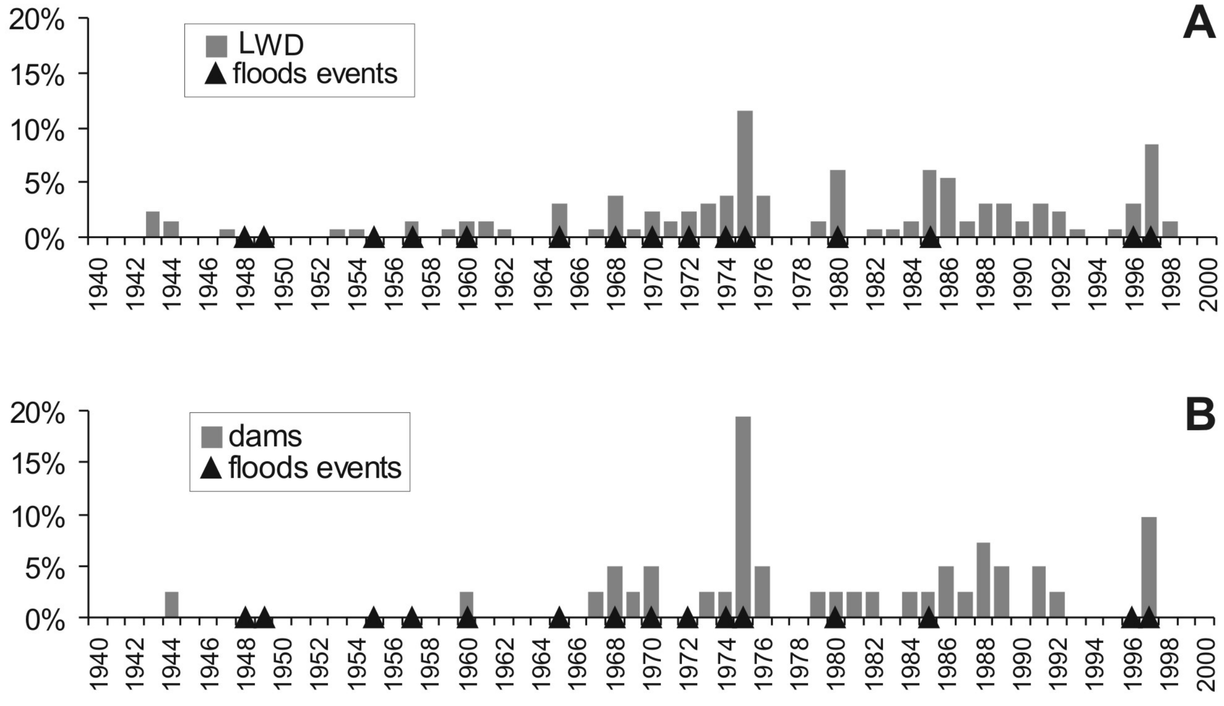

Figure 4: Percentage distribution of all dated logs (A) and key-member logs of wood dams (B) recruited to Kamienica Stream in particular years.

The age structure of large woody debris correlates with the occurrence of major floods during the period 1943-2000, with 67% of all logs recruited during seven floods that occurred between 1960 and 1980, and 48% of them delivered to the channel during 4 floods from the 1980s-1990s.

Age structure and longevity of wood dams

Figure 4B shows the age structure of logs functioning as key-members in the initiation of wood dams. The age of dams correlates with the age of LWD ($r=0.79$ $p<0.05$). The largest numbers of the dams were created by logs delivered in 1975 (19.5%) and 1997 (8,9%), two years of major floods (Kaczka 1999). Both the number and age of the dams decrease in the downstream direction (Fig. 5). Nevertheless, the dams in the entire investigated reach show high longevity and have survived several floods (15 in the case of the oldest dams and at least 4 for more than half of the dams).

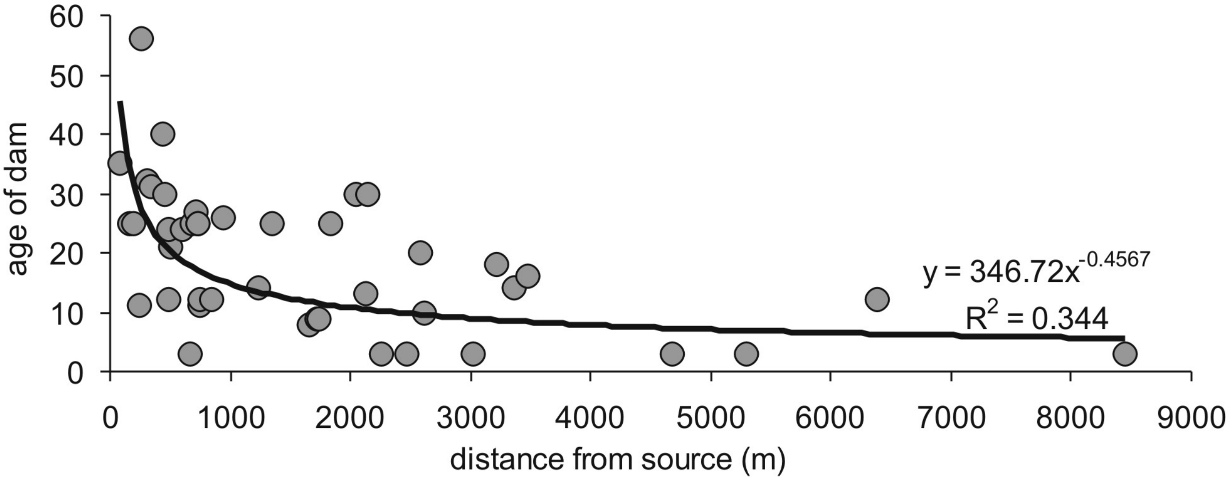

Figure 5: Age distribution of wood dams as a function of the distance from the source of Kamienica Stream.

Results from investigations of lowland streams in Poland (Malik 2005) and Sweden (Dahlstrom et al. 2005) revealed that the age of in-channel LWD can range from around 12 to hundreds of years, depending on the decay resistance of the species growing in the riparian forest and the history of the catchment. The life span of dams in Kamienica Stream is similar to those studied in streams of British Columbia (Keller & Tally 1979, Jones & Daniels 2008) and the USA west coast (Swanson et al. 1976). In the more dynamic environment of mountain streams, processes of recruitment and destruction of LWD are not only more intense, but also more frequent. Therefore, the longevity of wood pieces and wood dams is relatively short. However, fast destroyed or decayed in-channel wood is rapidly replaced by new trees recruited to the channel. Under such conditions, wood resistance becomes less important whereas the management of streams remains one of the crucial factors controlling supply and presence of in-channel wood. The age of both LWD and wood dams occurring in the channel of Kamienica did not exceed the time when the stream was taken under protection in a regional national park. Although the age of in-channel wood in such a mountain stream probably cannot reach the age of wood found in lowland streams, older wood could be expected but was most likely removed under the previous forest management practices.

Conclusions

The amount of large woody debris in Kamienica Stream is sufficient to influence geomorphological and biological processes in the channel. The relatively short life span of LWD is related to frequent floods, destruction of in-channel wood and recruitment of new trees. The relationship between the occurrence of such events and the age of LWD is significant, with 51% of all logs delivered during

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major floods. The age of dams correlates with the age of LWD ($r=0.79$ $p<0.05$) and their longevity is related to dam location. The oldest dams occur in the uppermost course of the stream were they better can resist floods.

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Rock fall as a source of sediment in the forested mid-mountain zone in the Kamienne Mts (Sudetes – SW Poland)

Malik, I.[1], Owczarek, P.[2] & P. Migoń[3]

[1]*University of Silesia, Department of Quaternary Paleogeography and Paleoecology, Sosnowiec 41–200, ul. Bedzinska 60, Poland,*
[2,3]*University of Wroclaw, Institute of Geography and Regional Development, pl. Uniwersytecki 1, 50-137 Wroclaw, Poland.*
Email: irekgeo@wp.pl

Introduction

The spatial and temporal nature of different types of mass movements is often recorded in tree ring width and wood anatomy (Heinrich & Gärtner 2008). A dendrogeomorphological study focussed on reconstructing debris flow and rock falls (Bauman & Kaiser 1999, Gärtner et al. 2003, Perret et al. 2006). Rock falls usually occur above the tree line mainly caused by mechanical weathering occurring within the exposed rocks. Rock fragments differing in shape and size are usually transported downslope and deposited on the lower forested parts of the slope. Falling rocks are dangerous for people living in the villages located in the path of rock falls, and sometimes particularly large boulders can destroy buildings.

In the Kamienne Mts rock falls occur in the completely forested area (Fig. 1a). Falling rocks often wound trees growing downslope of the rock fall activity zone. Creeping sediment tilts trees growing in areas where material is deposited (Fig. 1b). This gives us the opportunity to reconstruct slope activity over the last 150 years.

The aims of this study are (1) to identify sedimentary rock as a source of rock fall on the basis of geomorphic forms; (2) to date the rock fall events by means of dendrochronological evidence; (3) to determine the sediment transport events in the deposition zone of the rock fall area and (4) to combine the dendrochronological results derived from rack fall activity and sediment movement.

Figure 1: Pictures of a rock fall (A) and creeping sediment (B) recorded by tilted trees growing at the foot of the Suchawa massif.

Study area

The study was carried out in the mountains of the Middle Sudetes Range called the Kamienne Mountains (southern Poland). The scree cones where samples were collected are located on the slopes of Mt. Suchawa at an altitude of 850 – 780 m a.s.l (Fig. 2).

The Kamienne Mountains are a residual range extending in a W-E direction and are mainly built of volcanic and subvolcanic units of Permian age, with the subordinate presence of clastic sedimentary rocks, from shale to conglomerate. The juxtaposition of mechanically strong and resistant volcanic rocks and weak sedimentary rocks is reflected in considerable local relief and steep slope gradients, up to 40-45° (Żelaźniewicz 1997). Consequently, these are favourable conditions for mass movements which are expressed in a variety of processes. Landform assemblages on slopes indicate lateral spreading phenomena, deep-seated rotational slides (including multiple slides), and shallow translational slides. In a few cases, landslide head scarps have subsequently been affected by boulder and particle fall, resulting in block accumulation, and scree and talus deposition.

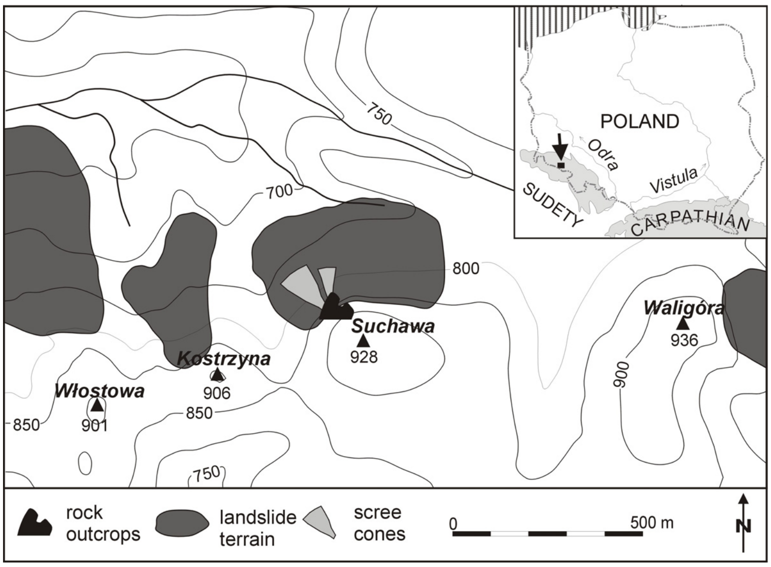

Figure 2: Location of the study area.

The Kamienne Mountains receive 800-900 mm of precipitation per year. Most of the intensive rainfall episodes are linked to synoptic situations in which cyclonic activity approaching from a westerly direction creates conditions for continuous heavy precipitation in Central Europe (Štekl et al. 2001, Migon et al. 2002). The area is located in the temperate Atlantic climatic zone, but in the mountains a relatively large number of days per year are observed showing temperatures below 0^oC (120 – 145 days) (Fig. 3). Diurnal freeze–thaw cycles are frequent in late-autumn and early-spring.

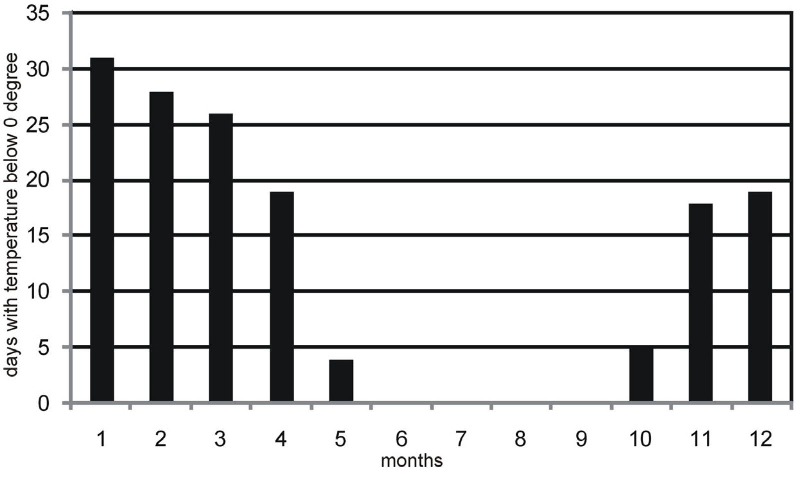

Figure 3: Number of days below 0ºC at Sokolowsko station (1954-1969) (560 m a.s.l.), Kamienne Mountains.

The talus cones are located on northern slopes of the Suchawa Mt (928 m a.s.l.) (Fig. 2). This apron-like accumulation of rockfall debris, with length 150 – 200 m, develops below the rock wall, which is built of volcanic rocks (rhyolitoids). The material is angular and grade finer at the top and coarser near the margins. The gradient of the scree slopes reaches 45º.

Methods

Firstly the sediment zone was surveyed using a tape-measure, pole, and Frieberg 59 compass. From sixteen trees with stems buried by sediment (up to 1,5 m), 48 cores were collected (three cores per tree, 1 parallel and 2 perpendicular to the direction of slope). We also took cores from 10 trees growing at the same altitude but 130m away from the rock fall to provide control results regarding geomorphic influence.

After gluing and polishing the cores a skeleton plot was used to find signature and pointer years. The age of the trees sampled was calculated. Following this, tree ring width was measured and the local chronology was developed from trees growing away from the rock fall. In the next step we compared the tree ring pattern from the site chronology with the ring curve from individual trees growing below the rock fall with the intention to define geomorphic events recorded in ring structure. Additionally we determined in which years traumatic rows of resin ducts and reaction wood was formed. These specific features provide information about the date when falling rocks wounded trees and sediment creep occurred.

Results and discussion

Rock weathering, deposition and sediment creep

The trees sampled started growing between 1850 and 1870, which means that the forested area located below the rock fall was free of fresh sediment that time. At the end of the nineteenth and beginning of the twentieth centuries many traumatic resin ducts were formed in the cores studied. (Fig. 4, 5).

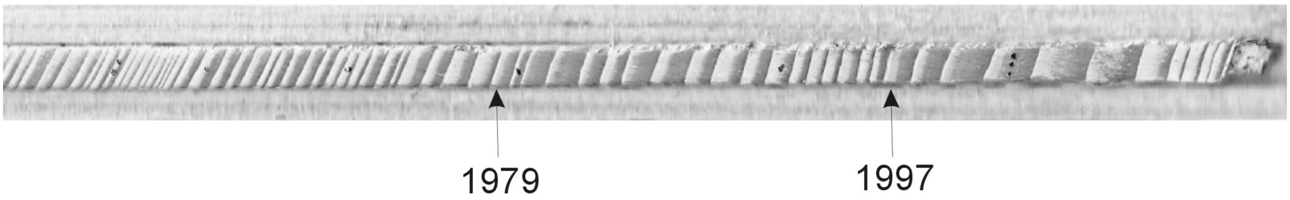

Figure 4: Years 1979 and 1997 when compression wood occurred within one of the cores collected from a tree growing below the rock fall.

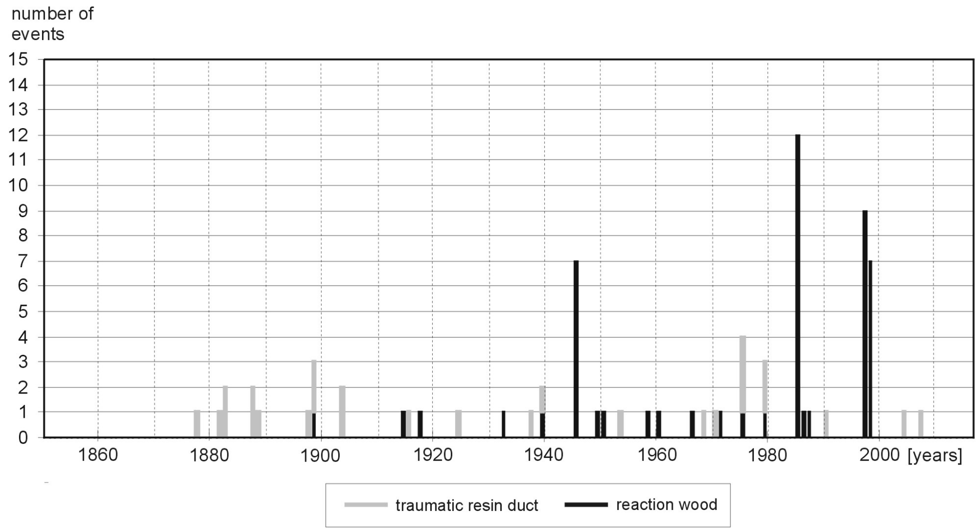

Figure 5: Graph presents the first year when compression wood occurred and years with traumatic resin ducts.

The comparison of ring patterns from trees growing below the rock fall with those from trees sampled as controls regarding geomorphic impact do show differences (Fig. 6). Tree ring suppression occurred in trees from the last decade of the nineteenth century growing below the rock fall. This phenomenon is not found in the case of trees sampled as controls (Fig. 6).

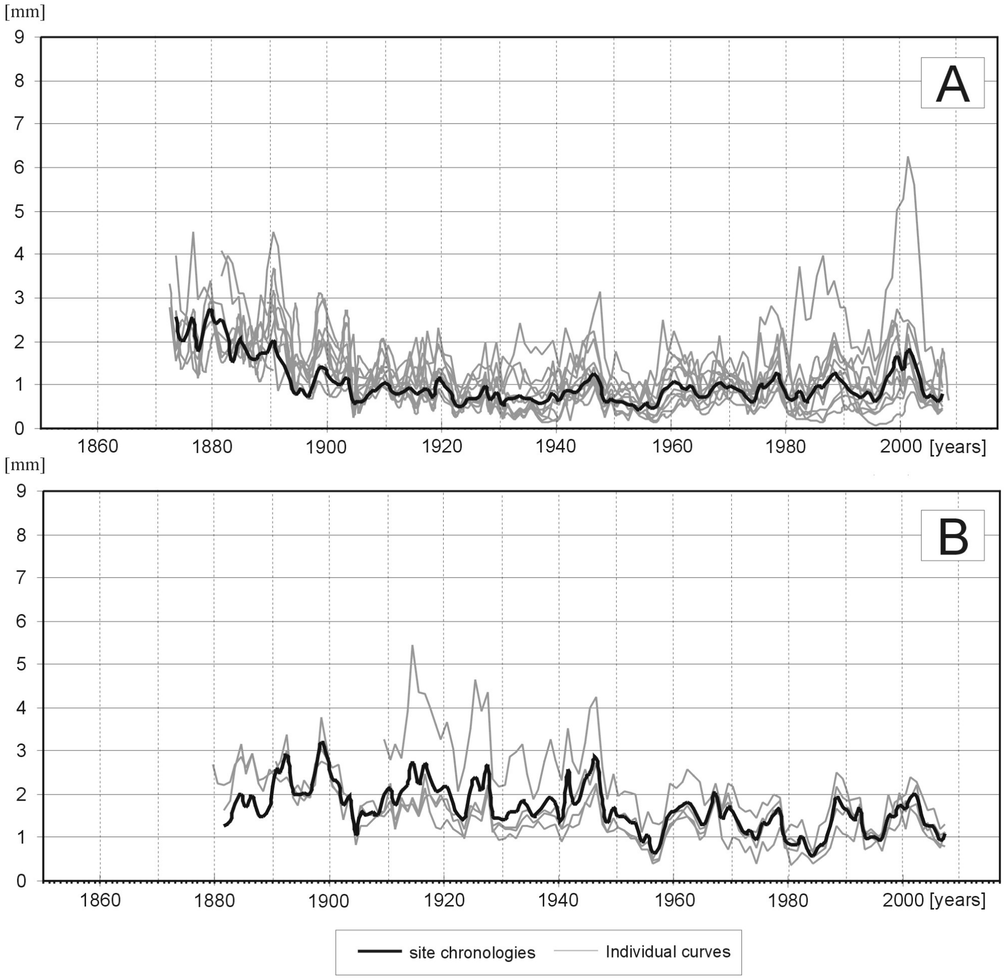

Figure 6: Tree ring curves and site chronologies (A – ring width curves and chronology from trees growing below the rock fall, B - ring width curves and chronology from trees outside the passage of the rock fall.

Consequently, sediment started building up or frequency of rock fall increased in the area when the trees sampled started growing. A period with a great intensity of rock weathering and accumulation of sediment commenced in 1890. Mechanical weathering occurred at the turn of the nineteenth and twentieth centuries, There were numerous great rainfall events (1880, 1883, 1897, 1903, 1907, 1910) at that time in the Sudetes so the weathered material was transported down slope. The next period with great rock fall activity was recorded between 1960 and 1990 when there were many years in which traumatic rows of resin ducts were formed. Simultaneously numerous trees produced reaction wood on the stem side facing the rock fall. This is an effect of sediment creep tilting sampled trees (tilted trees are clearly visible in the figure 1A). Reaction wood was particularly evident in 1997/98 when an extraordinary rainfall event occurred in Poland in July 1997.

Conclusions

1. The results suggest that rock falls occur in forested mid-mountain zones and material is then transported down slope on the talus relatively quickly. We identified dozens of rock fall events recorded in the annual rings as traumatic rows of resin ducts. Most of them occurred between 1890 and 1910 and towards the end of twentieth century.
2. A great amount of sediment burrs tree stems. This is the result of sediment creep during great rainfall events, which occurred in particular in the Kamienne Mountains in 1945, 1985 and 1997.

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Dendrogeomorphological potential of *Salicaceae* from SW Spitsbergen (Norway)

Owczarek, P.

Institute of Geography and Regional Development, University of Wroclaw, Pl. Uniwersytecki 1, 50-137 Wroclaw, Poland
Email: piotr.owczarek@geogr.uni.wroc.pl

Introduction

In arctic and alpine ecosystems, where trees are rare or absent, dendrochronological research is limited. Geomorphic processes in the High Arctic have not been investigated before from a dendrogeomorphological point of view, although a large number of dendroecological and dendroclimatological studies have been carried out on arctic dwarf shrubs (Warren Wilson 1964, Kuivinen & Lawson 1982, Woodcock & Bardley 1994, Shaver 1986, Rayback & Henry 2005, Schweingruber & Poschold 2005 , Bär et al. 2006, Au & Tardif 2007). An extremely short growing season, long, cold, dark winters and low precipitation influence the development of the tundra vegetation cover specific to the High Arctic. Arctic tundra is located in the northern hemisphere, encircling the North Pole and extending south to the coniferous forests of the taiga. In this paper the use of tundra shrubs (*Salix polaris* and *Salix reticulata*), their age and changes in wood anatomy is briefly described as a potential source of dendrogeomorphological information from the High Arctic.

Study area

Field work was done in SW Spitsbergen in the Svalbard Archipelago (Fig. 1). The landscape is dominated by mountain massifs aligned along lines of longitude and rising to *ca.* 500–600 m a.s.l. and coastal plains consisting of several marine terraces.

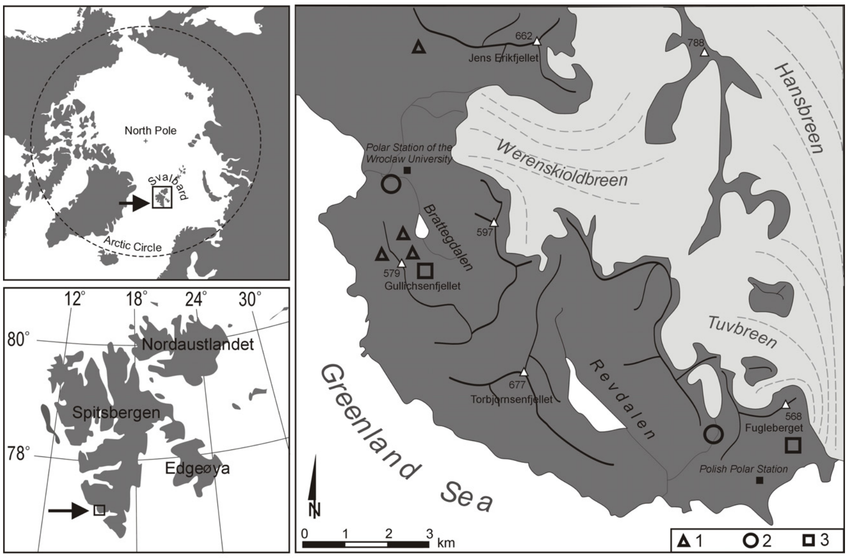

Figure 1: Location of the study area with places of detailed research: 1 – debris flows, 2 –valley bottoms, 3 – talus cones analyzed.

The mean annual air temperature is −4.4°C, ranging from −11.3°C in January to +4.4°C in July (Marsz & Styszyńska 2007). The annual amount of precipitation is low, (200 – 300mm), as it is typical in arctic regions. Variations in the Arctic climatic conditions which are connected mainly with the topography of the area and the influence of the ocean and glaciers, the geology and the thickness of snow cover, determine the development of the local vegetation (Fig. 2). The

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vegetation of the tundra community is dominated by low creeping dwarf shrubs and different species of mosses, herbs and lichens. The vegetation period is rather short, starting in June until, approximately, the end of August, i.e. it ranges from 40 to 70 days. Four vegetation zones can be distinguished on Spitsbergen Island: (1) *Papever dahlianum* zone (southern part of the island), (2) *Salix polaris* zone (northern shore of Horsund and interior of the island), (3) *Dryas octopetala* zone (middle and northern shore of Spitsbergen) and (4) *Casiope tetragona* zone (especially middle part of the island) (Rønning 1996). The tundra community is particularly rich on the plains. On screes, moraines and block fields, the vegetation cover is generally no more than 10-15%.

Figure 2: General view of the Hornsund Fjord area, SW Spitsbergen.

Material and methods

Wood materials

Two species of dwarf shrub were used to date geomorphic processes using dendrogeomorphological methods. These belong to the Willow family (*Salicaceae*): *Salix polaris* and *Salix reticulata*. ***Salix polaris*** (Wahlenb.) (Fig. 3A) is commonly known as polar willow (Påhlsson 1985). This dwarf shrub reproduces by seeds and also reproduces vegetatively by rooting at the nodes of stems. Salix polaris is a deciduous, prostrate, trailing shrub usually less than 8 cm tall which commonly forms mats (Fig. 2). It is a creeping shrub with long shoots which is common on Spitsbergen. This species can be found in different conditions, both on moraines and dry screes as well as on wetlands. ***Salix reticulata*** (L.) (Fig. 3B) is called net-leaved willow (Påhlsson 1985). It is a low (8 – 10 cm) creeping shrub which reproduces vegetatively. In comparison to *S. polaris*, *S. reticulata* has larger oval green leaves. The main stem is located just under the soil surface and *S. reticulata* grows on dry, sunny, gravel slopes. It is common on scree slopes.

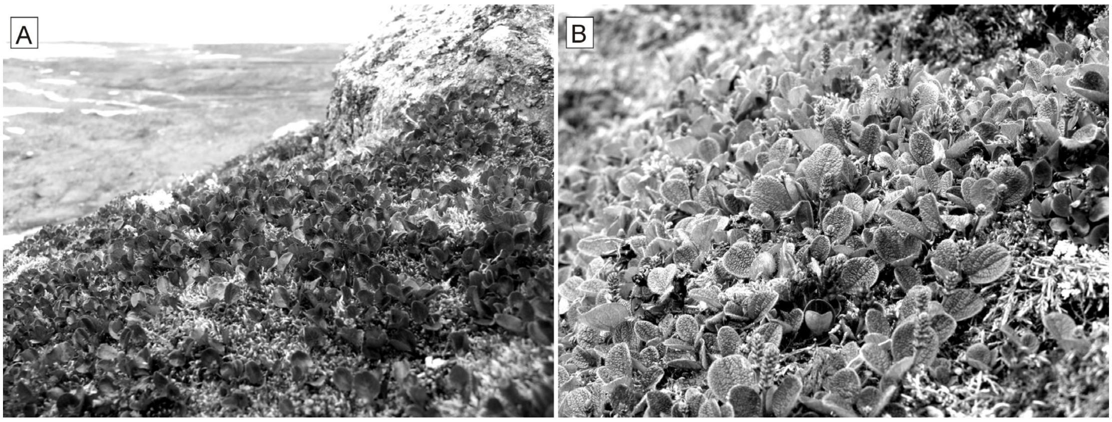

Figure 3: Species, which were used to dendrochronological research: (A) Salix polaris Wahlenb. – Polar willow, (B) Salix reticulata L. – Net-leaved willow.

Geomorphic mapping and sample collection

The study sites were selected according to the accessibility of *Salicaceae* species and their location on typical periglacial land forms. The collection of samples and field research were carried out during the arctic summer in 2007 and 2008. Simple geodesic methods were used to map land forms (debris flows, fluvio-glacial terrace margins) drown to a scale of 1:500.

The two major dendrogeomorphological approaches applied here use the age of dwarf shrubs and event-response dating using ring patterns and wood anatomical changes in the shrubs affected. Complete individuals of *S. polaris* and *S. reticulata* including the root and branch systems were collected in the field (Fig. 3). A minimum of ten samples was collected from each debris flow track. Samples were taken along several transects across debris cones and terraces. Each individual was documented by digital photos.

Laboratory analysis of materials collected

In order to explore the oldest part of the sample, individual plants were sectioned every 4 – 6 cm. This cutting was necessary, because the oldest part is located on the border between the stem and the root and this isn't visible on the basis of the physiognomic structure of *Salicaceae* (Schweingruber & Poschold 2005). The samples were sectioned with a GSL 1 sledge microtome, taking 15 – 20 µm cross-sections from 4 to 6 different locations along the length of the individuals (Fig. 4).

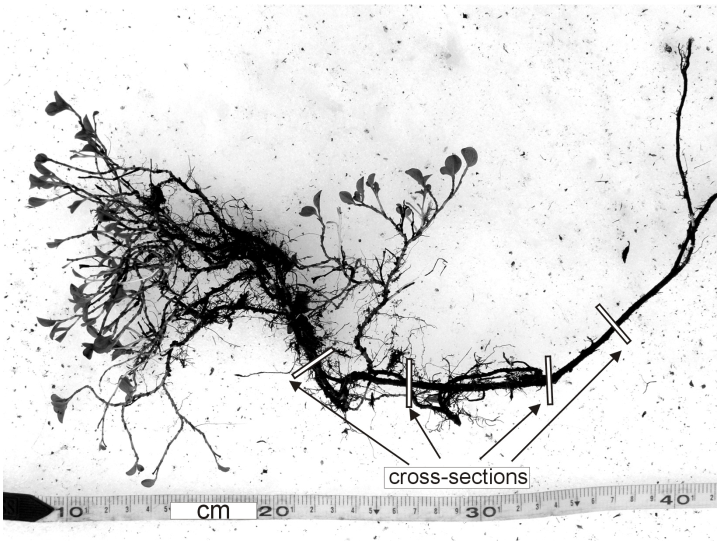

Figure 4: Individual of Salix polaris. White-black lines – cross-sections taken from the sample.

Microtome sections were prepared from the whole diameter of selected segments. Maximum stem diameters ranged from 0.5 cm to 1.1 cm. Sections were stained with Safranin and Astrablue and following this digital photographs were taken of the micro-sections for the tree-ring analysis.

Potential of *Salicaceae* in geomorphological analysis

Growth-rings

Growth-ring boundaries in arctic *Salicaceae* have been variously reported, particularly for *Salix arctica* (Pall.) (Beschel & Webb 1963, Warren Willson 1964). *Salix polaris* and *Salix reticulata* have clearly visible, countable and measurable annual growth rings. The oldest individual sallow tree (*Salicaceae)* analysed was 78 yrs old. These species are semi ring-porous and have well-defined growth-rings (Fig. 5A) whose boundaries are delimited by one or more rows of flattened latewood cells (Fig. 5B). These cells, which are rectangular in cross section, are usually smaller in *S. reticulata than* in *S. polaris,* thus the boundaries of *S. reticulata* tree-rings are more visible and easier to count. Growth-rings in the individuals examined ranged from relatively wide 0.8 mm in width, to extremely narrow rings less than 0.01 mm in width, usually seen in *S. polaris*.

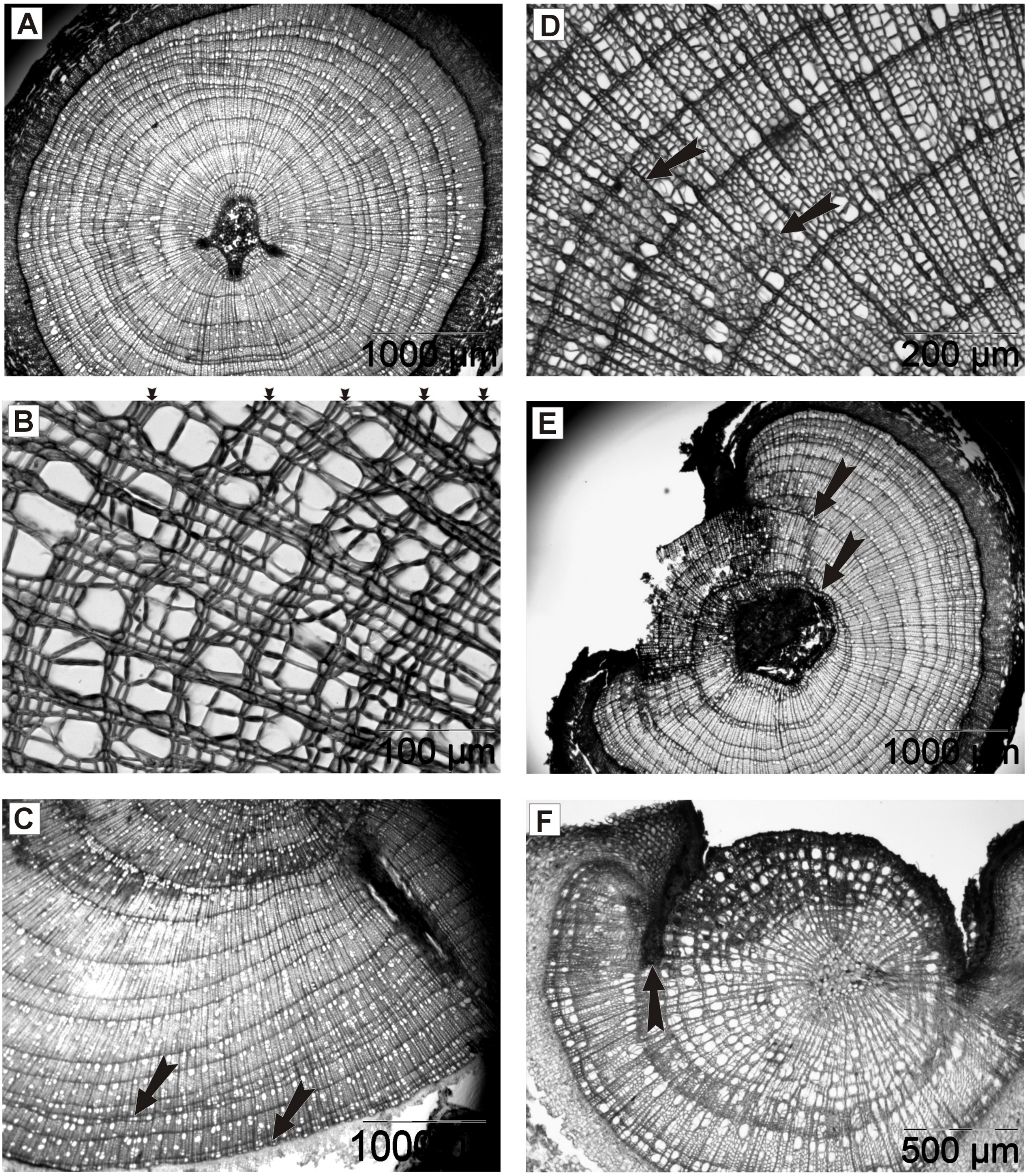

Figure 5: Examples of wood anatomy features of Salix polaris and Salix reticulata. (A) growth rings, estimated age of the sample is 14 years, (B) ring boundaries, which consist of two or more rows of rectangular cells and are indicated by arrows, (C) portion of the section that includes two discontinuous growth rings, (D) tension wood, arrows indicate on the irregular gelatinous fibers, (E) two generation of scars, 12 years old and 9 years old, (F) 4 years old scar, overgrowth starting from the lateral edges of the injury is distinct visible.

Discontinuous growth rings are very common in the species analyzed (Fig. 5C). The age of samples is used to determine the minimum age of geomorphic forms or timing of geomorphic processes. The oldest (70-80 year old) samples were collected in the small, partly glaciated Arie valley located to the north of the Polish Polar Station (see Fig. 1). Two levels of fluvio-glacial terraces are distinctly visible in the morphology of the valley bottom. It was possible to identify the minimum age of terrace development on the basis of the age of the samples examined. The highest terrace, located approx. 25-30 m above the valley bottom, is older than 78 years. The retreat of the Arie Glacier, which started about 80 years ago, influenced the incision of the river channel and the development of a lower level of the valley.

Reaction wood

Reaction wood, called tension wood in angiosperms, is often visible in the dwarf shrub species analysed. This type of wood is only found on the upper side of a tilting stem and root and indicates a change in stem position. Tension wood cells exhibit irregularly shaped secondary walls, so-called gelatinous fibers (Fig. 5D) (Schweingruber 1996). This parameter plus geomorphological features enables to reconstruct the spatial and temporal patterns of slope movement, e.g. debris flow events or solifluction. Reaction wood was analysed in the samples which grew on debris flow tracks. Branches and stems of *S. polaris* and *S. reticulata* are very flexible and so they can survive during high energy geomorphic events.

Scars

Scars appear when falling or flowing rock particles collide with roots, stems or branches of dwarf shrubs. Injures are overgrown by callous tissue produced by the surviving cambial cells adjacent to the wound (Fig. 5E,F), thus it is possible precisely to determine geomorphic events according to the position of the scar on the cross-section (Hupp et al. 1987, Shroeder & Butler 1987, Stoffel & Bollschweiler 2008). Wounded arctic shrubs can be found both in valley bottoms and on steep scree slopes, but injured shrubs, which grow only on steep slopes, can be used in dendrochronological analysis in the High Arctic. Wounds on dwarf shrubs growing in valley bottoms and other flat areas cannot to be analyzed, because a large number of the injuries are related to animals (polar bears, reindeers).

Conclusions

It was shown that using *Salicaceae* can be very helpful in the analysis of geomorphic processes in the High Arctic area. The features of *S. polaris* and *S. reticulata* wood anatomy, such as tree-ring variations, reaction wood and a distinctly visible layer of cambium cells which grow over the injury, enable to determine the minimum age of the landform form and the frequency of natural geomorphic events in the past.

Acknowledgements

Field work during the summer 2007 and 2008 was carried out as part of the Wroclaw University Polar Expedition. I would like to thank Dr. Holger Gärtner for his help and useful suggestion during laboratory analysis of the samples and for valuable comments which led to an improvement of the manuscript.

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SECTION 5

METHODS

Effect of sample preparation and scanning resolution on the Blue Reflectance of *Picea abies*

Babst, F.[1], Frank, D.[2], Büntgen, U.[2], Nievergelt, D.[2] & J. Esper[2]

[1]*Department of Environmental Sciences, University of Basel, Basel, Switzerland*
[2]*Swiss Federal Research Institute WSL, Birmensdorf, Switzerland*
Email: fbabst@gmx.ch

Introduction

Assessing past and recent climate variability is an important task in environmental change research. Various methods and techniques have been developed in order to generate high-quality proxy data. In Tree-rings, which are perhaps the most important annually resolved proxy that spans the past millennium (Esper et al. 2004), particularly strong climate signals have been achieved by measuring maximum latewood density (MXD) using the widely established X-ray method (Polge 1966, Schweingruber 1988, Parker et al. 1978, D'Arrigo et al. 2000, Cown et al. 2004). Such data have been produced to successfully reconstruct past temperature variations from far northern (Briffa et al. 2001) and high elevation (Büntgen et al. 2006) environments, based on various conifer species. In praxis, the application of this technique is not directly accessible for many researchers due to costly equipment, a laborious sample preparation and time consuming measurement procedures. For this reason, efforts have recently been made to either increase the efficiency of X-ray densitometry (Bergsten et al. 2001) or develop alternative paleoclimate proxies which are as reliable as the X-ray based MXD method, but can be applied more readily and efficiently (Frank 1998, Sheppard et al. 1996, Schinker et al. 2003).

McCarroll et al. (2002) assessed the suitability of multiband digital images (RGB) of pine (*Pinus sylvestris)* laths as a surrogate for x-ray measured MXD. The colour images were acquired using a common flatbed scanner and commercially available software. The blue channel proved to correlate most strongly (r = -0.96) with wood density. Following this study, a direct comparison of the two methods was carried out in building a well-replicated pine chronology (1777-2002) that revealed inter-series correlations of the blue intensity measurements similar to classical MXD data -- ranging from 0.61 to 0.75. Correlation analyses with mean monthly summer temperatures were found to be even higher (-0.65 to -0.80) than those obtained for MXD. This knowledge suggests that minimum blue reflectance (MBR) could serve as a surrogate for classical MXD measurements (Campbell et al. 2007). Since MBR is a relatively new approach, few protocols on wood preparation, methodological proceeding and technique fine-tuning exist. No standard procedure has been established yet and various research questions related to sample surface treatment, scanning resolution, measurement tracks and digital imaging remain open.

The present study investigates for the first time the effect of sample surface preparation and other potential influences such as scanning resolution or image saturation on the quality of the annually resolved MBR measurements. This task seems crucial to standardize the preparation procedures and thus make MBR results from different laboratories directly comparable. For the purpose of this study, a series of laths from a young spruce (*Picea abies*) with relatively wide rings has been produced and both, MXD and MBR were subsequently measured, the latter considering several different sample treatments.

Materials and Methods

Sample preparation

In order to obtain directly comparable results from both, the X-ray densitometry and the reflected blue light measurements, a series of 30 wood laths was produced. These pieces originate from one spruce tree which grew in the area of Birmensdorf in the Swiss lowlands at 47°21′15.98″N, 8°26′16″E, ~500m above sea level. The material was chosen to test the MBR method on a different conifer species than previous studies and the wide rings represent an ideal test bed to assess uncertainty introduced by method. Also does *Picea abies* not include a change in the surface colour based on heartwood/sapwood transition. In a first step, all samples were prepared for density measurements according to the principles described by Schweingruber et al. 1978.

In a previous test using *Pinus uncinata* laths from the Spanish Pyrenees (see Büntgen et al. 2008 for site description), the reflected blue light proved to react extremely sensitively to minor changes in surface colour caused by small cracks, scratches or inclusions. Therefore it appeared necessary to ensure an identical measurement path for the comparison of both methods, MXD and MBR. This was done by scratching a straight track into the surface of each lath, using a sharp needle. This way, the resulting path was visible on the X-ray film (required for conventional density measurement) as well as in the RGB colour-scan which forms the basis of the MBR technique.

To investigate the influence of surface preparation on resulting BR curves, different treatment were applied on a second series of samples at different scanning resolutions. For the first run of scans, the wood pieces were left in the state of a rough cut with a single-bladed saw. Subsequent scans were taken from an ever smoother surface achieved by sanding with grits of 60, 120, 220 and 400 grains per mm^2 ensuring that the wood did not burn as this would bias the result dramatically. To prevent a loss of measurement tracks through sanding, foils were printed beforehand that allowed redrawing the exact tracks after each sanding step.

Measurements

MXD preparation and measurements were carried out at the Swiss Federal Research Institute WSL in Birmensdorf. The data was produced using a WALESCH 2003 X-ray densitometer with a resolution of 0.01mm and brightness variations transferred into g/cm3 using a calibration wedge (Eschbach et al. 1995). Relationships between the absolute (volume and weight) and radiographic (X-ray) wood density (considering different species) were used as correction factors (Lenz et al. 1976). The resulting MXD values are simple measurements of cellulose acetate that can differ from the volumetric-gravimetric value (Schweingruber et al. 1978).

In this study, we used a calibration wedge made from cellulose acetate with a density of 1.274 g/cc and a continuously graded thickness (Schweingruber 1988). For conventional density measurement, cracks and inclusions are avoided if possible, which results in an erratic path that cannot easily be reproduced (Eschbach et al. 1995). For the purpose of this study, a reproducible track is indispensable to ensure the comparability of the two methods. Therefore, the paths which were scratched in advance were strictly followed during the measurement process and superficial disturbances were not bypassed. This has the advantage that the changes in density and light reflection caused by such disturbances remain comparable.

The same samples as used for X-ray densitometry were scanned using an Epson Expression 10000XL flatbed scanner. The hardware resolution of this system is 2400 dpi. It is possible to achieve resolutions up to 4800 dpi in which case an interpolation algorithm is executed. Image analyses were performed using the Image-Pro Plus 4.5 digital software. This program allows individual extraction of the three colour channels (R, G, and B) along a defined straight path to export for statistical analyses and presentation. The segment along which the blue values were taken is 0.08 mm wide. This is narrow in comparison to the 0.14 mm segment length of one of eight possible Dendro 2003 sensors (Eschbach et al. 1995). As a consequence, one single path of BR values is more susceptible to surface variability than an MXD track which integrates a greater area. A median of three parallel BR paths proved to resemble the MXD values best and were therefore considered for the analysis.

Results and Discussion

Influence of surface preparation

Sample surface treatment greatly influences the resulting BR values. The first scans of the roughly cut surface produced a very unsteady curve. Despite the fact that the ring borders could easily be detected with the naked eye, the data showed no decrease of the BR in the latewood and a clear ring pattern remained absent. Figure 1 and figure 2 show the effect of an ever smoother surface on the blue intensity. In table 1, the effect of sanding with different sandpaper grits is summarized. These figures reveal that a very smooth surface is required to gain realistic results with distinct latewood minima. The degree of surface preparation implies sensitivity of the reflectance level to the fineness of sanding.

Table 1: Effect of an increasingly smooth surface on blue intensity data. The degree of graining refers to the different steps of sanding that were applied.

Sandpaper grit [grains / mm^2]	**Effect on resulting BR curve**
60	Some peaks become visible; large variability in the early-wood; pattern unsteady and insufficient for ring identification
120	Peaks become more distinct; early-wood variability is reduced though still noticeable; ring borders are visible
220	BR latewood peaks are even more pronounced; early-wood noise reduced; ring borders distinct; clear trend towards a lower reflectance
400	Noise is negligible; further slight shift towards less intensity; resemblance with MXD curve

Scanning resolution

Comparison of data derived from wood pieces scanned at 600, 1200m and 2600 dpi revealed little difference between the two lower resolutions. Some latewood peaks were more pronounced at 1200 dpi than at 600 dpi, and the variance in the earlywood appeared slightly smaller. If the scanning resolution was increased to 2600 dpi -- which is above the hardware resolution of the device -- the effect on the blue intensity was distinct. There was a strong shift towards less intensity and the peaks of the latewood even reached a BR of zero. The exact reason for this effect is unclear, but it probably results from the interpolation algorithm which is applied to raise the spatial resolution. Thus, the scanning resolution has to be kept within the hardware resolution of the available scanning device to prevent unwanted data manipulation.

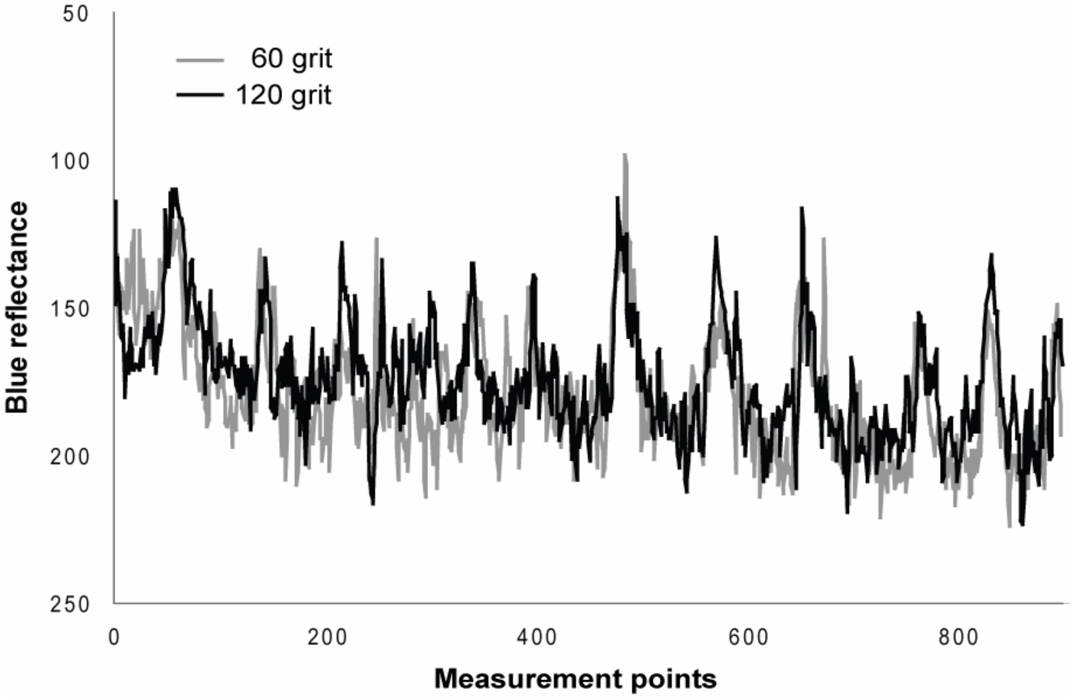

Figure 1: Blue reflectance of a Picea abies sample from Birmensdorf. Grey and black curves show results from scans of surfaces sanded with a 60 and 120 grit, respectively.

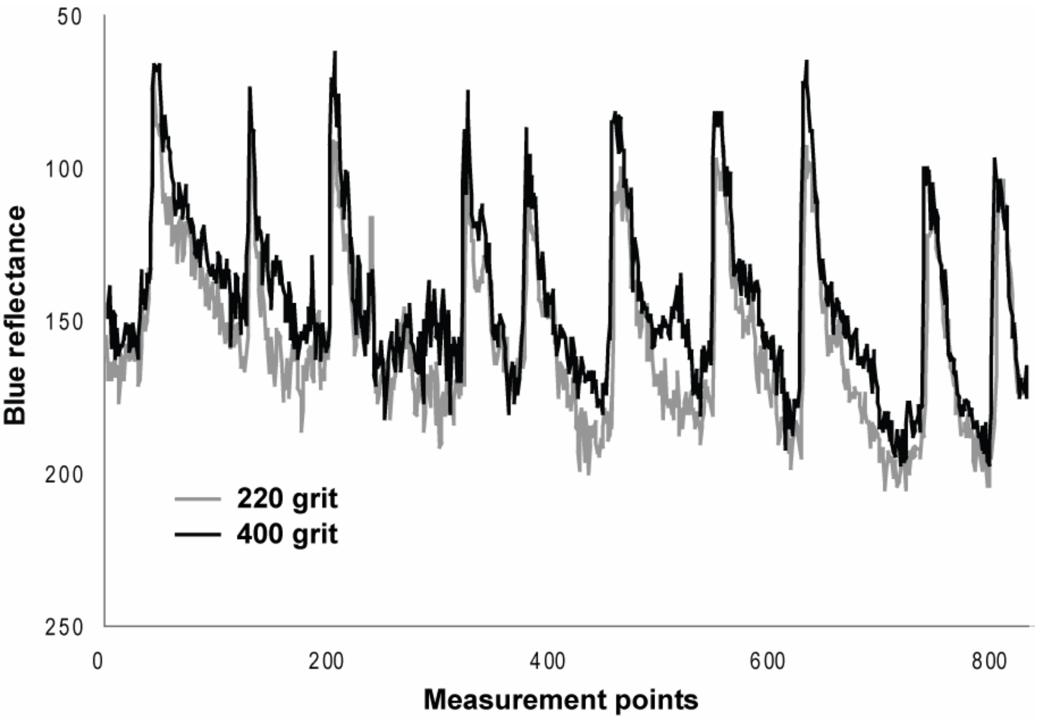

Figure 2: Blue reflectance of Picea abies sanded using a 220 (grey curve) and 400 grit (black) paper .

Colour saturation

The fact that the source of the reflected blue light values is a standard RGB picture allows data manipulation with digital imaging techniques. If the saturation of the digital image is changed, there is a direct influence on the level of the BR curve. Figure 3 demonstrates the effect of a saturation reduction of 50%. The data shown in this plot is obtained from one of the 2600 dpi scans of the *Picea abies* laths in a state of density measurement preparation. This biased data was used to test, whether a change in colour saturation allows the "lost" latewood peaks to be restored and thus a resolution above hardware properties of the scanning device could still be used. When the saturation is reduced, a clear shift towards higher blue intensity is visible and the latewood peaks,are restored. At the same time the amplitude of the peaks is largely reduced. Therefore the saturation of the digital image from which the blue intensity is taken should remain at 100%. This is feasible if an appropriate scanning resolution is considered.

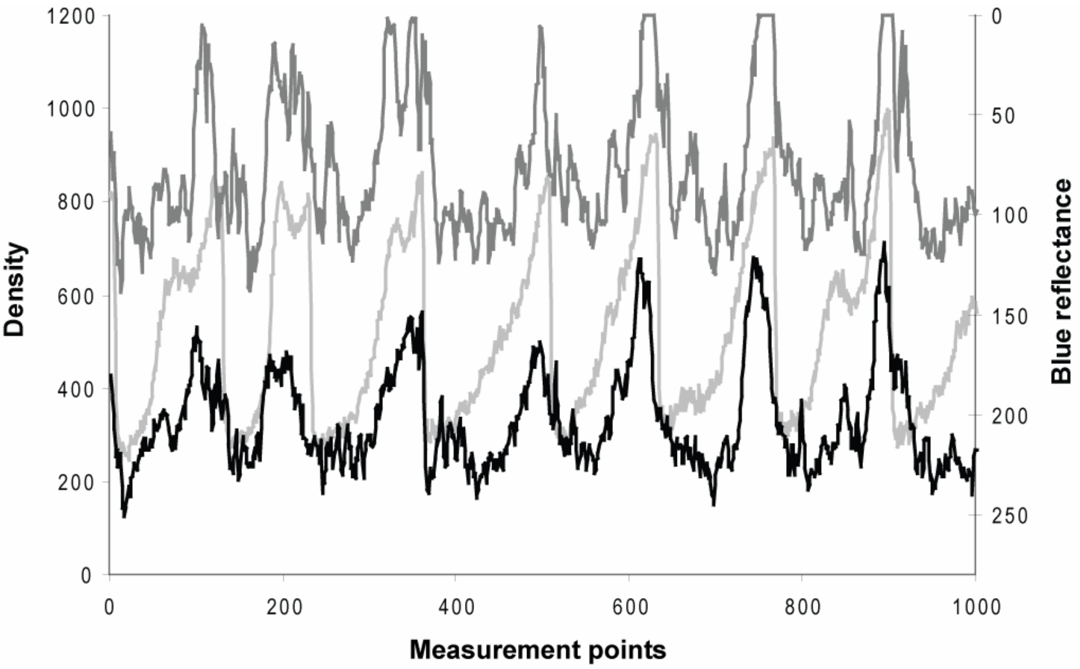

Figure 3: Reduction of the image saturation by 50% of a Picea abies sample. The top curve is the blue reflectance scanned with 2600 dpi at a saturation level of 100%. The middle curve is MXD from the same sample. The bottom curve shows BR with a saturation of 50%.

Comparison of minimum blue reflectance (MBR) and maximum latewood density (MXD)

Previous studies on this subject used *Pinus sylvestris* samples from northern Scandinavia (McCarroll 2002, Campbell 2007). Here, a comparison of the two methods applied on the above mentioned *Picea abies* wood is presented with the aim of confirming the promising results of previous studies using a different coniferous tree species. Despite the finding that a smoother surface improves the BR output, the surface of the wood laths received no further treatment after the wood density had been measured. This was done in order to not artificially alter the direct comparison shown in figure 4. The diagram demonstrates that the data from both methods correlate very well and that apart from the variance in the BR earlywood data, which is reltated to the slightly rough surface caused by the twin-bladed saw, the pattern is quite similar.

Analysis of the density profiles showed that the clearest climate signal derives from the variation in maximum latewood density (Schweingruber 1978). Therefore the crucial question is whether the difference in the minimum blue reflectance (MBR) of each ring reflects the MXD peaks. Figure 5 reveals the analogy of MBR and MXD in 18 consecutive years. The correlation between the two curves is -0.79. The correlation coefficients between MBR and MXD for each of the 30 samples range from -0.56 to -0.89 with an average of -0.78. It is probable that these values could be improved by further smoothing of the surface before measuring MBR.

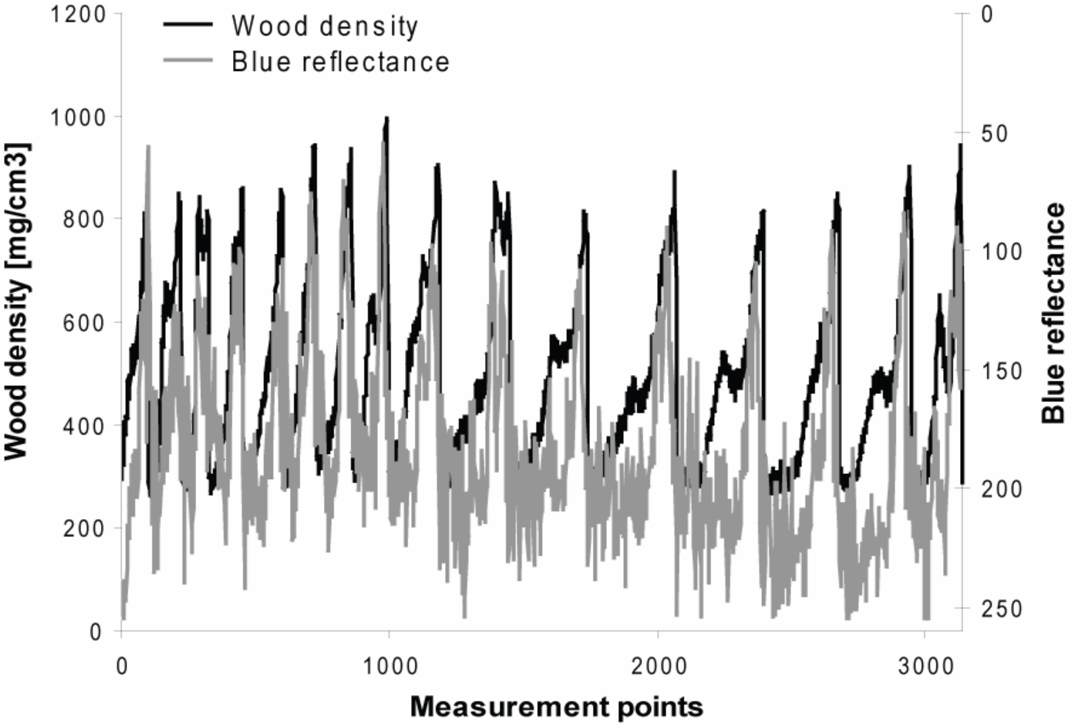

Figure 4: Direct comparison between density and blue reflectance measurements. The surface was treated identically for both methods and a scanning resolution of 1200 dpi was chosen for BR measurements.

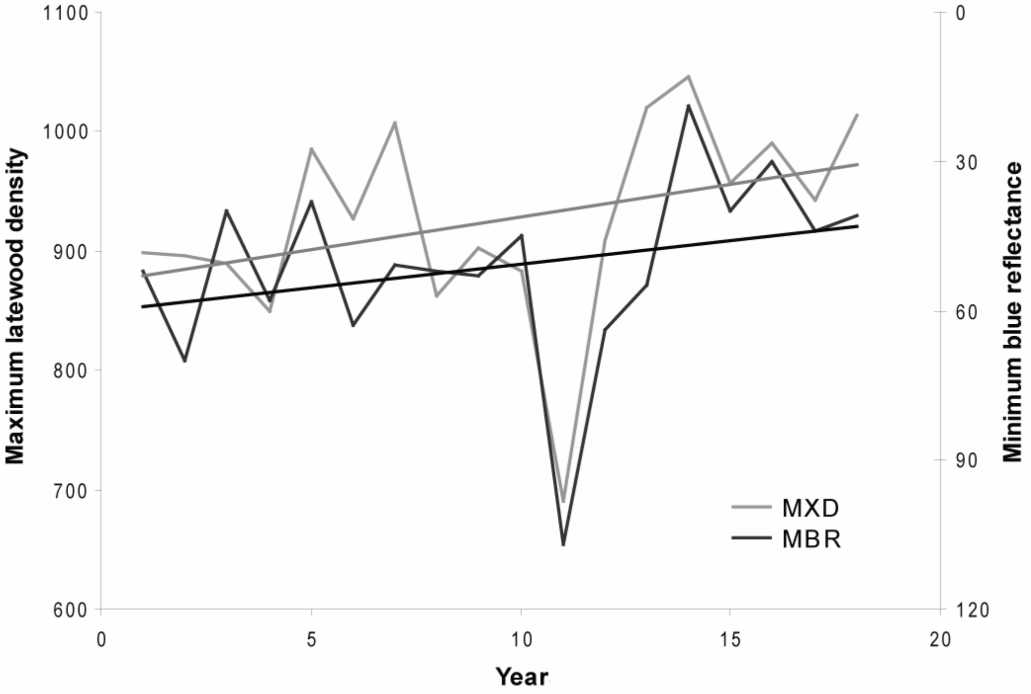

Figure 5: Comparison of minimum blue reflectance and maximum latewood density of 18 consecutive years. Both curves are shown with their linear trends. The correlation between MBR and MXD is -0.79.

Conclusions

Our results emphasize the influence of sample preparation and scanning resolution on the output of blue intensity measurements. It is shown that before Minimum Blue Reflectance can be used as a proxy for the reconstruction of past temperature variability, preparation and measurement standards need to be established. Sanding samples with 400 grit paper, scanning at a resolution of 1200 dpi, and image saturation of 100% were shown to produce most reliable results in the high-frequency domain. However, the results presented in this study derive from the simplest possible spruce samples evading challenges like changes in surface colour due to heartwood-sapwood transition or narrow rings of climatically sensitive trees. Therefore, further tests are necessary – including various species and large sample collections – before the settings mentioned above can be established as a standard preparation. The tests that were carried out so far suggest that many methodological challenges need to be overcome before blue reflectance can be used to reconstruct longer term climate changes, and especially those that exceed the length or age of the wood samples. In particular, the necessary calibration that "ties" measurement series to absolute density or reflectance levels remains elusive.

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Modeling of tree roots - Combining 3D Laser scans and 2D tree ring data

Wagner, B. & H. Gärtner

Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland
Email: bettina.wagner@wsl.ch

Introduction

In times of the global change debate the global carbon cycle plays a crucial role. Trees and forests function as carbon (C) sinks, due to their photosynthesis (Ritson & Sochacki 2003) and hence, counteract global warming. Forests cover 30 % of Earth's land surface (Brunner & Godbold 2007) and consequently, forest biomass plays a key role in the global carbon cycle (Cheng et al. 2007). About 20-40 % of the total forest C is accounted for by roots (Brunner & Godbold 2007), depending on the tree species and ecological conditions (Le Goff & Ottorini 2001).

However, the estimations for root biomass remain rough and more accurate calculations are necessary for reliable results about the global carbon budget. Moreover, information and accurate models of root systems are desirable und useful for applications other than biomass calculations. In mountain regions forests often act as protection forests against avalanches and debris flows. It is necessary to analyze e.g., tree anchorage to have detailed information about the three-dimensional (3D) architecture of root systems and their development. Furthermore, forests act as a biodiversity pool and provide habitat for 2/3 of all animal and plant species (Brunner & Godbold 2007). It is important to fully understand ecosystem processes to guarantee these purposes in the future and counteract forest dieback. Therefore growth processes, including root growth, need to be considered.

The laser scanning technique has been established during the last years in geodesy and several other disciplines like architecture, archaeology, and engineering. Forestry is one of the newer fields of application, where different laser techniques, airborne (Lim et al. 2003, Rossmann et al. 2006) and terrestrial laser scanning (TLS) have been used. Latter scanners have mainly been used for forest inventories, acquiring the aboveground structure of the forest and describing the state of forest as a base for management activities (Aschoff & Spiecker 2004, Bienert et al. 2006, Pfeifer & Winterhalder 2003).

An entire root system was for the first-time scanned by Gärtner & Denier (2006), who evaluated the laser scanner technique as an effective method for the detailed acquisition of root system data. The root model by Gärtner & Denier (2006) showed root structure at the time of uprooting but provided no information regarding the spatio-temporal development of the root system.

The aim of this study is to develop an annually resolved 3D growth model for tree root systems. As a prerequisite a 3D surface model of a root system needs to be captured which will then be combined with ring-width data. For the first time these results will allow an accurate quantification of root development thereby providing fundamental data for quantifying the below ground carbon cycle and thus the relationship between above and below ground productivity. Moreover, bifurcation patterns and root length can be analyzed easily within the model. Fine roots will be excluded from this study, because the laser scanner cannot capture such fine elements accurately. The question addressed in this paper is if terrestrial laser scanning is an appropriate device technique for the lifelike illustration of a root system. Possibilities and limitations of this technique are shown. Moreover a first approach to integrate age information of tree rings into the 3D surface model is described and an outlook on future work is given. The main focus of this paper aims to elaborate on the new methodology used, although first results are presented.

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Material and methods

Laser scanning is a combination of hardware (the laser scanner itself) and software (Schulz 2007). The laser scanner produces high-resolution clouds of 3D data points of a scanned object within short time (depending on the resolution) and these points need to be processed with appropriate software (Schulz 2007). Each data point has its own x, y, z coordinate and an additional coefficient, which depends on the object's reflectivity. While the use of a laser scanner enables a fast acquisition of the entire root system in 3D, the subsequent modeling process is rather time consuming. The programs used here are Geomagic Studio 9, Geomagic Qualify 8, and Cyclone 5.8 software.

Data acquisition

The scanner used in the presented study is the Imager 5006 from Zoller & Fröhlich. Technical data are listed in table 1. The data acquisition was accomplished within the measuring laboratories at the Institute of Geodesy and Photogrammetry at the ETH Zurich. The scanner has a static position during the scanning process. It is not possible to capture the surface of a 3D object at once, due to obstacles and line-of–sight obstructions (Schulz 2007) and, therefore, 10 scan perspectives were scanned; some were made from the lowest possible tripod position to reach the objects underside.

Table 1: Technical data of the Imager 5006.

Range	1 – 79 m
Resolution Range	0.1 mm
Linearity error up to 50 m	≤ 1mm
Data acquisition rate	≤ 500 000 Pixel/sec.
Field of view vertical/horizontal	310°/ 360°
Resolution vertical/horizontal	0.0018°/0.0018°
Accuracy vertical/horizontal	0.007° rms/ 0.007° rms
Range noise at 10 m	
-Reflectivity 10% (black)	1.2 mm rms
-Reflectivity 10% (dark grey)	0.7 mm rms
-Reflectivity 10% (white)	0.4 mm rms

Scanner Calibration

The scanner itself and the scan procedure are influenced by several factors (range measurement principle, scan position, angle of influence etc.), which can cause measuring errors (Schulz 2007). Some occur according to the mechanical imperfection of an instrument and others are caused by the experimental setup or the properties of the scanned object. Simple shapes (cubes, cylinders, spheres) and objects of metal, wood and paper with different surface characteristics (color, roughness, and reflectance) were scanned to become aware of the test sensitivity to different factors (scattering-, shadowing effects etc.) (Fig.1). Four sphere targets with known diameter (15 cm) were placed in the scan scene for the following registration of the single scan positions.

Registration of single scans

The single scan positions (Fig. 1) need to be combined to get a holistic 3D model of an object. This process is known as registration of multiple scans. Each viewpoint of a scanner refers to a local scanner coordinate system. A transformation related to one reference data set needs to be done between the coordinate systems of the different scans with. The registration was performed with Cyclone 5.8 software.

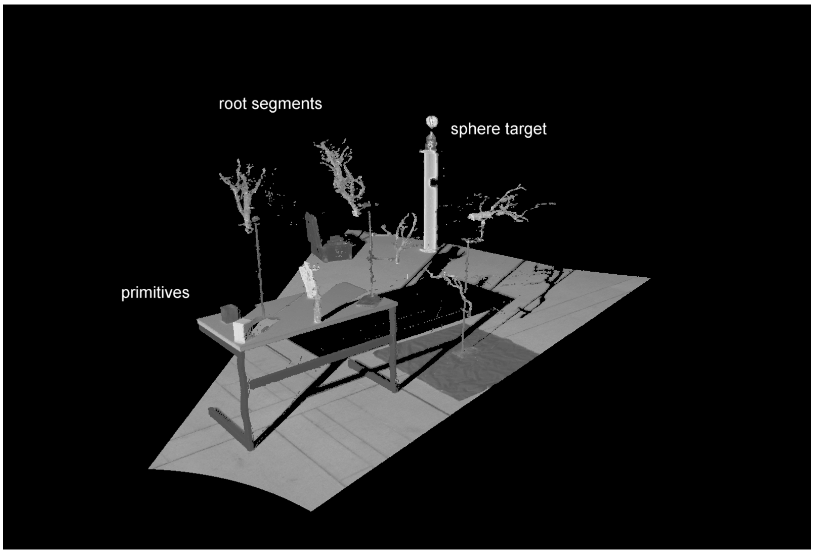

Figure 1: Scan position with primitives, root segments and a reference target (sphere).

Data Processing

For the later calculation of the root volume or biomass it is necessary to wrap the point cloud and to generate a surface. With Geomagic several triangulation and NURBS (Non Rational b-splines) models were created (Fig. 2). Different Filter functions are available in the software package and the impact of different filters was tested for their suitability to generate accurate surfaces (uniform samples, remove spikes, reduce noise, select outliers).

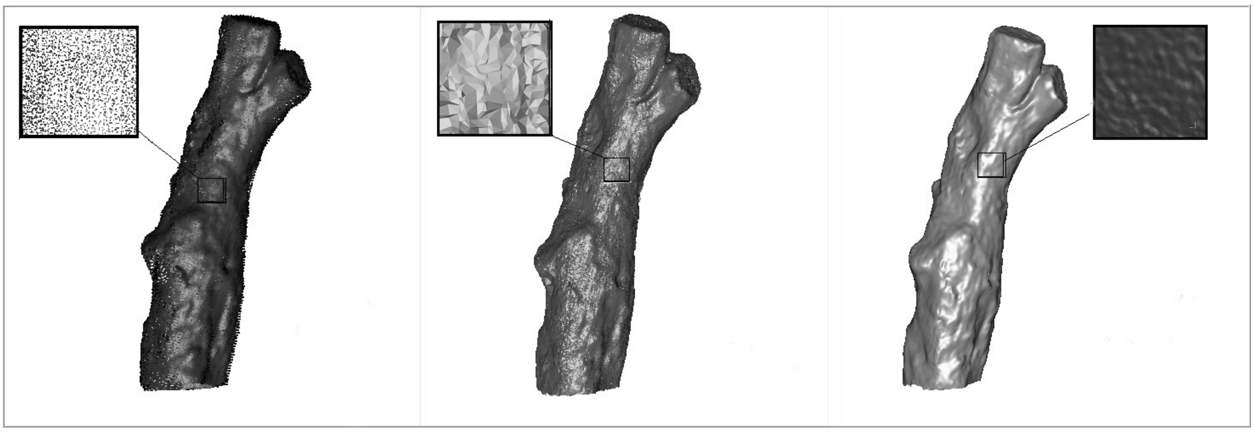

Figure 2: Surface modeling techniques: point cloud, triangulation and NURBS model (from left to right).

Tree-ring measurements

After the root surface has been modeled in an adequate way, the root system was cut to obtain cross sections where tree-rings were measured. The cross sections were cut perpendicular to the root axis. Ring widths were measured on each cross section along four radii according to standard techniques used in dendrochronology (Cook & Kairiukstis 1990). A corresponding cross section was created in the model with Geomagic (at the same position where the cross section was measured in reality).

Fusion of 3D and 2D data sets

The point cloud of the model contains points represented by x, y, z coordinates but tree rings were measured in distances and they lack coordinates. The 3D model coordinates need to be calculated to integrate the rings (here: the ring boundaries) into Geomagic (Fig. 3). Simple trigonometric formulas were used to find the right orientation of the measured radii within the model. However, before those calculations were accomplished missing variables were determined.

First of all the segments (**s**) between the four starting points on the outermost ring boundary were calculated (Fig. 3: dashed line). The starting points (x, y coordinate) needed for measurements along the radii were gained from Geomagic (Fig. 3; P1, P2, P3, and P4).

$$\mathbf{s} = \sqrt{(y_1-y_0)^2+(x_1-x_0)^2}$$

The calculated segment (s) and two of the radii form a triangle. Angle α was calculated for each triangle using the arc cosines function. The distance between each starting point and the pith were measured with TSAP (Figure 3: s_1, s_2 = arrows on cross section).

$$\boldsymbol{\alpha} = \arccos\left(\left(s_1^{\,2} + s^{\,2} - s_2^{\,2}\right) / \left(2 * s_1^{\,2} * s\right)\right)$$

The azimuth direction angle (t) was determined for the latter calculation of intersection point coordinates by using arc tangent function and x and y coordinates of the two given starting points.

$$\mathbf{t} = \arctan\left(\left(y_1-y_0\right) / \left(x_1 - x_0\right)\right)$$

Consequently, it was possible to calculate the coordinates (x_n, y_n) of the intersection point (P_I) between two ring width radii for each triangle. x_1 ,y_1= coordinates of point P1.

$$\mathbf{x_n} = x_1 + s_1 * \cos(t \pm \alpha)$$
$$\mathbf{y_n} = y_1 + s_1 * \sin(t \pm \alpha)$$

Those intersection points can deviate slightly for each of the four triangles. Hence, a mean value was calculated to receive a single intersection point (X_M = x coordinate; Y_M= y coordinate) per cross section, which is representing the grown centre point of the cross section.

$$\mathbf{X_M} = \tfrac{1}{4} \sum x_{n\ i,\,x}$$
$$\mathbf{Y_M} = \tfrac{1}{4} \sum y_{n\ i,\,y}$$

For the following calculation of tree ring borders the difference (MR) between the entire radii and the ring widths (R) (sum of rings) was needed.

$$\mathbf{MR_{n+1}} = s_1 - (R_1+R_2+\ldots+R_n)$$

Finally, coordinates (y_{Rn} x_{Rn}) for tree ring borders were calculated. Coordinates of triangles P1 and the intersection point were used.

$$\mathbf{y_{Rn}} = y_{P1} + y_M - y_{P1} / s_1 * MR_n$$
$$\mathbf{x_{Rn}} = x_{P1} + x_M - x_{P1} / s_1 * MR_n$$

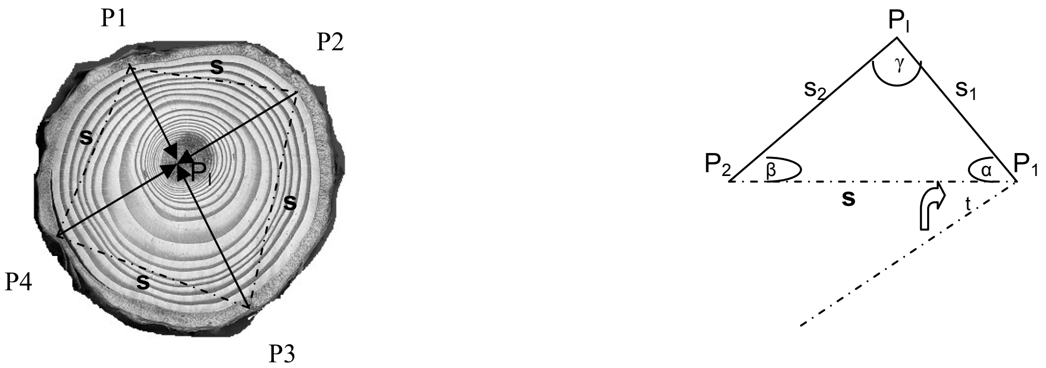

Figure 3: Cross section with ring measurements indicated (arrows, left side) and trigonometric parameters to calculate the intersection point P_I (right side).

Results

Volume computations

The deviation of the calculated from the real volume of the object was below 5 % for the scanned primitives (Tab.2). However, there was a distinct difference in the level of deviation depending on the specific shape of the scanned object. The volume deviation for the cube varied around 0.2%, while the deviation for the sphere lied in the range of 4%, which is still a reliable result. The deviation for the cube calculations was continuously reduced using higher resolutions of the scanner, which was not the case for the sphere. Here, the deviation increased when using the highest resolution (Tab. 2).

The more complex the scanned structures were the higher the resulting deviation, as it can be seen for the scanned root. Here, the calculated volume was up to 15 % higher than the real volume. The root model Root1_filter_single_pos (see Tab. 2), with filter techniques applied for single scan positions before merging them to a holistic model, was below 5 % as well.

Table 2: Volume computations for objects of different shapes scanned in different resolution (high, super, ultra) and processed with different filter techniques (e.g. uniform samples, remove spikes, reduce noise, select outliers).

Object	**Calculated Volume (cm^3)**	**Real Volume (cm^3)**	**% Deviation**
Sphere_high	939	904.8	3.8
Sphere_super	935	904.8	3.4
Sphere_ultra	948	904.8	4.8
Cube_high	2425	2432.5	0.3
Cube_super	2428	2432.5	0.2
Cube_ultra	2436	2432.5	0.1
Root1_high	457	397.5	15.0
Root1_super	446	397.5	12.2
Root1_ultra	459	397.5	15.5
Root1_filter_single_pos	414	397.5	4.2
Root1_inclusion	515	397.5	29.6
Root2_high	209	185.6	12.6
Root2_relax	198	185.6	6.7
Root3	234	217	7.8
Root3_relax	229	217	5.5
Cylinder_high	2526	2450	3.1

Integration of ring information

Geomagic is providing surveying Instruments (point to point, model to plane etc.). The model Root1_filter_single_pos (compare Tab.2 and Fig.4) was surveyed and the measured distances and cross sections were consistent with the proportions in reality. Cross sections were isolated from the model representing the same sections as the ones used for ring width measurements. Using the procedures explained in the material and methods section (compare also Fig. 3) it was possible to merge the points representing the annual ring borders into the 3D model. By calculating the intersection point of the four radii, which represents the location of the centre of the root (central cylinder) the correct orientation of the measured ring widths of each radius was defined (Fig. 4).

A first step to automate the procedure was done in MATLAB (functions were written in m.files), but further efforts are necessary to make the model applicable and to create an automated program, which is optimizing the efficiency of the work.

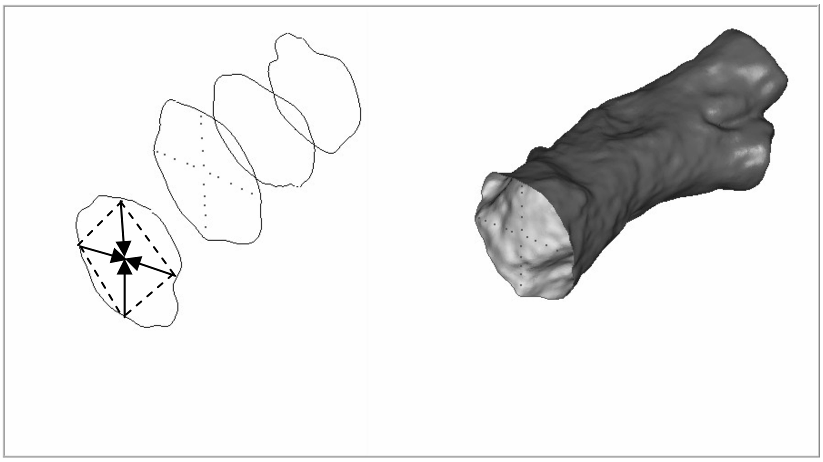

Figure 4: Merged tree ring borders (points) measured from 4 sides (arrows = measured radii, dashed line = calculated segments (s) between starting points for ring measurements, compare Fig. 3).

Discussion

The aim of this article was to give an overview of the applicability of a TLS for modelling tree roots and especially for the calculation of root biomass. Moreover, it wanted to show a first approach how to integrate tree ring or age information into the surface model and to highlight the necessity of this data combination.

The volume calculations in this study have been diverse and it seems necessary to evaluate laser scanning for this application further. While volume computations for simpler shapes (spheres, cubes, cylinders) showed sufficient results (less than 5 % deviation in volume), the calculations for complex root structures were differing up to 15 % from the actual volumes. However, an accurate representation of the root system's surface (3D model) is crucial for ongoing analysis and for finally integrating ring width measurements. Therefore, deviations between the modelled and the real volume need to be detected and causing factors identified. The main factors in this regard are (I) higher shadowing effects due to obstacles and line-of–sight obstructions during data acquisition triggered by heterogeneous and complex structures (Fabris et al. 2007, Schulz 2007); (II) data noise in the point clouds due to scattering effects (mixed pixels, angular displacement, detector saturation etc.); (III) different filter techniques applied to the point cloud.

(I) The main drawback of scanning is that hidden parts cannot be reached by the laser beam (Danjon & Reubens 2007). Parts of missing data can be obtained due to several scan positions (Schulz 2007), but for any missing data left interpolation techniques need to be used. A crucial question is if interpolation is appropriate to replace those data rather then to deform the surface. In this regard Fabris et al. (2007) tested different algorithms. They found some interpolation techniques with sufficient results comparable to the accuracy of the laser scanner, although some interpolation algorithms were poor. Especially a semi-automatic approach was revealed to be useful. First a carrying skeleton was generated manually and subsequently the holes were filled automatically (Fabris et al. 2007), which agrees with our findings. Even though the impact of different filling techniques was rather small (< 2.5 %) the danger of error propagation needs to be considered (Pfeifer et al. 2007).

(II) Scattering is a well-known phenomenon when applying laser scanning techniques (Lichti et al. 2005). It is mainly depended on the surface structure, shape and colour (Schulz 2007). A diffused band with a depth of about 6 mm can be produced instead of a planar structure (Pfeifer et al. 2007). Thus, the surface can deviate from the actual object structure. Mixed pixels occur when an incident laser beam hits two surfaces, resulting in a false point in the range discontinuity region (Litchi et al. 2007). It is likely that the number of mixed pixels increases with higher object complexity, since the possibility that a laser beam hits two different surfaces at once is higher with structures close to each other, thus explaining the lower accuracy for roots compared to spheres etc.

(III) In general, filter techniques had a smaller impact on the volume computations (Tab. 2). In contrast it seemed more important if Geomagic filters were applied to the different scan positions before merging them to an entire object or to point clouds already merged before (volume deviation 4.2 %). Latter model was surveyed with Geomagic to authenticate the results of the model. First measurements showed that the diameters and length measurements matched the once in reality.

However, a combination of the factors mentioned above can generate a major error in volume and hence, biomass calculations. Missing data (depending on the amount) are likely to have an impact on the volume computations. Hence, it is important to avoid unnecessary data loss in the setup. A possible approach is to cut the root system into smaller sections and scan them separately (Danjon & Reubens 2007).

Different registration and filter techniques may result in a high variability in surface structure and volume and consequently essential mistakes can occur. Another offset in volume was caused by inclusions (deviations about 10 % more volume). Thus, missed inclusions are able to induce inaccurate volume computations and need to be fully erased by the operator. In simpler structures it might be easier to detect those inclusions, which could explain a higher accuracy for the simpler shapes. One of the fundamental problems is that TLSs have been adopted quite fast without paying attention to the erroneous points they are producing (Lichti et al. 2005).

Conclusion and Perspectives

The laser scanning technique is a promising technique for forestry. Especially the surface structure of root systems can be described in a detailed way. Moreover, the first models have already shown that Geomagic and Cyclone can easily compute distances between points and polygons and thus, can serve as a survey program for root systems. When a root model is developed, root length and distribution patterns can be measured in a virtual scene and do not have to be accomplished in the field anymore. In addition it was possible to integrate ring borders into the surface model. This enables the reconstruction of the root's development and provides additional information on bifurcation and root length patterns.

Even though the volume calculations from the model created by a TLS are diverging from the actual volumes, it is likely that a higher accuracy will be achieved in near future. Thus, if it is possible to fully integrate the age information in form of annual rings into the model it will be possible to replace the point clouds from today's scanner generation with the ones in future. The technical development of laser scanning devices is fast, due to a high acceptance of laser technique on the market. Companies try to fulfil customer's requirements and are developing rapidly new devices with higher accuracy and fewer errors (Sternberger 2007). Thus, the effort of integrating the rings into a surface model is fully justified. In fact, the aim has to be to develop a model, which can be adapted to the newest stand of technology.

Root systems can be modelled using different approaches and at different levels of detail. Many studies concentrate either on topology, on geometry or biomass estimations (Danjon and Reubens 2007). Most models for biomass calculations are either stand specific or bound to certain species and management methods (Bolte et al. 2004, Le Goff & Ottorini 2001, Nielsen & Hansen 2006). Moreover, often only rough estimations with widely differing percentages are given (Gärtner & Bräker 2004). Therefore, the aim for future research is to develop a model, which is independent of environmental conditions and species.

Most biomass models only represent one singular state of a tree and lack information about root development over time. With a ground penetrating radar it is possible to repeat measurements of a root system developing in time and, hence, a basic approach towards a root development model was shown (Nadezhdina & Cermák 2003). However, trees are continuously growing and it is rather time consuming to achieve a detailed picture of root development with repeated measurements. The laser scanning technique has been shown to offer a more efficient and accurate method.

A first step was reached and age information has been placed in the correct position within the surface model. In the next step the approach will need to integrate the entire ring structure into the model and interpolate between the cross sections (Fig. 5). A big advantage of the approach presented here, besides acquiring the present state of biomass, is the ability to reconstruct the past growth patterns of the root system with annual resolution.

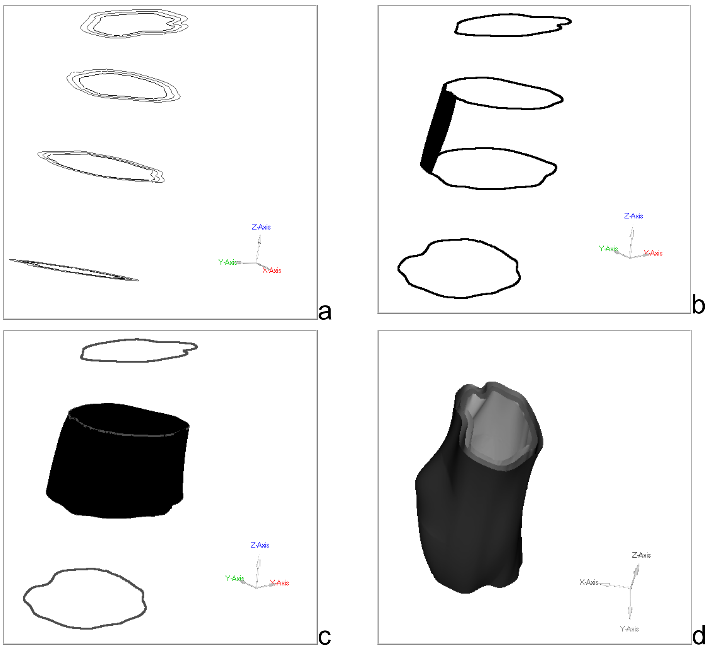

Figure 5: Approach towards an interpolation between cross sections (a) cross section with tree rings marked, b) stepwise interpolation with Geomagic, c) interpolated surface between 2 tree rings d) nested model of root segments contains different surfaces for age classes.

Future investigations need to verify if a model based on terrestrial laser data is applicable on a broad scale and to an entire root system.

Further calculations are necessary to assess the approach for the accurate description of entire root systems and biomass calculations. Other methods and techniques will be examined for the suitability to capture the 3D structure and to achieve a higher accuracy.

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Influence of pith offset on tree-ring chronology trend

Esper, J.[1,2], **Frank, D.**[1], **Büntgen, U.**[1] **& A. Kirdyanov**[3]

[1]Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland
[2]Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland
[3]V.N. Sukachev Institute of Forest SB RAS, 660036 Krasnoyarsk, Akademgorodok, Russia
Email: esper@wsl.ch

Introduction

The reconstruction of long-term climate variations and accurate estimation of temperature amplitude remain major challenges of contemporary palaeoclimatology (Cook et al. 1995, Esper et al. 2005). One of the key methods to address these issues is the Regional Curve Standardisation (RCS, Esper et al. 2003) that has meanwhile successfully been applied to a variety of tree-ring datasets (e.g., Briffa 2000, Büntgen et al. 2005, 2006, 2008, Cook et al. 2002, Esper et al. 2002, Frank et al. 2007, Luckman & Wilson 2005, Naurzbaev et al. 2002), and is considered the standard method for regional tree-ring based temperature reconstructions in the recent IPCC report (IPCC 2007, see also Esper & Frank 2008).

A potential limitation of this method, however, seemed to be a lack of information on innermost tree-rings, the so-called "pith offset" (PO), defined as the number of (missing) years between the innermost ring on a core sample and the pith of the stem in breast height. Missing PO information -- typical for dendrochronological datasets -- is relevant to RCS, as it affects the alignment of tree-ring data by cambial age, and thus the course and position of the regional curve used for detrending of all measurement series (details in Esper et al. 2003).

The influence of PO on chronology trend has been addressed for so-called composite datasets integrating samples from living trees and relict material (Esper et al. 2003), but remained unclear for RCS detrended chronologies from only living trees. Such chronologies have, however, recently been produced for Central Asia, North Africa, and the high northern latitudes (e.g., Briffa et al. 2001, Esper et al. 2007a, 2007b), for example. RCS detrended timeseries from only living trees might particularly be prone to trend biases, as PO is not distributed over much of the chronology period -- such as is the case for well-replicated composite chronologies -- but is concentrated to the beginning of the timeseries.

We here analyse these potential biases and test the influence of PO on chronology trend using a large collection of tree-ring width (TRW) and maximum density data (MXD) from living larch and pine trees in Western and Central Siberia. PO data were estimated by WSL and Sukachev Forest Institute staff considering the curvature and size of innermost rings on core samples, diameter of the stem, and information from other cores of the same tree if available. We analyse the age-trend of TRW and MXD data and show how PO is increased and concentrated towards the beginning of the dataset. The influence of PO on chronology trend is analysed using residual timeseries derived from RCS detrended TRW and MXD chronologies that do and do not include PO information. Results are briefly discussed with respect to their relevance for long-term climate reconstruction.

Material and Methods

The tree-ring material considered to study PO effects represented a diverse collection of four *Pinus sibirica* and four *Larix sibirica* sites sampled over the past 10 years in Western and Central Siberia (Fig. 1). The data included 515 cores samples from which 82,000 MXD and TRW measurements were obtained. Sample replication varied substantially among sites, from 22 cores in the 'southern' WPi60 site to 101 cores in UPi68 northwest of the Ural Mountains (Tab. 1). The network reached north into the Taymyr Peninsula and included a site at 70.4°N (WLa70).

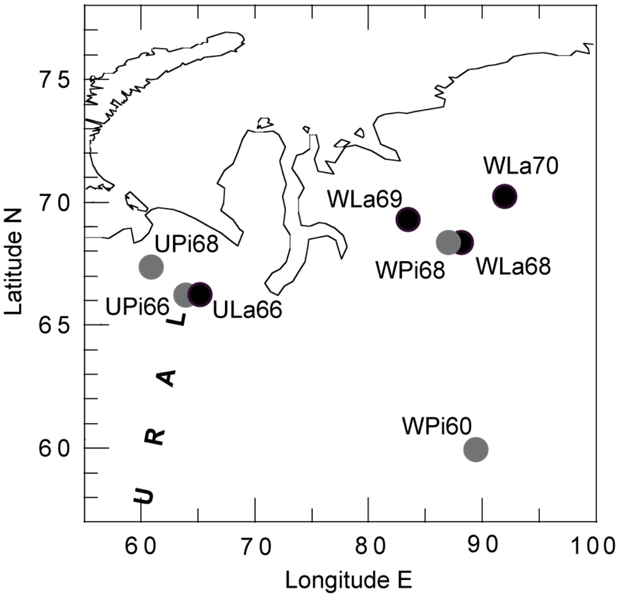

Figure 1: Map showing the eight tree-ring sampling sites in Western and Central Siberia. Black circles indicate the larch sites ULa66, WLa68, WLa69, WLa70; grey circles the pine sites CPi60, UPi66, UPi68, WPi 68. Numbers refer to latitude north, "U" to Ural, and "W" to Western plain.

While the majority of site chronologies reached back well into the 17th century, the oldest trees were collected at UPi66 (back to 1550 A.D.). The mean segment length over the whole network was 159 years, but reached from 82 years in UPi68, where fieldwork included sampling both old and young trees, to 227 years in ULa66, which represented a more traditional collection of only old trees. Average Rbar of all sites was 0.55 for both MXD and TRW, and reached from 0.36 in the southern WPi60 site (MXD and TRW) to 0.70 in WLa70 (MXD) and 0.72 in ULa66 (TRW).

We detrended the TRW and MXD data using RCS (Esper et al. 2003) applied on a site-by-site basis (Esper et al. 2007b), once with and once without consideration of PO (Cook and Kairiukstis 1990, Fritts 1976). RCS included smoothing the arithmetic mean of all measurement series per site using a 10-year spline, and calculation of ratios from these 'regional curves'. Site chronologies were calculated using a bi-weight robust mean, and regional timeseries developed by averaging all tree-ring sites in Western and Central Siberia. These records -- one developed with and one without consideration of PO -- were then used to calculate residual timeseries that allowed a straightforward assessment of the influence of PO on RCS detrended TRW and MXD data from a larger network of temperature sensitive tree-ring sites.

Table 1. Sampling sites in Western and Central Siberia. MSL is mean segment length. Rbar is the mean interseries correlation calculated over the well replicated 1800-1990 period using spline detrended data.

Site	Lon.	Lat.	Species	No. Cores	First Year	Last Year	MSL	Rbar (MXD)	Rbar (TRW)
UPi66	65.5	66.8	Pinus	39	1550	2001	199	0.39	0.40
ULa66	65.5	66.8	Larix	34	1641	2001	227	0.69	0.72
UPi68	60.2	67.8	Pinus	101	1751	2000	82	0.57	0.48
WPi60	89.2	60.8	Pinus	22	1745	2005	165	0.36	0.36
WPi68	87.8	68.3	Pinus	97	1632	1998	182	0.38	0.43
WLa68	87.8	68.3	Larix	81	1638	1998	149	0.65	0.66
WLa69	83.7	69.0	Larix	57	1664	2000	84	0.64	0.64
WLa70	92.9	70.4	Larix	84	1663	2002	184	0.70	0.66

Results

Age-trend and pith offset

Alignment of all tree-ring data by cambial age revealed mean MXD values centred around 0.8 g/cm^3 and mean TRW values ranging from about 0.5 to 0.2 mm per year (Fig. 2). The trend of the MXD data was much smaller, and included a slight increase until about 50-100 years and a longer-term decrease until about 200 years. In comparison, TRW increased more rapidly over the first 50 years, and then showed a steeper decrease until about 200 years. These differences in shape and level between the two parameters, i.e. the more significant age-trend of the TRW data (Bräker, 1981), suggested that consideration (or none-consideration) of PO information would have a slighter effect on the MXD data, as the change of the regional curve and the underlying data structure would be smaller with these measurements.

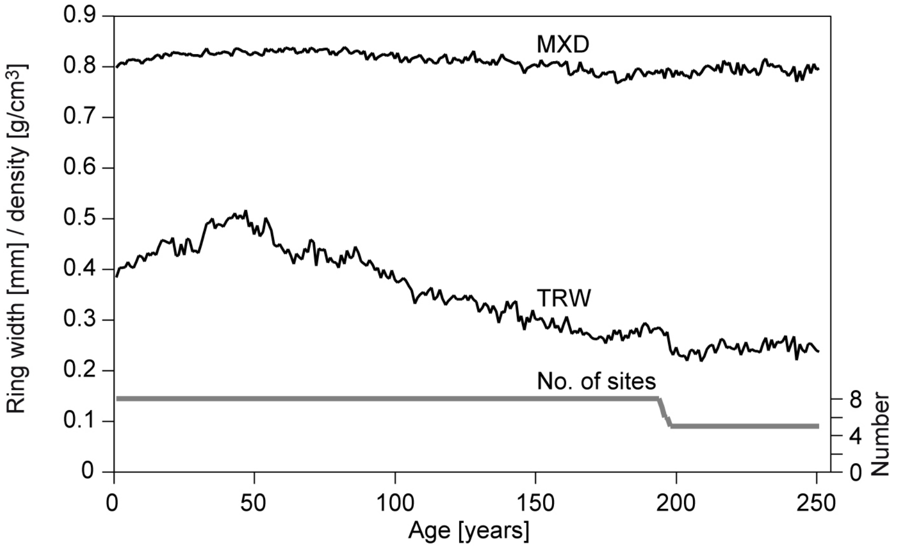

Figure 2: Age trends in Siberian tree-ring data. Mean TRW (in mm) and MXD (in g/cm3) data of eight Siberia tree-ring sites aligned by cambial age. Records are arithmetic means weighted by the number of measurement series per site. Sites records were truncated at a replication of 10 core series. Bottom curve indicates the number of tree sites included in the mean curves.

Average PO of all 515 tree-ring series was found to be 19 years; 92 core samples contained the pith, i.e. offset was zero. Alignment of these data by calendar years revealed a weak relationship between PO and tree age, i.e. offset increased back in time (Fig. 3). While the variance of these data was quite large, including PO of more than 160 years, a straight regression line suggested that PO decreased from about 40 years to below 20 years over the past four centuries. This association between PO and tree age likely resulted from an increased chance of missing the pith by a larger number of rings when sampling old trees, which was either due to a larger stem diameter and/or smaller tree-rings of the older trees. For the analysis of PO trend effects, the tendency of increasing PO back in time suggested that larger biases could arise (in comparison to composite chronologies with more evenly distributed PO), as the changes between chronologies with and without PO-consideration are concentrated over a constrained period. This temporal concentration together with the sizeable age-trend of the TRW data (see above) could potentially alter the trend of RCS chronologies quite considerably.

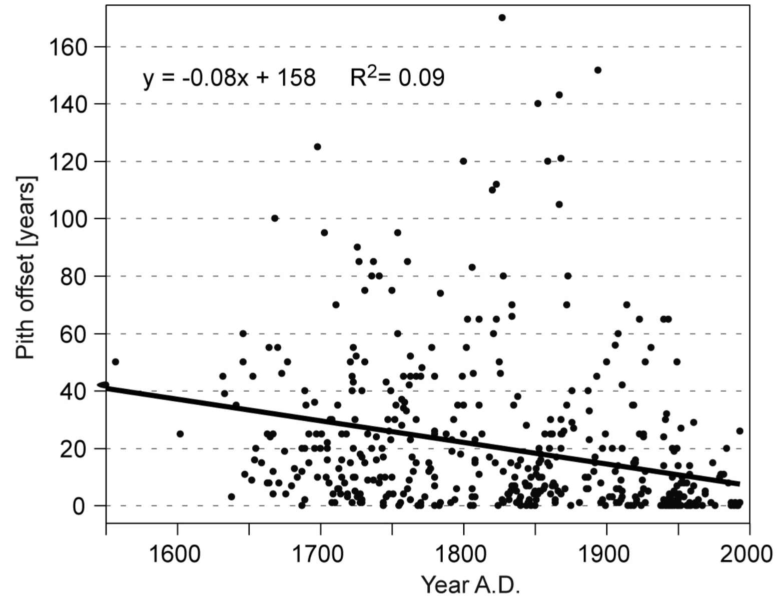

Figure 3: PO distribution of all 515 tree-ring series back to 1550. Straight line resulted from linear least squares fit to the PO data.

Effects of pith offset on regional TRW and MXD chronologies

Calculation of regional mean chronologies integrating all 515 RCS detrended measurement series revealed little influence of PO on the variance and trend of Western and Central Siberian tree-ring data (Fig. 4). This is the case for both MXD, that contained only a slight age-trend, and TRW, that contained a strong age-trend including changes from about 0.5 to 0.2 mm/year.

Residual records of these data indicated hardly any change between the (with and without PO) MXD chronologies, and minor differences between the respective TRW chronologies, if related to the overall variance and trend of these timeseries. The variance of the residual records also increased back in time, which was likely related to the reduction in site and core replication as indicated at the bottom panel of figure 4.

Discussion

The evaluation of PO influence on RCS chronologies showed that missing information of the offset of core samples from the pith has no substantial effect on the trend of MXD and TRW timeseries. This conclusion was supported by tests applied to a regional-scale network of tree-ring sampling sites in Western and Central Siberia with an average PO of 19 years.

While this result was perhaps not unexpected for MXD data, just because of the smaller age-trend inherent to this tree-ring parameter, the relatively small changes between TRW chronologies seemed to be a relevant finding. The TRW data considered here contained a distinct age-trend, and analysis of PO distribution revealed a concentration of offset towards the beginning of the records. Both these properties, however, did not produce large changes in the resulting RCS chronologies that would alter conclusions on the long-term history of climate as can be derived from such data.

Our tests thus indicate that missing PO information, if in the order of about 20 years and for tree-ring data with similar properties than the network analyzed here, is of minor importance to tree-ring based climate reconstructions.

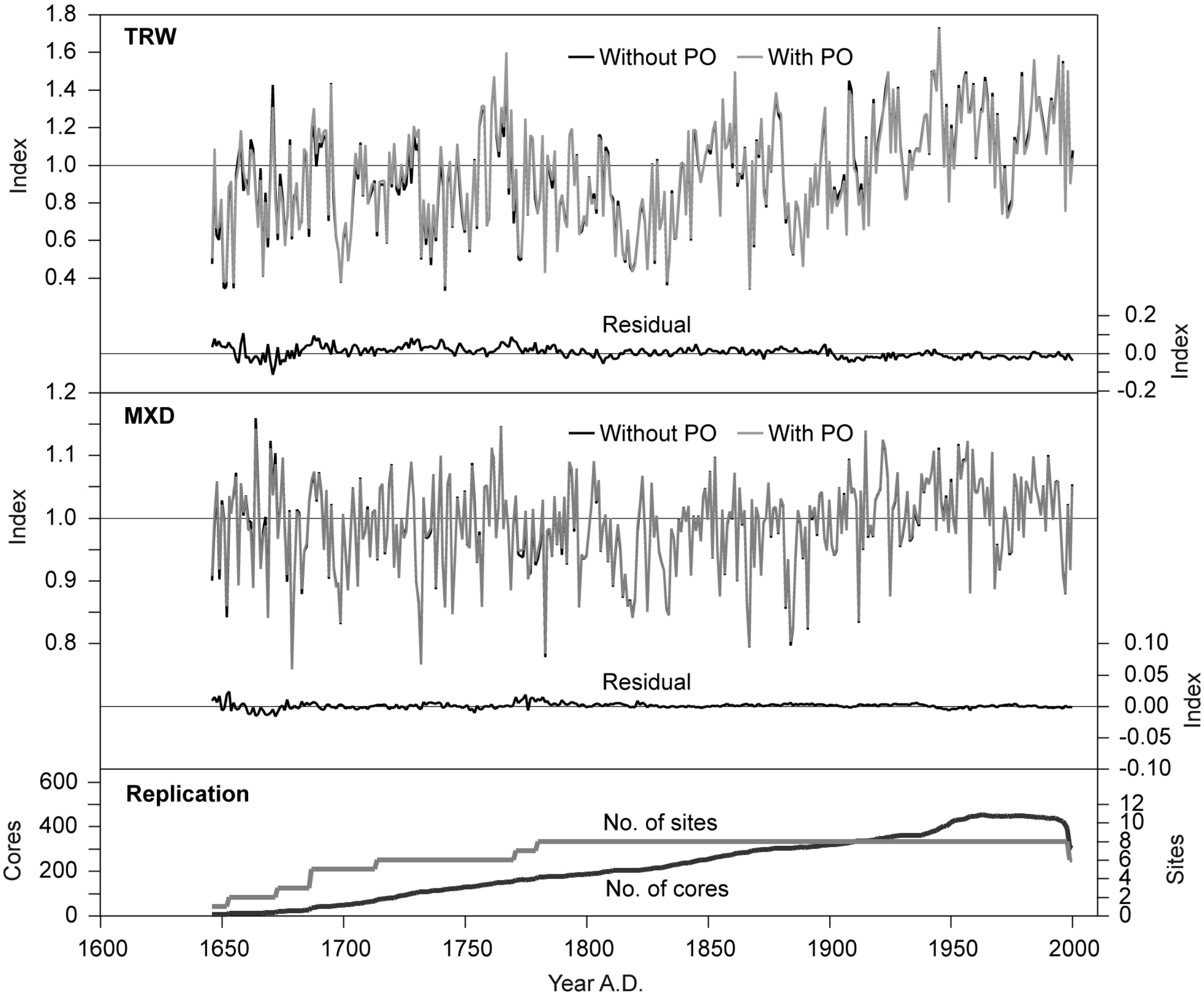

Figure 4: Effect of PO on regional TRW and MXD timeseries. Top and middle panels show the TRW and MXD chronologies calculated with and without consideration of PO, and their residuals at the bottom of the panels. The records displayed here are arithmetic means of eight RCS-detrended site chronologies. Bottom panel indicates the number of site chronologies and core samples integrated in the regional TRW and MXD timeseries.

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PODIUM DISCUSSION TRACE 2008

The *'Divergence Problem'* in tree-ring research
– Podium Discussion TRACE 2008 –

Büntgen, U.[1], Wilson, R.[2], Wilmking, M.[3], Niedzwiedz, T.[4] & A. Bräuning[5]

[1]Swiss Federal Research Institute WSL, Switzerland
[2]University of St. Andrews, Scotland
[3]University of Greifswald, Germany
[4]University of Silesia, Poland
[5]University of Erlangen-Nürnberg, Germany
Email: buentgen@wsl.ch

Introduction

Evidence for reduced sensitivity of tree growth to temperature has been reported from multiple forest sites along the mid to high northern latitudes and from some locations at higher elevation. This alleged large-scale phenomenon reflects the inability of temperature sensitive tree-ring width and density chronologies to track increasing temperature trends in instrumental measurements since around the mid-20th century. In addition to such low-frequency trend offsets, resulting in warmer instrumental and cooler reconstructed temperatures, the potential inability of formerly temperature sensitive trees to reflect high-frequency climate signals derives from some boreal and alpine sites. These two observations have recently been introduced as the *'Divergence Problem'* (DP), with causes and scales being discussed in a variety of recently published high-ranking peer-review articles. If the DP turns out to be a real and widespread phenomenon (coincidentally) paralleling anthropogenic-induced changes of atmospheric composition as well as global warming, it would not only have a substantial effect on biomass productivity rates, with serious implications on carbon sequestration, but it would further question the overall ability of tree ring-based temperature reconstructions to capture earlier periods of putative warmth, such as the so-called Medieval Warm Period, and subsequently to model possible reactions of forest ecosystems in a warming world. Here we synthesize the main points of a *Podium Discussion* that took place during the international conference TRACE (April 2008), which stressed the DP from different perspectives: ecology, climatology, and methodology. The existing body of literature related to the DP is briefly reviewed, while highlighting regional-scale evidence for and against the phenomenon and discussing main sources of uncertainty that contribute towards complicating the issue.

Definition

D'Arrigo et al. (2008) recently defined the DP as: "the tendency for tree growth at some previously temperature-limited northern sites to demonstrate a weakening in mean temperature response in recent decades, with the divergence being expressed as a loss in climate sensitivity and/or an offset in trend". To expand on this definition, we should clarify that the DP is commonly expressed in the *dendrochronological* literature as a 'response related' divergence between tree ring-based reconstructed temperatures and actual measured temperatures. Moreover, a 'growth divergence' (GD) has been reported for some high-latitude and high-elevation sites, where formerly homogeneous sites show emergent subpopulations of trees with diverging growth patterns during the late 20th century (Wilmking et al. 2005, Pisaric et al. 2007, Zhang et al. 2008). This GD is found between subsets of trees within one study site and commonly indicates different longer-term growth trends. While the DP can be thought of as a *dendroclimatological* expression, the GD reflects a more *dendroecological* perspective.

Evidences

The existence of the DP is not spatially complete and appears to be more prevalent to some areas.

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Evidence for a potential DP was first noted in Alaska (Jacoby & D’Arrigo 1995, Taubes 1995), which appears to be a specifically sensitive region to the phenomenon (Barber et al. 2000, Jacoby et al. 2000, Lloyd & Fastie 2002, Davi et al. 2003 (for ring-width), Wilmking et al. 2004, 2005, D’Arrigo et al. 2005, Driscoll et al. 2005). However, using a large northern hemisphere network of maximum latewood density chronologies with regional composites across northern North America, Northern Europe and Siberia, Briffa et al. (1998) demonstrated widespread evidence for the DP. Despite this apparent large-scale distribution of the phenomenon, at a site or regional level, the DP is not observed at all studied locations (e.g., Jacoby et al. 1996, D'Arrigo et al. 2000, 2001, Wilson & Luckman 2002, Cook et al. 2003, Davi et al. 2003 (for density), Wilson & Topham 2004, Büntgen et al. 2005, 2006a, 2007, 2008b, Frank & Esper 2005, Luckman & Wilson 2005, Youngblut & Luckman 2008, Wilson et al. 2007). Moreover, the current body of literature reveals that the DP does not exist at lower latitudes (Briffa et al. 1998, Cook et al. 2004, Büntgen et al. 2008a). Therefore, the DP should not be thought of as an endemic large-scale phenomenon with one overriding cause, but rather a local- to regional-scale phenomenon of tree-growth responses to changing environmental factors including multiple sources and species-specific modification (Tab. 1).

Table 1 Overview of available publications sorted by tree species that provide possible ecological explanations for the DP (only first author mentioned) when studying ring-width data only. All studies represent northern mid- to high-latitude or -altitude environments and demonstrate either a changing relationship over time between climate and radial tree growth (climate/TRW), show emergent subpopulation behavior (GD), physiological growth thresholds (differing growth responses to certain climatic thresholds), or age/size effects (differing age or tree size classes denoting different growth responses to climate). All of these phenomena possibly contribute in various ways to the DP.

Species	**Climate/ TRW**	**GD**	**Thresholds**	**Age/size effects**
Abies alba	Smith 1999			
Abies alba	Wilson 2004			
Larix dahurica	Wilmking 2005			
Larix deciduas	Carrer 2006		Rossi 2007	Carrer 2004
Larix deciduas				Rossi 2008
Larix gmelinii	Lloyd 2007			
Larix sibirica	Wilmking 2005			
Larix sibirica	Lloyd 2007			
Picea abies	Wilson 2004		Rossi 2007	Rossi 2008
Picea abies	Büntgen 2006			
Picea abies	Lloyd 2007			
Picea glauca	Jacoby 1995	Wilmking 2005	D‘Arrigo 2004	Szeicz 1994
Picea glauca	Wilmking 2005	Driscoll 2005	Wilmking 2004	
Picea glauca	Driscoll 2005	Pisaric 2007		
Picea glauca	Lloyd 2007			
Picea mariana	Lloyd 2007			Wilmking 2008
Picea mariana	Wilmking 2008			
Picea obovta	Lloyd 2007			
Picea rubens	Smith 1999			
Picea sitchensis	Lloyd 2007			
Pinus banksiana	Lloyd 2007			
Pinus cembra	Oberhuber 2007		Rossi 2007	Rossi 2008
Pinus sibirica	Wilmking 2005	Wilmking 2005		
Pinus sylvestris	Linderholm 2004			Linderholm 2004
Pinus sylvestris	Wilmking 2005			
Pinus sylvestris	Lloyd 2007			
Pinus tabulaeformis	Zhang 2008	Zhang 2008		
Sabina przewalski	Zhang 2008	Zhang 2008		Yu 2007
Tsuga mertensiana	Biondi 2000			
Tsuga mertensiana	Lloyd 2007			

Causes

A discussion of candidate reasons for the DP is detailed in D'Arrigo et al. (2008), which we briefly summarize here: Potential causes at the local- to regional-scale include recently occurring temperature-induced late summer drought-stress (Jacoby & D'Arrigo 1995, Barber et al. 2000, Lloyd & Fastie 2002, Büntgen et al. 2006b), complex non-linear growth responses to changing climatic and/or ecological settings (Vaganov et al. 1999, D'Arrigo et al. 2004, Wilmking et al. 2004), the utilization of an imprecise instrumental target for calibration (e.g., maximum temperatures may be more appropriate than mean temperatures – Wilson & Luckman 2002, 2003, Büntgen et al. 2008a, Youngblut & Luckman 2008), and affects of airborne pollution (Yonenobu & Eckstein 2006). At larger spatial scales, changes in stratospheric ozone concentration (Briffa et al. 1998, 2004) and/or effects of global dimming on photosynthesis rates (D'Arrigo et al. 2008) have also been proposed, but have not yet been robustly tested.

Superimposed on these biological and ecological related issues are methodological-induced uncertainties (see Büntgen et al. 2008b for an overview) including the tree-ring detrending methods applied during the standardization process and 'end-effect' issues emerging from different techniques of chronology development (Cook & Peters 1997, Melvin 2004). Further biases may emerge from the calibration technique applied (e.g., regression versus scaling) and calibration interval used (Esper et al. 2005), as well as the time-series smoothing practice performed (Mann 2004).

This concert of tree ring related uncertainties is complemented by potential sources of instrumental station error, e.g., the homogenization technique applied, 'micro-site' effects and effects gained from 'urban heat islands' (Frank et al. 2007). Such limitations of the target data, multivariate growth/climate interactions, and methodological issues can systematically bias inferred relationships with tree growth.

It should also be noted that several recent studies observed a similar phenomenon in chronologies from drought sensitive tree-ring sites that express a loss or weakening of the growth/climate response with instrumental precipitation sums and/or drought metrics in the post-1970s (e.g., Brazdil et al. 2002, Wilson & Elling 2004, Wilson et al. 2005, Zhang et al. 2008). Potential reasons for the observed late 20th century discrepancy include pollution effects for the Central to Eastern European region. A systematic and sophisticated analysis based on a complete and updated data collection is, however, still missing.

Solutions

As there are likely multiple causes for the DP, which are not only tied to a certain species and region, but may also be related to methodological issues (e.g., detrending and chronology development), there is simply not one uniform solution to overcome the DP. On the contrary, the issue must be systematically studied on a site-by-site basis or within climatically homogenous regions where a network of sampling sites and reliable long-term instrumental measurements are available. Consequent testing for the ability of ring-width and density data to track temperatures during the exceptional recent warmth is necessary to understand the reliability of long-term climate reconstructions. Such tests are, however, complicated, as a variety of environmental factors including climate, ecology, stand structure and competition, forest history, and human influences simultaneously impact tree-growth. Therefore, well-replicated temperature sensitive tree-ring data and carefully homogenized meteorological target data, which both extend back into the 19th and forward into the 21st century facilitate a more robust study of the DP. Both conditions, as well as an unprecedented warming trend since the past ~150 years, exist for the European Alps. Accordingly, Büntgen et al. (2008b) compiled a unique network of the main Alpine conifer species larch and spruce. TRW measurements from 124 sites were aggregated, carefully detrended, and resulting chronologies compared with well-documented and homogenized climate data from numerous high-elevation instrumental stations. The TRW data were first analyzed to emphasize common growth trends and climate responses as a function of site elevation, location and species.

Split period correlations were then used to assess proxy/target relationships over time. That is, a subset of TRW chronologies was calibrated to summer temperatures over the early 1864-1933 period and subsequently helped assessing their (independent) ability to track late 20th century warming. In this regard, however, it should be emphasized that the current quality level of instrumental measurements recorded across the Greater Alpine Region is exceptional and not reached in other parts of the globe. Subsequently, it is highly recommended to apply quality controls via outlier tests, such as the one introduced by Alexandersson (1986). The corresponding open source software (*AnClim*; Štěpánek 2007) should be mentioned. Moreover, in the light of reducing potential station measurement inconsistency, consideration of area means is recommended – more is always better. Investigations on the DP should not only be based on 'standard' climatic parameters, but also on extreme values and more complex indices including drought metrics, radiation duration, ozone and airborne pollution.

Ultimately, from a *dendroclimatic* point of view, we need to be very careful which chronologies we actually use for deriving spatiotemporal forceful reconstructions. While being an important (and credent) sub-community within the grand *Global Climate Change Consortium*, we should not forget the main principles of *dendrochronology*, and one cannot overemphasize the importance of careful site selection. If the aim of a study is to reconstruct temperature, then sites from near the latitudinal or upper treelines are most likely ideal – general assumptions, however, cannot be made! One should not be surprised that growth/climate relationships may be weak or variable if a site is represented by a few individuals sampled far away from the temperature controlled forest boundaries. Dendrochronologists should be very cautious about finding apparent divergence between their proxy chronologies and instrumental target values if the data considered were located in an area that would not be expected to be climatically sensitive and where correlations between tree parameter (TRW or MXD) indices are relatively weak (i.e., $r < \sim 0.45$) even in the periods when chronologies apparently show a climate signal. Certainly, a myriad of non-climatic factors could influence individual trees, individual sites or even regions. However, if the trees/sites are sampled from carefully selected locations in a climatically homogenous area, the common forcing signal (presumably climate) will dominate the chronology signal, if a sufficient number of trees is collected from multiple sites – again, more is always better.

In some respects, there is a clash of methodological approaches that dendro-climatologists or -ecologists need to keep in mind. A dendroecologist might be more interested in small-scale processes and growth responses of individual trees or populations to environmental changes, whereas a dendroclimatologist is generally interested in the mean response of many trees (and many sites) to an overriding larger scale forcing which more often than not will be climate related. This has also implications for the use of tree-ring data taken from freely available data pools (e.g., ITRDB) for large-scale modeling purposes: Before being included in climate modeling studies, metadata about the specific sampling strategies for an underlying tree-ring data set should carefully be considered. Nevertheless, as both approaches are built upon similar ecological principles, it might be worthwhile to better synthesize the different research agendas in the face of today's apparent unprecedented rates of climate and ecological change.

Conclusions

From our brief synthesis of a *Podium Discussion* that took place at the international conference TRACE (April 2008), it is clear that there is NO systematic DP affecting all conifer sites over vast areas of the Northern Hemisphere and that there is also NO single causal mechanism superimposed on the relationship between tree growth and temperature.

This review reveals that future dendroclimatic research should not ignore potential complex and nonlinear growth responses to a changing climate system, which may challenge the current interpretation of the principle of uniformity as well as methodological biases that emerge from tree-ring detrending and chronology development. Possible directions to reduce general uncertainties related to the DP should include:

- *(i)* Sampling strategies at the site level that improve not only the selection of location (i.e., tree-line environments where the probability of only one climatically driven limiting factor is greater) but also increase the number of trees which should be up to an order of magnitude greater than the “traditional” amount of 15-20 individuals.
- *(ii)* Sampling of different age-classes to avoid sub-population biases instead of focusing only on the oldest trees within a population.
- *(iii)* Sampling more than one single site to represent and assess different ecological settings at the regional-scale, such as altitudinal gradients, various substrate types, different slope exposition and inclination, as well as inter-species variety.

Moreover, methodological recommendations to overcome the DP with particular emphasize on improving the quality of tree ring-based climate reconstructions include:

- *(i)* Exploring chronology development techniques that reduce artificial variance changes through time.
- *(ii)* Utilizing detrending methods that allow possible lower frequency information to be obtained, and diminish ‘end-effect’ problems coinciding with the recent warming trends.
- *(iii)* Selecting representative subsets of homogenized instrumental target data.
- *(iv)* Evaluating the effects of different calibration techniques such as scaling and regressing. Calibration/verification statistics are poorer after scaling, but regression becomes always critical when the target data have values well above or below the mean of the calibration period.
- *(v)* Reducing of end-effect amplification due to the smoothing technique applied.
- *(vi)* Omitting simple site deviation into ‘responders’ and ‘non-responders’ (those data that do or do not correlate with climate) without considering independent screening periods.
- *(vii)* Understanding the DP – including high-frequency loss in climate sensitivity and/or low-frequency trend offset – at the local to regional level, before drawing conclusions for larger-scales.

Finally, we should underline that the DP *‘hype’* is very much dendro-centric while representing one potential challenge for dendroclimatology, and thus needs to be overcome to derive reliable tree ring-based climate reconstructions. The DP actually provides an opportunity to re-assess established assumptions, principles, sampling strategies and methods rather than debunking dendroclimatic expertise. Hence, we recommend picking up this challenge in a productive way to deepen our understanding of tree growth responses to various environmental factors and to develop new techniques or to improve established approaches of tree-ring data processing. In this case, the DP will stimulate and improve our discipline.

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List of participants

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ABRAMS, MARC
School of Forest Resources, Penn State University, 307 Forest Resources Building, University Park, Pennsylvania, USA
Email: agl@psu.edu

BABST, FLURIN
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: flurin.babst@wsl.ch

BECK, WOLFGANG
vTI, Institute for Forest Ecology and Forest Inventory, Eberswalde, Germany
Email: w.beck@bfh-inst7.fh-eberswalde.de

BEDNARZ, B. MATEUSZ
Faculty of Forestry, Cracow Agricultural University, Krakow, Poland
Email: RLBEDNAR@CYF-KR.EDU.PL

BREGIN, MAGDALENA
Polish Academy of Sciences, Krakow, Poland
Email: mag.bregin@gmail.com

BERNABEI, MAURO
CNR/IVALSA, S. Michele all'Adige, Trent, Italy
Email: bernabei@ivalsa.cnr.it

BETLEJ, DOROTA
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: duskaduska@poczta.onet.pl

BIJAK, SZYMON
Faculty of Forestry, Agriculture University, Warsaw, Poland
Email: Szymon.Bijak@wl.sggw.pl

BOEREN, ILSE
Inst. für Botanik (210), Universität Hohenheim, Stuttgart, Belgium
Email: iboeren@africamuseum.be

BOGINO, STELLA MARYS
Departamento de Producción Vegetal y Recursos Forestales. Universidad de Valladolid, Palencia, Spain
Email: sbogino@pvs.uva.es

BONTADI, JARNO
CNR/Ivalsa, Italy
Email: bontadi@ivalsa.cnr.it

BOURA, ANAÏS
UMR-CNRS-MNHN n°5143 Paléobiodiversité et Paléoenvironnements, Muséum National d'Histoire Naturelle, Paris, France
Email: boura@mnhn.fr

BRÄUNING, ACHIM
Institute of Geography, Erlengen-Nuremburg University, Erlangen, Germany
Email: abraeuning@geographie.uni-erlangen.de

BROOKHOUSE, MATTHEW
Fenner School of Environment and Society, The Australian National University, Canberra, Australia
Email: Matthew.brookhouse@anu.edu.au

BRUMELIS, GUNTIS
University of Latvia, Faculty of Biology, Riga, Latvia
Email: guntis.brumelis@lu.lv

BUBAK, WŁODZIMIERZ
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: wlodku@gmail.com

BUCHWAL, AGATA
Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poznan, Poland
Email: kamzik@amu.edu.pl

BURCHARDT, IRIS
Institut für Geographie der Universität Erlangen – Nürnberg, Nürnberg, Germany
Email: iburch@geographie.uni-erlangen.de

BÜNTGEN, ULF
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: buentgen@wsl.ch

CEDRO, ANNA
Climatology and Marine Meteorology Department, Szczecin University, Szczecin, Poland
Email: abcania@univ.szczecin.pl

CELMA, MIREIA
Universitat Autonoma de Barcelona, Barcelona, Spain
Email: mireia_celma@hotmail.com

CZAJKA, BARBARA
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: lunastar@autograf.pl

DANEK, MAŁGORZATA
AGH Academy of Science and Technology, Krakow, Poland
Email: kosa@geolog.geol.agh.edu.pl

DUROST, SEBASTIEN
Laboratoire de Chrono-Écologie, UMR 6565 CNRS, Université de Franche-Comté, F – Besançon, Belgium
Email: Sebastien.durost@ulg.ac.be

ELFERTS, DIDZIS
University of Latvia, Faculty of Biology, Riga, Latvia
Email: didzis.elferts@lu.lv

FAN, ZE-XIN
Institute of Geography, Erlengen-Nuremburg University, Erlangen, Germany
Email: fanzexin@yahoo.com.cn

FISCHER, STEFANIE
Institute of Geography, University of Bonn, Bonn, Germany
Email: fischer@giub.uni-bonn.de

GÄRTNER, HOLGER
Swiss Federal Research Institute WSL, Zürcherstrasse 111, Birmensdorf, Switzerland
Email: holger.gaertner@wsl.ch

GEA IZQUIERDO, GUILLERMO
Departamento Sistemas y Recursos Forestales, CIFOR-INIA, Madrid, Spain
Email: guigeiz@inia.es

GODEK, MICHAŁ
University of Wrocław, Wrocław, Poland
Email: godek@meteo.uni.wroc.pl

GORSIC, ERNEST
Faculty of forestry, Zagreb, Croatia
Email: egorsic@sumfak.hr

GRICAR, JOZICA
Slovenian Forestry Institute, Department of Yield and Silviculture, Ljubljana, Slovenia
Email: jozica.gricar@gozdis.si

GRIEßINGER, JUSSI
University of Erlangen-Nürnberg, Department of Geography, Nürnberg, Germany
Email: jgriess@geographie.uni-erlangen.de

GRUNEWALD, KARSTEN
Landscape Research Centre, Dresden, Germany
Email: karsten.grunewald@landschaftsforschungszentrum.de

GRYC, VLADIMIR
Mendel University of Agriculture and Forestry Brno, Department of Wood Science, Brno, Czech Republic
Email: gryc@mendelu.cz

GÜNTHER, BJÖRN
University of Technologies Dresden, Institute of Forest Utilization and Forest Technology, Dresden, Germany
Email: guenther@forst.tu-dresden.de

HAFNER, POLONA
Slovenian Forestry Institute, Ljubljana, Slovenia
Email: polona.hafner@gozdis.si

HAYDEN, BONNIE
Concordia University, Montreal, Canada
Email: b_hayde@alcor.concordia.ca

HEINRICH, INGO
Research Centre Jülich, Jülich, Germany
Email: i.heinrich@fz-juelich.de

HELLE, GERHARD
Research Centre Jülich, Jülich, Germany
Email: g.helle@fz-juelich.de

HOUBRECHTS, DAVID
Université de Liège, Liège, Belgium
Email: dhoubrechts@skynet.be

JOHANN, STEFANIE
Geographisches Institut, Universität Bonn, Bonn, Germany
Email: Stefanie.johann@web.de

KACZKA, RYSZARD JERZY
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: kaczka@ultra.cto.us.edu.pl

KAGAWA, AKIRA
Forschungszentrum Jülich GmbH ICG-V Jülich, Germany
Email: akagawa@ffpri.affrc.go.jp

KAISER, KLAUS FELIX
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: kf.kaiser@access.uzh.ch

KLIMEK, KAZIMIERZ
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: klimek@wnoz.us.edu.pl

KRĄPIEC, MAREK
Dendrochronological Laboratory, AGH University of Science and Technology, Krakow, Poland
Email: mkrapiec@geol.agh.edu.pl

KRUMM, FRANK
Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland
Email: krumm@slf.ch

KUSZNERCZUK, MARTA
Institute of Earth Sciences, Maria Curie Skłodowska University, Lublin, Poland
Email: makuszer@o2.pl

LUCE, ILUTA
University of Latvia, Faculty of Biology, Riga, Latvia
Email: Iluta.luce@lu.lv

MAGNUSZEWSKI, MICHAL
Warsaw University of Life Sciences, Warsaw, Poland
Email: Magnuszewski@wl.sggw.pl

MAHLBERG, MICHAEL,
Institute of Geography, University of Bonn, Bonn, Germany

MALIK, IRENEUSZ
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: irekgeo@wp.pl

MAMOŇOVÁ, MIROSLAVA
Technická Univerzita Zvolen, DF, KND, Zvolen, Slovak Republic
Email: mamonova@is.tuzvo.sk

MATYJA, MARCIN
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: marmat80@go2.pl

MARTIN-BENITO, DARIO
Departamento Sistemas y Recursos Forestales. CIFOR-INIA, Madrid, Spain
Email: dmartin@inia.es

MAZIARZ, MONIKA
Department of Geography and Regional Development, University of Wroclaw, Wroclaw, Poland
Email: tonalli@o2.pl

MCMURRY, ERIN
Missouri Tree-Ring Laboratory, School of Natural Resources, University of Missouri-Columbia, Columbia, USA
Email: ermfcd@mizzou.edu

MEYER, MATTHIAS
Technische Universität Dresden, Forest Botany, Germany
Email: matthias.meyer@mailbox.tu-dresden.de

MIELIKÄINEN, KARL
Finnish Forest Research Institute (METLA) Vantaa, Finland
Email: kari.mielikainen@metla.fi

MOSER, LEA
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: lea.moser@wsl.ch

NÁFRÁDI, KATALIN
University of Szeged, Department of Geology and Paleontology, Szeged, Hungary
Email: geokata@freemail.hu

NEUWIRTH, BURKHARD
Institute of Geography, University of Bonn, Bonn, Germany
Email: b.neuwirth@giub.uni-bonn.de

NIEDŹWIEDŹ, TADEUSZ
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: niedzwie@ultra.cto.us.edu.pl

OLIVAR, JORGE
University of Freiburg, Freiburg, Germany
Email: Jorgeoli17@hotmail.com

OPAŁA, MAGDALENA
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: magdaopala@hotmail.com

OWCZAREK, PIOTR
Department of Geography and Regional Development, University of Wroclaw, Wroclaw, Poland
Email: piotr.owczarek@geogr.uni.wroc.pl

PANAYOTOV, MOMCHIL
University of Forestry, Sofia, Bulgaria
Email: mp2@abv.bg

PIRAINO, SERGIO
Dipartimento di Biologia Vegetale, Università di Roma Sapienza, Rome, Italy
Email: Sergio.piraino@gmail.com

POLLINI, CLAUDIO
CNR/IVALSA, S. Michele all'Adige, Trent, Italy
Email: pollini@ivalsa.cnr.it

PREMYSLOVSKA, EVA
Mendel University of Agriculture and Forestry Brno, Department of Wood Science, Brno, Czech Republik
Email: eva.premyslovska@atlas.cz

RAČKO, VLADIMIR
Technická Univerzita Zvolen, DF, KND, Zvolen, Slovak Republic
Email: racko@is.tuzvo.sk

RAKOWSKI, ANDRZEJ
Silesian University of Technology, Institute of Physics, Radiocarbon Laboratory, Gliwice, Poland
Email: Andrzej.rakowski@polsl.pl

REINECKE, SABINE
University of Freiburg, Freiburg, Germany
Email: Sabine.reinecke@ifp.uni-freiburg.de

REMISZ, JOANNA
Department of Geography and Regional Development, University of Wroclaw, Wroclaw, Poland
Email: remisz@geom.uni.wroc.pl

ROBERT, ELISABETH
Vrije Universiteit Brussel (VUB), Laboratory for Plant Biology and Nature Management (APNA), Brussel , Belgium
Email: EROBERT@VUB.AC.BE

RYNCARZ, PIOTR
Pedagogical University in Krakow – Institute of Geography, Krakow, Poland
Email: ryncarz@ap.krakow.pl

SCHEITHAUER, JÖRG
Landscape Research Centre, Dresden, Germany
Email: joerg.scheithauer@landschaftsforschungszentrum.de

SCHLESER, GERHARD
Research Centre Jülich, Germany
Email: g.schleser@fz-juelich.de

VON SCHNAKENBURG, PETER
Institut of Geography, Erlangen, Germany
Email: pvons@web.de

SCHULTZ, JOHANNES
University of Bonn, Department of Geography, Bonn, Germany
Email: schultz@giub.uni-bonn.de

SEBŐK, SZILVIA
University of Szeged, Department of Geology and Paleontology, Szeged, Hungary
Email: seboksz@geo.u-szeged.hu

SENSUŁA, BARBARA
Department of Radioisotopes, Institute of Physics, Silesian University of Technology, Gliwice, Poland
Email: Barbara.sensula@polsl.pl

SHAO, KENJIRO
Department of Civil Engineering and Systems Management, Nagoya Institute of Technology, Nagoya, Japan
Email: show@nitech.ac.jp

SIMARD, SONIA
Department of Fundamental Sciences, University of Quebec in Chicoutimi, Chicoutimi, Canada
Email: Sonia_Simard@uqac.ca

SPIECKER, HEINRICH
Insitute for Forest Growth, University of Freiburg, Freiburg, Germany
Email: instww@uni-freiburg.de

STAMBAUGH, MICHAEL
Missouri Tree-Ring Laboratory, School of Natural Resources, University of Missouri-Columbia, Columbia, USA
Email: stambaughm@missouri.edu

SZYCHOWSKA-KRĄPIEC, ELŻBIETA
AGH, University of Science and Technology, Faculty of Geology, Krakow, Poland
Email: szycha@geol.agh.edu.pl

SZWARCZEWSKI, PIOTR
University of Warsaw, Faculty of Geography and Regional Studies, Department of Geomorphology, Warsaw, Poland
Email: pszwarczewski@wp.pl

TIMONEN, MAURI
Finnish Forest Research Institute, Vantaa, Finland
Email: mauri.timonen@metla.fi

TOMUSIAK, ROBERT
Faculty of Forestry, Warsaw University of Life Science, Warsaw, Poland
Email: rtomusiak@wl.sggw.pl

VISSER, RONALD
National Organization for Scientific Research (NWO), section Humanities, Netherlands
Email: r.visser@racm.nl

VOLLAND-VOIGT, FRANZISKA
Friedrich-Alexander-Universität-Erlangen-Nürnberg, Germany
Email: fvolland@geographie.uni-erlangen.de

WAGNER, BETTINA
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: Bettina.wagner@wsl.ch

WEBER, PASCALE
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
Email: pascale.weber@wsl.ch

WEIDNER, KATHRIN
Research Centre Jülich, Jülich, Germany
Email: kathrin_weidner@freenet.de

WILS, TOMMY
University of Wales Swansea, School of the Environment and Society, Swansea, United Kingdom
Email: tommywils@gmail.com

WILMKING, MARTIN
Institute for Botany and Landscape Ecology, University Greifswald, Greifswald, Germany
Email: Wilmking@uni-greifswald.de

WILSON, ROB
School of Geography & Geosciences, University of St Andrews, St Andrews, United Kingdom
Email: rjsw@st-andrews.ac.uk

WISTUBA, MAŁGORZATA
Faculty of Earth Sciences, University of Silesia, Sosnowiec, Poland
Email: malgorzatawistuba@gazeta.pl

WROŃSKA-WAŁACH, DOMINIKA
Institute of Geography and Spatial Management, Krakow, Poland
Email: d.wronska@geo.uj.edu.pl

YAMAN, BARBAROS
Zonguldak Karaelmas University, Bartin Faculty of Forestry, Department of Forest Botany, Bartin, Turkey
Email: yamanbar@gmail.com

ZIELONKA, TOMASZ
Institute of Botany Polish Academy of Sciences, Krakow, Poland
Email: ibzielonka@ib-pan.krakow.pl

ZIN, EWA
Warsaw University of Life Sciences, Warsaw, Poland
Email: kumak-nizinny@o2.pl

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