Preface

This volume contains extended abstracts from talks and posters presented at the fifth TRACE (Tree Rings in Archaeology, Climatology and Ecology) conference that was held in Tervuren (Belgium) between April 20 to 22 of 2006. The annual TRACE conferences seek to strengthen the network and scientific exchange of scientists and students involved in the study of tree rings. This annual conference is an initiative of the 'Association for Tree-Ring Research' (ATR). One goal of this conference is to give young scientists and students the opportunity to present concepts, ongoing and finished work.

The conference was hosted by the Laboratory of Wood Biology & Xylarium of the Royal Museum for Central Africa and the Laboratory of Wood Technology of Ghent University. The organizers were pleased to welcome an international group of 90 scientists and students from Belgium, Canada, Czech Republic, France, Germany, Italy, Japan, Latvia, The Netherlands, Mexico, Poland, Portugal, Romania, Russia, Slovenia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom and the USA. The participants all presented excellent oral and poster presentations and discussed their current research. In total, 34 talks were presented, covering the fields of Cultural Heritage (3), Climatology (7), Glaciology (1), Isotopes (5), Geomorphology (4), Ecology (8) and Wood anatomy and Cambial activity (6). Furthermore, 39 posters were displayed to the audience.

Two invited speakers gave a talk about the study of tree-ring patterns in wooden cultural heritage. Prof. Dieter Eckstein focussed on dendro-provenancing, where tree-ring studies are used to document and to reconstruct the historical timber trade in Europe. Prof. Partick Hoffsummer gave an overview of his exhaustive work on roofs from historical buildings in Northern France and Belgium, and the evolutional patterns that can be observed in their construction. As an overall conclusion of the conference Prof. Fritz Schweingruber plead for an integration of dendrochronology and wood anatomy to improve their mutual performance.

The editors of the TRACE proceedings 2006 are delighted to present 34 extended abstracts of tree-ring studies that were communicated during the conference. We would like to thank the reviewers for their valuable comments on the first versions of these manuscripts. Furthermore, the organisers would like to thank the participants for the lively discussions and enthusiastic exchange of ideas.

Also, the contribution of our sponsors, Fund for Scientific Research of Flanders, the Belgian Science Policy, Olympus Belgium and RinnTech, was highly appreciated. We hope to meet you again very soon!

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Anouk Verheyden
Hans Beeckman
Holger Gärtner
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SECTION 1

CULTURAL HERITAGE

Dendrochronological proof of origin of historic timber – retrospect and perspectives

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Introduction

The dendrochronological proof of origin of historic timber – better known as 'dendro-provenancing', had been developing rather unnoticed before it took shape as a new sub-field of tree-ring research. We do not know who used the term 'dendro-provenancing' for the first time. The fact, however, that timber in the past was transported over long distances, was suspected already 40 years ago. A very early, if not the earliest, report was on the timber used for building a cog excavated in Bremen/Northern Germany in the beginning of the 1960s. The tree-ring analysis was made by Liese and Bauch (1965). The origin of the oaks used was dendrochronologically determined to be from the upper reaches of the river Weser some 400 km south of the shipyard in Bremen. They were felled around 1385 AD. However, in the 1960s only two reference chronologies for oak existed in the whole of Europe. One was built by Hollstein (1970). The other one has been assembled since the 1930s by Bruno Huber and his group in Munich (Huber, Giertz-Siebenlist 1969); its 14th century part was covered by building timber from the source area of the river Weser and its upper tributaries. It cannot be taken for granted that on the basis of the present-day, dense chronology network the origin of these timbers for the cog would be confirmed. The dating, however, is indisputable.

In the following, we will first exemplify the history of development of 'dendro-provenancing' and then offer some thoughts for further discussion and research.

Retrospect

Accidental indications of far-distant timber transport

The earliest dendrochronologically proven long-distance timber transport in Central Europe is reported for the Viking-time place of trade Hedeby in Northern Germany, the early medieval settlement of Dorestad in the Netherlands, and the Slavonic settlement Wolin in Poland in the estuary of the river Odra. All three settlements were founded around 800 AD and located close to waterways (Fig. 1). However, the timbers were mostly not intentionally imported but they originally served as containers (Fig. 2a) for the transport of various liquids and solid goods. At their destinations, these barrels were re-used as enclosures for wells and for this purpose put deep into the ground down to the groundwater level and hence survived until the present time (Fig. 2b). In the case of Hedeby, the wooden wells were made of Silver fir, a tree species which was not naturally growing so far north (Fig. 3). Hence, wood anatomy provided the first evidence for a far-distant timber transport (Behre 1969). Only recently,

these barrels were dendrochronologically dated with the Southern German fir chronology (M. Friedrich, Stuttgart-Hohenheim University, pers. comm.). For Dorestad, the question of the origin of the oak timber was dendrochronologically answered as early as in 1975 by Eckstein, van Es and Hollstein by comparing the tree-ring series with the then already existing network of local chronologies along both sides of the river Rhine, established by Hollstein (1970), showing the highest similarity with chronologies at the middle reaches of the Rhine near Mainz (Fig. 4). In Wolin, according to T. Ważny (Toruń University, pers. comm.), imported timber was indeed found in the construction of a pagan temple, dated to 965/966 AD (Fig. 5). It presumably came from the middle reaches of river Odra. Apparently, after a 150-year intense development in Wolin, high-grade domestic construction timber was no longer available in sufficient quantities.
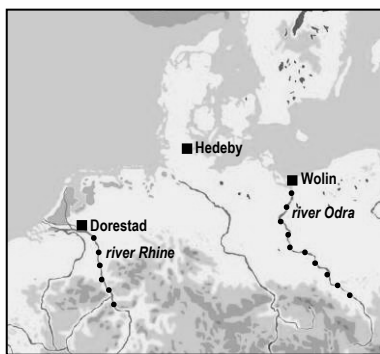
Figure 1: Location of the early medieval settlements Dorestad, Hedeby, Wolin
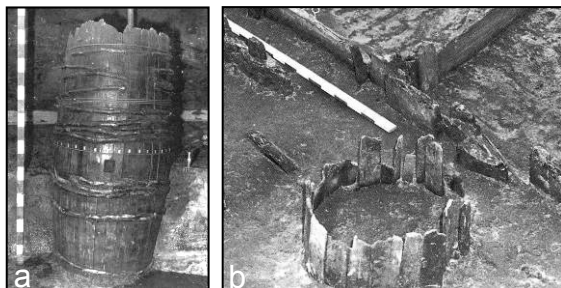
Figure 2: Hedeby; a: barrel made of Silver fir, b: in secondary use as enclosure of a well. Photo: Arch. Landesmuseum, Schleswig

Figure 4: Location of Dorestad and of 24 site chronologies for comparison (Eckstein et al. 1975)
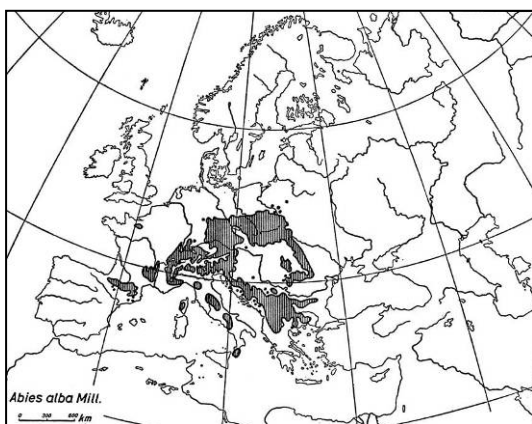
Figure 3: Natural distribution of Silver fir (Dengler 1971)
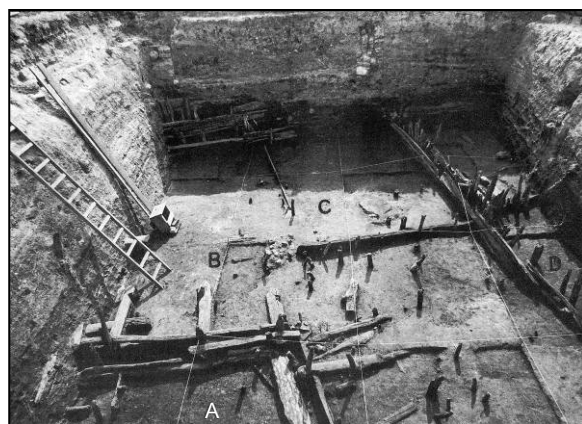
Figure 5: Wolin; excavated area of the temple. A: temple, B: yard, C: barn (Filipowiak 1992)

Baltic timber in Western Europe – a long story

After these early, but sporadic and accidental indications of timber transport, the determination of the origin of historic wood moved into the focus of interest only after dendrochronology had started to be applied in art-history (Bauch, Eckstein 1970). It turned out that the Dutch and Flemish painters, such as Rubens, Rembrandt and many others, but also the early German painters (Fig. 6), up to around 1650 AD painted on oak panels of at least two provenances with completely different tree-ring characteristics.
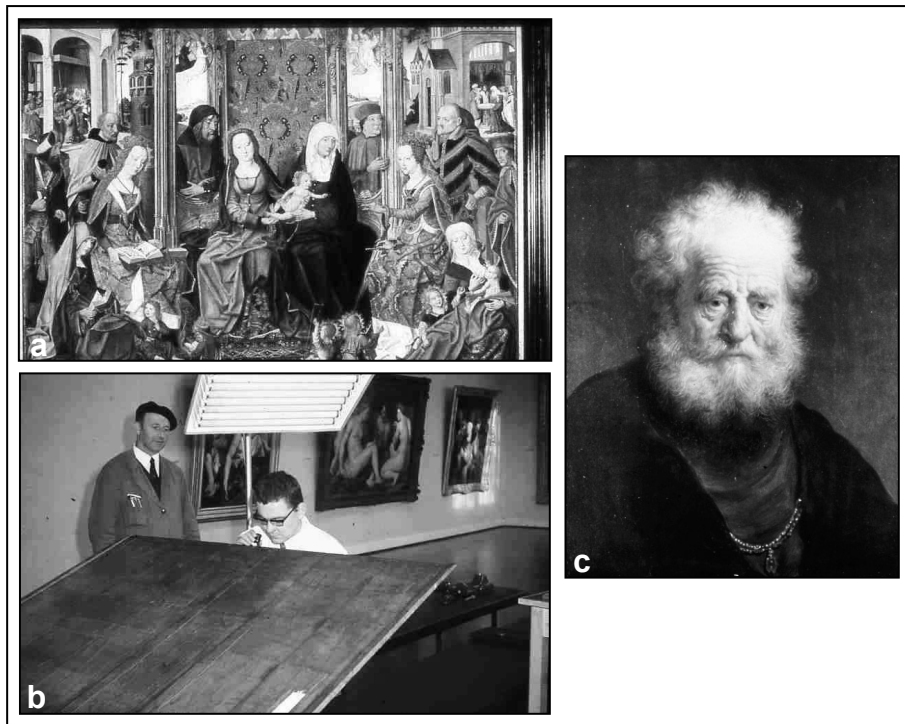
Figure 6: Paintings on oak boards; a: Gothic painting of the Cologne School, unknown German master (early 15th century), b: Rubens, c: Rembrandt, both 1st half of 17th century

One group represented timber of obviously Dutch/West German origin and, because no Dutch tree-ring chronology was then in existence, was dated doubtlessly with the two German reference chronologies, mentioned before (Huber, Giertz-Siebenlist 1969, Hollstein 1970). The tree-ring series of the other group, many of them covering more than 300 years, were assembled to a 400-year 'floating chronology', which for the time being had to remain undated. Few panels even contained wood of both provenances (Eckstein, Bauch 1974). After 1650, the painters preferred either more and more canvas or used oak panels of Dutch/West German origin or of other tree species, sometimes even from tropical trees, such as teak (Bauch, Eckstein 1981). From these observations, we deduced that the woodland, where the trees included into the hitherto undatable 'floating chronology' have grown up, was exploited or no longer accessible. Since the tree-ring characteristics of that group also occurred in wood used by English painters of the 16th and 17th century (Fletcher 1978), a woodland on both sides of the British Channel, which at present is entirely deforested, was assumed in a first approach. The alternative assumption that an import of wood from a far-distant provenance could have continuously taken place for over 200 years was hard to

imagine. Only when the same situation as in the Netherlands was experienced in Lübeck, a Hanseatic and harbour town at the Baltic Sea, did this possibility become more and more attractive. Within one huge wooden complex, the Triumphal Cross and the Wooden Screen in the Cathedral (Fig. 7) created by the famous Northern European wood-carving workshop of Bernt Notke (1440-1509), we were confronted with two clusters of timber, very distinctly different regarding their tree-ring pattern. Whereas the more than 2 m tall sculptures were dated by a local reference chronology, all plank-shaped wood parts remained undatable for the time being although they matched very well with each other and amazingly also with the floating chronology of Dutch and Flemish paintings on oak panels (Eckstein 2005).

Figure 7: Lübeck/Germany, Cathedral; Triumphal Cross and Wooden Screen by Bernt Notke

The same was true for the ornamental wooden lining of the large organ in the Jacobi church and for the painted wooden boards of the screen in the Holy Ghost Hospital, both in Lübeck. Many of these plank-shaped wooden parts originated from 200-300 years old, slow-grown oak trees. But it was hardly conceivable that wood with such properties had grown somewhere in a Western European coastal area.

On the track of the mystery
The mystery was solved only 15 years after the onset of art-historical dendrochronology, when Baillie (1984) suspected that the source area for art-historical timbers could have been somewhere in the Baltic, and T. Ważny, then in Warszawa and now in Toruń, in close cooperation with the Hamburg laboratory assembled a regional oak chronology for the Gdańsk area/Northern Poland (Eckstein et al. 1986). The impact of this co-called Gdańsk/Pomerania chronology on 'dendro-provenancing' will be briefly illustrated. In Figure 8, the coastal area of the Southern Baltic Sea including the locations of Lübeck and of the approximate areas of regional reference chronologies are shown.
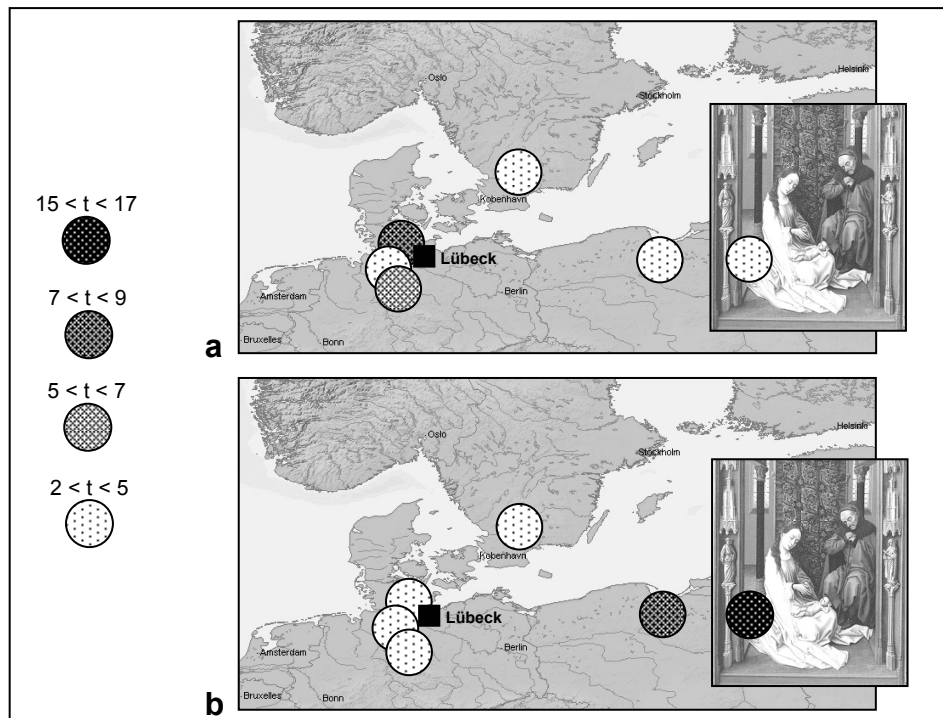
Figure 8: Lübeck/Germany, Cathedral, Triumphal Cross and Wooden Screen; comparisons of the mean curves with regional chronologies and with a chronology of Dutch/Flemish panel paintings (insert: R. van der Weyden, part of an altarpiece, Berlin), a: 5 large sculptures (170 tree rings), b: 20 screen-boards (313 tree rings)

According to this map, the wood for the five huge sculptures of the Triumphal Cross is confirmed to be of domestic origin (Fig. 8a), whereas the wooden parts of the Screen originate somewhere from the Polish/Baltic region (Fig. 8b). It is exciting that there is even a much higher similarity with the tree-ring chronology assembled from Dutch and Flemish panel paintings. The area where these oaks had been growing is not yet doubtlessly identified; it was definitely in the area east of the river Odra. Because of the high intercorrelation between the tree-ring series of this cluster, the woodland in question was very likely rather narrowly limited. It has nowadays become common practice to initially try to date art-historical oak wood with Polish/Baltic reference chronologies (e.g., Lavier, Lambert 1996, Bonde et al. 1997, Mills, Crone 1998, Klein, Esteves 2001, Ważny 2002, 2005, Läänelaid, Nurske 2006).

The part of the Hanseatic League in this puzzle

Meanwhile, the importance of the Hanseatic League, having organized and controlled most of the trade, including the timber trade, all over Northern Europe is well-known among European dendrochronologists. Gdańsk was one of the most important export harbours (Ważny, Eckstein 1987). The river Vistula and its tributaries, reaching even into the today's West Ukraine, made the large Polish forests accessible for exploitation. The oaks were felled, cleaved, floated down the river (Fig. 9a) to the harbour at the Baltic Sea coast (Fig. 9b) where the timbers were loaded on sea-going ships and brought to Lübeck or through the Danish Sound to the trading centres in Western Europe, even up to Portugal (Fig. 9c).
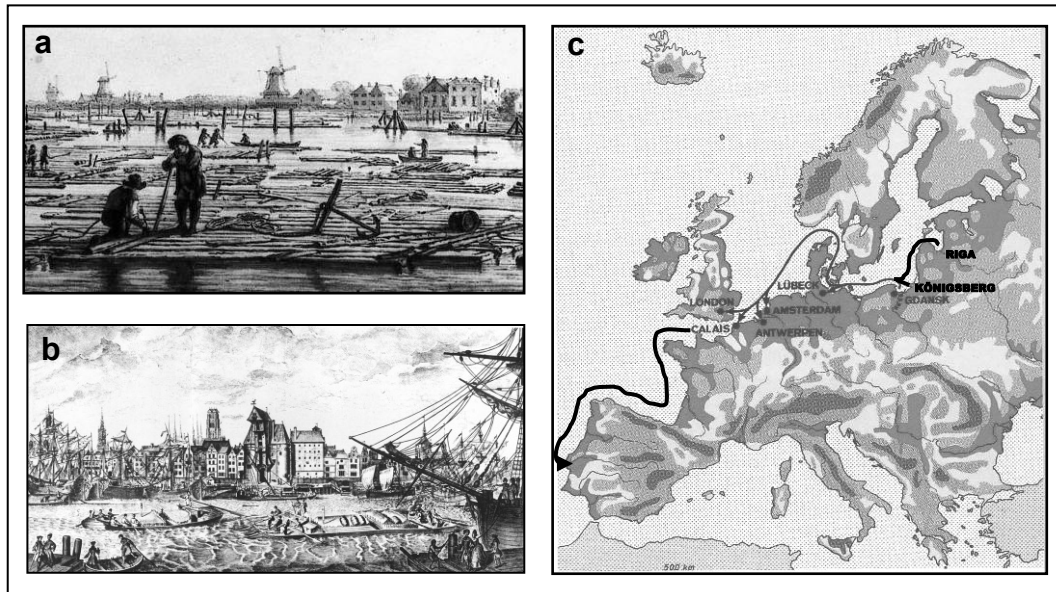
Figure 9: Trade of Baltic oak; a: rafting on a river (Scheifele 1996), b: Gdańsk habour (Jakrzewska-Śnieżko 1985), c: dendrochronologically derived trade routes

Around 1650, toward the end of the Thirty Years War, the power of the Hanseatic League had declined and the traditional trade routes from east to west, having worked well for several centuries, became disrupted. In consequence, high-grade Polish/Baltic oak wood for the panel production was not longer available on the Western European market.

Later on, other harbour towns farther east became more important than Gdańsk. Western European countries imported timber which is described in documents as 'righolt' (in English 'Riga timber') from the area of present-day Latvia; in particular, so-called Riga-pine was used for ship masts. Riga is located at the river Daugava which was an important trade route connecting Eastern and Western Europe. According to Zunde (1999), the timbers exported via Riga had been felled in increasingly larger distances over the course of time. In the 16th century it was in the present-day Eastern Belarus, in the 18th century the farthest eastward point was almost 1800 km from Riga, far beyond Moscow.

The reasons for this high and continuous timber transport mainly from east to west during the Middle Ages and early modern times have recently been summarized by Haneca et al. (2005) for the Netherlands and Northern Belgium. But the compiled facts and assumptions certainly apply to a much wider geographical area in Western Europe, because the increasing demographic evolution and in consequence the anthropogenic pressure on the woodlands were general phenomena with the consequence that the local forests could no longer cope with the steadily rising demand for high quality timber. The remaining local forests were mainly used for timber of less demanding quality, for firewood and for the production of acorns as fodder for animal husbandry (Fig. 10).

For the trade with high-quality timber between remote regions, timber assortments had to be defined (Ważny 2005) and agreed on by the partners involved in the business, because a buyer in Western Europe could not travel to the Baltic each time he wanted to order a certain quantity and quality of timber. The highest timber quality was represented by an assortment

called 'wainscot'. A few years ago, a cargo was lifted from a sunken ship from the bottom of the Baltic Sea near Gdańsk (Fig. 11). This was a unique occasion in that the definition and properties of wainscot written down in archives could be physically inspected. The ship is dated to 1398 AD and the wooden cargo to 1405-1408 AD (Ważny 2001). These wainscot boards are 236-252 cm long, 24-30 cm wide and 1.5-3.0 x 4.0-6.0 cm thick; that means, their cross-sections are trapeze-shaped (T. Ważny, pers. comm.).

Figure 10: November scene from Brevarium Grimani, around 1500, Venice

Figure 11: Gdańsk/Poland; wainscot lifted up from a sunken ship. Photo: T. Ważny in Centralne Muzeum Morskie, Gdańsk

To convey a rough impression from the amount of timber having passed through the Danish Sound, two figures may be helpful (Fig. 12). They are taken from the 'Dutch Sound Register', recorded by Dutch superintendents. This register indicates the date, name and origin of a shipper, the port of origin and of destination as well as the main cargo. Such data of 50,000 ships have been digitized for a 'Historical Information System' by Kroll and Labahn (2004). There is another documentation, the 'Danish Sound Duties', a tax record from the end of the 15th to the mid-19th century of all ships passing the Sound.
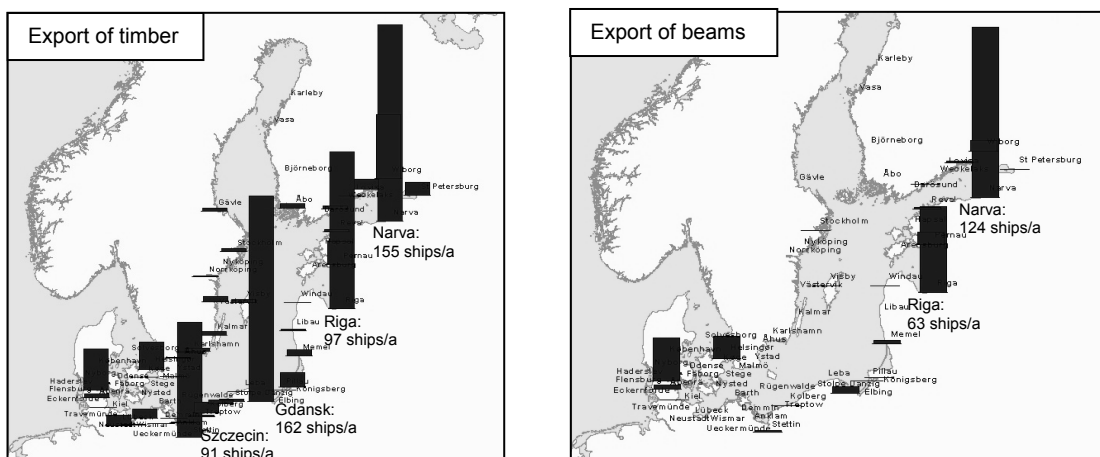
Figure 12: Dutch Soundregister for 1751 – 1753 (Kroll, Lahbahn 2004)

Perspectives

In medieval and early modern times, the long-distance transport of heavy and bulky goods, such as timber, was carried out not only across the sea but similarly also on the widely ramified European rivers (Fig. 13).

Figure 13: Early medieval trade routes in north and east Europe (Jankuhn 1963)

Meanwhile, dendrochronologists have repeatedly provided the physical evidence that timbers were moved over considerable distances in considerable quantities (e.g., Groves 1995, Levanič et al. 2001, Jansma et al. 2004, Wrobel 2004, Eißing 2005). Against this background, the question has now to be put forward whether we know the origin of the timbers included in all our composite standard chronologies, which we use as dating tools and climate archives. Moreover, for 'dendro-provenancing' we are not sure either whether the reference chronologies used for the determination of the origin of a timber really represent the region we assume. Actually, it cannot even be taken for granted that the Gdańsk/Pomerania chronology is exclusively made of Northern Polish oaks although the buildings included are located in Gdańsk and surrounding villages. The oaks may, at least partly, have been floated down the river Vistula from southeast Poland or from the present-day West Ukraine.

Is there a risk for circular reasoning? This suspicion is not ungrounded. Let us consider several regional oak chronologies, split them into four 150-year time windows (Fig. 14) and compare them with the Gdańsk/Pomerania chronology. In the time-window 1960 to 1811, all chronologies are composed of the tree-ring series from living trees whose origin can not be disputed; all t-values are, as expected, less than 5. For the time-window 1700 to 1551, there are rather high similarities between Gdańsk/Pomerania and Mecklenburg/Western

Pomerania, Hamburg area, and inner Lower Saxony (chronology established by H. H. Leuschner, Göttingen/Germany); accordingly, it may be concluded that timbers imported from North Poland were unconsciously included into these three chronologies. For the time-window 1500 to 1351, there again is apparently a Polish influence, this time in the chronologies of Mecklenburg/Western Pomerania, Lower Saxony (coastal area), and Southern Sweden (chronology established by T. Bartholin, then Lund/Sweden). In the time-window 1300 to 1151, the t-values for Lower Saxony (interior) and Denmark are around 8, and for Mecklenburg - Vorpommern and Lübeck even close to 11. The respective part in the Lübeck chronology was assembled from tree-ring series of the roof construction in the Holy Ghost Hospital, built in the 1280s very likely with timber from Northern Poland.
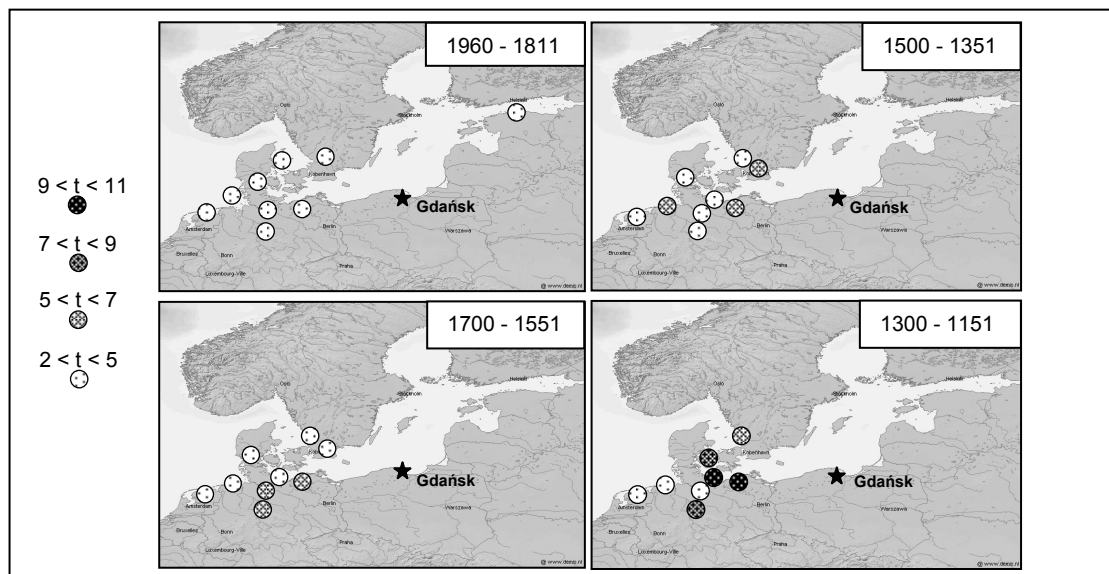
Figure 14: Comparison of the Gdańsk/Pomerania oak chronology with reference chronologies

The same approach is applied to pine chronologies around the Baltic Sea (Fig. 15). The point of reference is the island of Gotland. The Gotland chronology has proven very useful for dating objects from Northern Germany up to Estonia. The chronology part made from living trees, 1960 to 1811, is distinctly similar to the pine chronologies in Lithuania and Estonia. In the time-window 1700 to 1551, however, the Gotland chronology is highly similar to most other chronologies on the map. By no means can this be taken as evidence for a timber distribution from Gotland around the Baltic Sea. Simply the fact that the Gotland chronology, assembled in 1988 by T. Bartholin, existed earlier than the others made the Gotland chronology an acknowledged reference with the consequence that a timber export from Gotland to other regions was sometimes hastily assumed. The Gotland chronology has, without any doubt, a strong dating signal but no reliable signal for 'dendroprovenancing'.
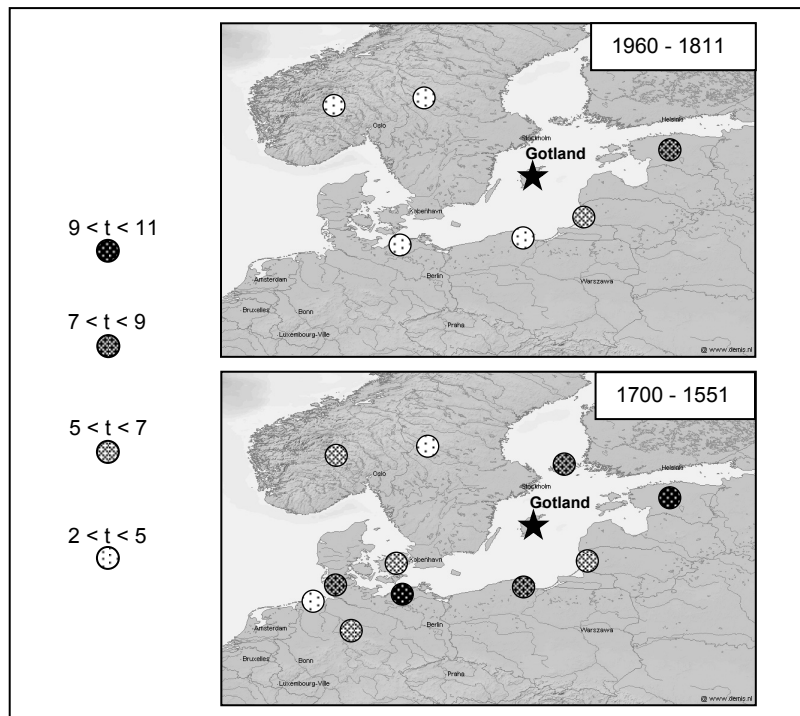
Figure 15: Comparison with the Gotland pine chronology with reference chronologies

Conclusions

To conclude, a quite dense network of regional and supra-regional composite chronologies has meanwhile evolved throughout most of Europe. But these chronologies were primarily established as dating tools. For 'dendro-provenancing', many of them will have to be dismantled and re-assembled on the basis of new criteria whose suitability has still to be discussed. Moreover, dendrochronology should be established and supported in countries of Eastern Central Europe, such as in Belarus and in the Ukraine, where useful new information can be expected. An indispensable, European-scale, approach has to deal with data sets from living trees; many of them already exist, more of them will have to be added, in order to assess the reach of the dominant signal of a tree population in dependence on the provenance. In this context, one has to take into account that the spatial extension of a tree-ring signal elaborated with living trees may not be stable in time and therefore will not necessarily reflect the situation in medieval or early modern times. Last but not least, historians and archivists should be involved and encouraged to open up and compile written sources, archived particularly between Riga and Amsterdam but also elsewhere, which remain otherwise inaccessible for the dendrochronological community.

Acknowledgements

References

Baillie, M.G.L. (1984): Some thoughts on art-historical dendrochronology. *J. of Archaeological Science 11:* 371-393.

Bauch, J., Eckstein, D. (1970): Dendrochronological dating of oak panels of Dutch seventeenth century paintings. *Studies in Conservation 15*: 45-50.

Bauch, J., Eckstein, D. (1981): Woodbiological investigations on panels of Rembrandt paintings. *Wood Science and Technology 15*: 251-263.

Behre, K.-E. (1969): Untersuchungen des botanischen Materials der frühmittelalterlichen Siedlung Haithabu (Ausgrabungen 1963-1964). *Berichte über die Ausgrabungen in Haithabu 2*: 7-55.

Bonde, N., Tyers, I., Ważny, T. (1997): Where does the timber come from? Dendrochronological evidence of the timber trade in Northern Europe. In: *Sinclair, A., Slater, E., Gowlett, J. (eds.), Archaeological Sciences. Proc. of a conference on the application of scientific techniques to the study of archaeology. Liverpool, Great Britain, July 1995. Oxbow Monograph 64*: 201-204.

Dengler, A. (1971): Waldbau. Vol. 1, Paul Parey, Hamburg, Berlin. 229 p.

Eckstein, D. (2005): Wood science and art history – interdisciplinary research illustrated from a dendrochronological point of view. In: *Van de Velde, C., Beeckman, H., Van Acker, J., Verhaeghe, F. (eds.), Constructing wooden images. Proc. of the symposium on the organization of labour and working practices of Late Gothic altarpieces in the Low Countries. Brussels, Belgium, Oct. 25th-26th, 2002. VUB Press, Brussels*: 19-26.

Eckstein, D., Bauch, J. (1974): Dendrochronologie und Kunstgeschichte – dargestellt an Gemälden holländischer und altdeutscher Malerei. *Mitt. der Deutschen Dendrologischen Gesellschaft 67*: 234-243.

Eckstein, D., van Es, W., Hollstein, E. (1975): Beitrag zur Datierung der frühmittelalterlichen Siedlung Dorestad, Holland. *Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek 24*: 165-175.

Eckstein, D., Ważny, T., Bauch, J., Klein, P. (1986): New evidence for the dendrochronological dating of Netherlandish paintings. *Nature 320*: 465-466.

Eißing, T. (2005): Dendro-provenancing in Thuringia and the southern part of Saxony-Anhalt. *Abstract Book of the International Conf. of Dendrochronolgy EuroDendro. Viterbo, Italy, Sept. 28th – Oct. 2nd, 2005*: 17.

Filipowiak, W., Gundlach, H. (1992): Wolin – Vineta. Hinstorff Verlag, Rostock. 137 p.

Fletcher, J. (1978): Tree-ring analysis of panels, paintings and chests. In: *Fletcher, J. (ed.), Dendrochronology in Europe. BAR International Series 51*: 303-306.

Groves, C. (1995): The dating and provenancing of imported conifer timbers in England: the initiation of a research project. In: *Sinclair, A., Slater, E., Gowlett, J. (eds.), Archaeological Sciences. Proc. of a conference on the application of scientific techniques to the study of archaeology. Liverpool, Great Britain, July 1995. Oxbow Monograph 64*: 205-211.

Haneca, K., Ważny, T., Van Acker, J., Beeckman, H. (2005): Provenancing Baltic timber from art historical objects: success and limitations. *J. of Archaeological Science 32*: 261-271.

Hollstein, E. (1970): Dendrochronologische Untersuchungen an Hölzern des frühen Mittelalters. *Acta Praehistorica et Archaeologica 1*: 147-156.

Huber, B., Giertz-Siebenlist, V. (1969): Unsere tausendjährige Eichenchronologie durchschnittlich 57 (10-159) fach belegt. *Sitzungsberichte Österr. Akad. Wiss., Mathem. Naturwiss. Klasse, Abteilg. 1, 178*: 37-42.

Jakrzewska- Śnieżko, Z. (1985): Gdańsk w dawnych rycinach. Wrocław-Warszawa-Kraków-Gdańsk-Lódz. Z.N. im. Ossolińskich: 148 p.

Jankuhn, H. (1963): Haithabu. Karl Wachholtz Verlag, Neumünster. 292 p.

Jansma, E., Hanraets, E., Vernimmen, T. (2004): Tree-ring research on Dutch and Flemish art and furniture. In: *Jansma, E., Bräuning, A., Gärtner, H., Schleser, G. (eds.), Tree rings in archaeology, climatology and ecology, Proc. of the Dendrosymposium. Utrecht, The Netherlands, May 1st – 3rd, 2003. Schriften des Forschungszentrums Jülich, Reihe Umwelt/Environment 44*: 139-146.

Klein, P., Esteves, L. (2001): Dendrochronological analysis in Portuguese panel paintings. In: *van Schoute, R., Verougstraete, H. (eds.), La Peinture et le Laboratoire - Procédés, Méthodologie, Applications. Peeters Verl., Leuven*: 213-220.

Kroll, S., Labahn, K. (2004): Die 'niederländischen Sundregister' als Quelle für den Fernhandel der Hafenstädte des Ostseeraumes während des 18. Jahrhunderts. In: *Braun, F., Kroll, S. (eds.), Städtesystem und Urbanisierung im Ostseeraum der Frühen Neuzeit. Beiträge des wissenschaftlichen Kolloquiums. Wismar, Germany, Sept. 4th – 5th, 2003. Geschichte - Forschung und Wissenschaft 5*: 294-312.

Läänelaid, A., Nurske, A. (2006): Dating of a 17th century painting by tree rings of Baltic oak. *Baltic Forestry 12*: 117-121.

Lavier, C., Lambert, G. (1996): Dendrochronology and works of art. In: *Dean, J., Meko, D.M., Swetnam, T.W. (eds.), Tree rings, environment and humanities. Proc. of the International Conference, Tucson/Arizona, 17th – 21st May, 1994. Radiocarbon*: 543-556.

Levanič, T., Pignatelli, O., Čufar, K. (2001): A regional larch chronology of trees and historical buildings from Slovenia and Northern Italy. *Dendrochronologia 19*: 221-229.

Liese, W., Bauch, J. (1965): Neue Beiträge zum Fund der Bremer Kogge. Das Alter der Bremer Kogge. *Bremer Jahrbuch 50*: 38-43.

Mills, C., Crone, A. (1998): Tree-ring evidence for the historic timber trade and woodland exploitation in Scotland. In: *V. Stravinskienė, R. Juknys (eds.), Dendrochronology and environmental trends: Poc. of the International Conference EuroDendro. Kaunas, Lithuania, June 17th – 21st, 1198. Vytautas University, Kaunas*: 46-55.

Scheifele, M. (1996): Als die Wälder auf Reisen gingen. Braun Buchverlag, Karlsruhe. 368 p.

Ważny, T. (2001): Dendrochronologia obiektów zabytkowych w Polsce. Muzeum Archeologiczne w Gdansku: 132 p.

Ważny, T. (2002): Baltic timber in Western Europe – an exciting dendrochronological question. *Dendrochronologia 20*: 1-8.

Ważny, T. (2005): The origin, assortments and transport of Baltic timber. In: *Van de Velde, C., Beeckman, H., Van Acker, J., Verhaeghe, F. (eds.), Constructing wooden images. Proc. of the symposium on the organization of labour and working practices of Late Gothic altarpieces in the Low Countries. Brussels, Belgium, Oct. 25th-26th, 2002. VUB Press, Brussels*: 115-126.

Ważny, T., Eckstein, D. (1987): Der Holzhandel von Danzig/Gdańsk - Geschichte, Umfang und Reichweite. *Holz als Roh- und Werkstoff 45*: 509-513.

Wrobel, S. (2004): Dendrochronologie – Datierung und Herkunft von Bauholz in der Hansestadt Wismar. In: *Braun, F., Kroll, S. (eds.), Städtesystem und Urbanisierung im Ostseeraum der Frühen Neuzeit. Beiträge des wissenschaftlichen Kolloquiums. Wismar, Germany, Sept. 4th – 5th, 2003. Geschichte - Forschung und Wissenschaft 5*: 173-183.

Zunde, M. (1999): Timber export from old Riga and its impact on dendrochronological dating in Europe. *Dendrochronologia 16*: 119-130.

The evolution of roofing in Northern France and Belgium from the 11th to the 18th century as revealed by dendrochronology

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Henri Deneux (1874-1969), brilliant architect-restorer of monuments in Reims after World War I, devoted most of his life to the study of the roof frameworks in northern France (Deneux 1927). Given his interest in new techniques, dendrochronology would probably have been more quickly applied to the monuments of early Europe if this architect of historic monuments had met the astronomer Andrew-Ellicott Douglass, pioneer in the analysis of tree-rings (Webb 1983). In any case, dendrochronology was applied for the first time in France only at the end of the 1960s. At present, the gathering of results of laboratory analyses, both public and private, has permitted the establishment of a database supporting an accurate and precise chronology which allows the work of Deneux to be viewed in a new light. For the first time in France and Belgium, a substantial effort was dedicated to the collection of a maximum of dendrochronological analyses in the aim of creating a synthesis of the history of architecture (Hoffsummer *et al.* 2002). We have profited both from the experience obtained from the studies of the monuments in Laon (Hoffsummer & Plouvier 1995) and the methodology developed as a result of the analysis of roof construction in Wallonie (Hoffsummer 1989, 1999).

This undertaking does not break new ground only with the use of dendrochronology. The approach is multidisciplinary, despite the inherent difficulties involved in the work of a team uniting historians, architects, art historians and scientists. In total, the corpus includes around 300 roofs of which a third have been analysed by dendrochronology. Deneux had observed around 500, but only a small proportion was described and illustrated in his article. Benefiting from our previous research, we were able to extend Deneux's territory to include a part of Belgium. There were two reasons for this: rural architecture was more often studied in Wallonie and the Escaut and middle Meuse basins and this territory covers, like the Lower Rhine, a transition zone between the Latin and Germanic worlds. Religious examples chiefly contributed to the collection for the period studied, from the 11th to 19th centuries, *in situ* roof frameworks of rural or common medieval architecture being more difficult to study. Archaeological excavations sometimes compensate for these lacunae by providing some data, at least in reference to the general organisation of wood construction and the disposition of load-bearing structures (Bans 1995).

The domain of carpentry is obviously not limited to ridge roofs. Other aspects are also explored, including half-timber construction, belfries, spires. The importance of carpentry is also underestimated in the construction of workplace or war machinery, scaffolding, arches. We are aware of such aspects but we consider that the systematic study of roofs has created

a general canvas whose broad characteristics can be applied to the analysis of other carpentry works.

The synthesis of dendrochronological analyses of a hundred or so roofs has permitted the development of an original database concerning the growth of oak during the last millennium (Lambert *et al.* 1996, Lambert & Lavier 1991). Certain dates on wood remain difficult, if not impossible. It would be mistaken to conceal these difficulties at the risk of discrediting the method. The tree is a living thing whose growth is affected by different factors, more or less striking. Among them, climate induces a characteristic signal which permits the correlations which can lead to a date. If the signal is cloudy, or completely dominated by the environment, the correlations become more sensitive. The action of man on the forest, either via clearing or massive deforestation, also has an impact which is more or less detectable in the sequence of tree rings (Lambert 1996, 1998). Of the hundred studies presented here, several present a substantial percentage of undated wood and three did not succeed at all. In most cases, a higher number of samples collected from a homogeneous structure increases the performance of results by widening the possibility of comparison between trees. There must be a substantial number of beams from which to take samples, which is not always available in small roofs. The "user" of dendrochronological dates must be aware of these limits.

On the other hand, the notion of "frame of reference" develops as a result of new computer advances by which an increasing number of comparisons between samples can be compared more rapidly. Little by little, it is becoming possible to create more coherent tree groups, independent of the traditional frames of reference for the Bourgogne, eastern France, the Paris or Meuse Basins, to cite only the most useful in the region studied. While these standard curves remain valuable for dating, new correlations of their components will lead to other research possibilities, in particular for study of the climate (Lambert 2002).

With a trace of bark, the dendrochronological date can be precise to the year or half-year. The use of green wood in architecture has been amply demonstrated, by both historians and dendrochronologists (Mille 1993). The dating of wood by tree rings thus has significance for the history of architecture. These analyses must be integrated into a global approach to analysis of a building and not sampled randomly. The archaeological study of the roof is crucial. The re-use, underpinnings and repairs often complicate the interpretation (Hoffsummer 2002, 2003). This is the case for the cathedral of Beauvais. To interpret the results correctly, the systematic reading of assembly marks is fundamental to verify the coherence of a structure. Fairly rudimentary or even non-existent in the roofs of the 12th century, assembly marks become more systematically used around 1220 and the use of simplified Roman numerals became widespread. Other traces of woodworking are related to transport, when it was floated: special signs identifying the cargo or the destination, perforations for the ties connecting the logs into rafts. We foresee the possibility of weaving the links between these "field" observations and the history of transport or commercial flow.

The modern forest is quite different from that of the Middle Ages. The pressure of man increased considerably beginning in the 16th century, as much to collect wood for architecture as for naval construction, which had different needs. The forest was also plundered for all

kinds of uses: kindling, industrial wood, wood for heat. Historians still have much work to do to help us penetrate this forest "reservoir" although the subject has been approached by several recent studies. These illustrate the difficulty of using accounting or judicial documents to answer only apparently simple questions, such as the development of French forest cover or the commerce of wood for construction. Dendrochronologists, perhaps, for the moment, have more answers, by showing certain displacements of wood over long distances.

The difficulty of procuring wood in the 16th century is a reality that the simple typological examination of roofs demonstrates. Obviously, roofs built by the most rich were not limited by this constraint. The great roofs of modern times at Reims, Paris or Troyes are always equipped with rafter-truss couples, which are lacking in the majority of other roofs of the same period.

The typological classification of roofs is a method which appears heavy and thankless. Nevertheless, at the first stage, it creates homogeneous groups. The simple visual comparison of samples at a constant scale is quite productive. We realise the great diversity in solutions to building a simple pitched roof. Among 300 examples, we can identify around 50 different types of structures. Each is an entity in itself that belongs to a very hierarchical corpus. Aided by dendrochronological analyses, and the chronology in general, we can observe these entities and place them in the more general context of the history of architecture. The evolution of roofs, under the form of working hypotheses, changes as a function of changing techniques or the effects of economic constraints.

The oldest roofs are relatively simple and low, with a fairly shallow incline (30-40°) resting on a series of rafter couples attached to close tie beams. Others, but very rare in the region studied, have trusses and purlins beginning in the 12th century. The first king posts do not appear before the end of the 12th century. Half timbered joint is more often used than tenon-mortise joints.

Intense times then mark the evolution of roof frameworks. From the end of the 12th century to 1220, certain joints were perfected, the incline of the roof became steeper (45-50°) and the carpenters launched the first frames divided in bays by the alternation between the tie beam trusses and trusses with sole pieces. These frames covered the first intersecting ribs whose extrados passes the top of the walls. In certain churches at the beginning of the 13th century, the reduction in the number of tie beams favoured another form of covering, lighter than the stone vault and more elegant than the simple ceiling: the wooden vault or "wainscot vaulted ceiling". This method was applied in all "Gothic" edifices from the 13th to 16th century. Other churches, like Saint Peter's of Montmartre, and especially those of the Rhine-Meuse region, however, remained loyal to the ceiling system. The period 1180-1220 was also marked by the use of oblique reinforcements – scarves and struts – in addition to traditional posts and collar beams. Could this have been part of a general current of thought in northern Europe? We find scarves in churches of Norwegian wood in the 12th century as well as in English roofs during the 12th-13th centuries (Ahrens 1981). The heightening of the choir of Notre Dame in Paris, around 1220, marks the apogee of this period of new ideas with a roof which overhangs vaults as high as the walls.

The development of the 13th century mirrors that of the carpenters. In 1220-1300, the roofs of grand monuments were richly covered in carefully attached materials which allowed steeper inclines (60°). They were thus high (often 10 to 12 meters) and wide (sometimes 15 meters), due to the increasing mastery of frame construction in spite of considerable wind loading. The nature of the structures joined together many thick rafters, one piece elements reaching 12, 15, 18 meters, linked in groups of ten. Solutions for triangulation and longitudinal bracing are varied; the sides were reinforced with longitudinal braces or purlins. The king post is no longer the only suspension piece of the tie beam: while it was extremely long, it was supported by long post brackets which formed a stirrup at the base. Consoles leaning on the flar walls could complete the plan of these large roofs. The ridge piece was added fairly early to certain monuments of Bourgogne, at Auxerre and Tonnerre.

In-depth studies of the roofs of Beauvais and Amiens shed new light on the history of two prestigious cathedrals. The age of the roof of the choir of Beauvais was unknown. We now know that the original framework, built soon after 1257, suffered in the upper parts of the church during the violent storm in winter 1284-85 but we also know that it held. The underpinnings of pillars, buttresses and stained-glass windows were made under its protection. The roof had been reinforced and slightly modified over time. Some oaks were cut down at this time, in 1284-85, that is, the same year as the trees for the choir roof at Amiens. The coincidence of the date forces comparison between these two edifices, some ten kilometres apart. The roof framework at Amiens is much lighter, as if the accident at Beauvais had incited the master builders to derive some insight from the misfortunes of their neighbours (Murray 1997, Taupin and Hoffsummer 2002). Much knowledge coexisted, besides, at this period. The construction sites open the same year at Soissons and Liège adopted other methods although they still shared the use of close coupling of long rafters. The techniques of bracing and the idea of principal trusses varied from one region to another. Amiens did not have collar ties in the principal trusses; the cathedral at Soissons did but lacked struts. The Sainte-Croix church in Liège belonged to the northern school and used large crossbeams inspired by the crucks.

These regional characters are observed when we compare the sickroom of Tonnerre with that, much further to the north, of the abbey of Bijlok at Gent, both particularly imposing, from 15 to 20 meters wide. The structure of the crossbeams at Gent, which resembles a truncated principal truss, recalls the cruck construction, while the roof at Tonnerre only amplifies the structure of the truss with tie beam and king post. The rural world escapes our analysis, due to lack of evidence. We know only that the carpenters had to demonstrate their abilities in other categories of buildings, such as barns and three-naved covered markets.

Few new ideas emerged during the continuation of the history of carpentry, except for the process of Philibert de L'Orme: his "invention pour bien bâtir à petits bois et à petits frais" (De L'Orme 1561, Perouse de Montclos 1991). Although marginal and imposed before the 19th century, the carpentry of joining reveals the principal concern of architects of modern times: to economise the wood. The majority of inventions of the 13th century were copied during the 15th to 18th centuries but procurement constraints for obtaining suitable wood for construction were strongly felt. Rafters, whose sections were continually reduced, were relegated to the

simple role of roofing pieces. In a general manner, the length of the wood diminished, favouring the development of tiered construction, particularly in the northern zone, and mastery of the construction of crossbeams. The reduction in quality of wood also generated solutions for ease of assembly. This is particularly true with respect to the disposition of purlins. In Picardy and the Paris Basin, more rarely in the north, these were simply placed on the cleats attached to the rafters. In the Lower Rhine, the situation was somewhat different, the massive use of resiniferous woods favoured the use of long, regular grained wood. The context is thus different from that of oak regions and this is reflected in the typology. Alsace was also influenced by the construction of crossbeams of Germanic type.

Summarised in a few lines, the development of roof carpentry north of the Loire was particularly rapid in the 13th century (Courtenay 1985, Simpson 1992), building on previous experience gained during the Low Middle Ages, but was then limited by the reduction of resources during modern times and finally cedes its place to metal structures soon after the Industrial Revolution. We can imagine the importance of carpentry knowledge during the 13th century but no text or treatise (Jousse 1627, de la Hire 1702) yields further information to aid in our understanding. The typology and evolution of carpentry are two aspects which allow us to rediscover this knowledge. Mechanics also plays a role. Wood structures pushed by the wind at 50 to 60 m altitude are not rigid and we have to study them according to the closest standards of the behaviour of plane bodies rather than those of reinforced concrete structures. Modern techniques of modelling should yield information not only for the history of architecture but also to aid in choosing the most suitable methods for conservation and restoration. Certain repairs in the framework would be better than the complete replacement of a patrimony record of knowledge of seven centuries, even if it is invisible to the eyes of the typical visitor of a historic monument.

References

Ahrens C. (1982): Frühe Holzkirchen im nördlichen Europa. Hamburg.

Bans J.-C. (1995): Les charpentes médiévales à fermes en France et dans le reste de l'Europe occidentale. In *Le bois dans l'architecture*, Paris, Actes des colloques de la Direction du patrimoine, 14, 180-191.

Courtenay L.-T. (1985): Where Roof Meets Wall : Structural Innovations and Hammer-Beam Antecedents, 1150-1250. *Annuals of the New York Academy of sciences*, 441, 89-124.

De L'Orme P. (1561): Nouvelles inventions pour bien bâtir et à petits frais, Paris, 1561.

De la Hire P. (1702): L'art de charpenterie de Mathurin Jousse, corrigé et augmenté de ce qu'il y a de plus curieux dans cet art et des machines les plus nécessaires à un charpentier, Paris, T. Moette, ed. Léonce Laget, 1978.

Deneux H. (1927): L'évolution des charpentes du XIe au XVIIIe siècle. *L'architecte,* p. 49-53, p. 57-60, p. 65-68, p. 73-75, 81-89.

Hoffsummer P. (1989): L'évolution des toits à deux versants dans le bassin mosan : l'apport de la dendrochronologie (XIe-XIXe siècle). Ph. D. University of Liège.

Hoffsummer P. (1999): Les charpentes de toitures en Wallonie, typologie et dendrochronologie (XIe-XIXe siècle). Namur, Ministère de la Région Wallonne, Division du patrimoine, coll. " Etudes et documents, monuments et sites " 1, 2nd edition, Namur.

Hoffsummer P. (2002): Les charpentes du XIe au XIXe siècle, typologie et évolution en France du Nord et en Belgique coll. " Cahiers du Patrimoine ", n°62, Monum, Editions du Patrimoine, Paris.

Hoffsummer P. (2003) : La dendrochronologie de l'architecture, au-delà de l'écrit, avec la précision de l'écrit. In : Noël R., Paquay I., Sosson J.-P. (Eds.) , Au delà de l'écrit. Les hommes et leurs vécus matériels au Moyen Age à la lumière des sciences et des techniques. Nouvelles perspectives. Brepols Publisher, 295-337.

Hoffsummer P. & Plouvier M. (1995): Sous les toits, les charpentes. In Plouvier M. (Ed.), Laon, une Acropole à la française (Aisne), coll. " Cahiers du Patrimoine ", Editions du Patrimoine, 95-116.

Jousse M. (1627): Le théâtre de l'art de charpentier, enrichi de diverses figures, avec l'interprétations d'icelles, fait et dressé par Mathurin Jousse. La Flèche, G. Griveau.

Lambert G.-N. (1993): Recherche de signaux anthropiques dans les séries dendrochronologiques du Moyen Age, exemple des séquences de Charavines-Colletière. In Collardelle M. (Ed.), l'Homme et la Nature au Moyen Age, paléoenvironnement des sociétés occidentales, actes du Ve Congrès international d'archéologie médiévale tenu à Grenoble, Paris, Errance, 143-152.

Lambert G.-N. (1998): La dendrochronologie, mémoire de l'arbre. In *La datation en laboratoire*, Paris, Errance, 13-69.

Lambert G.-N. & Lavier C. (1991): A new historical master chronology for dendrochronology of the oak in the East of France. Questions about the dating of small lots of wood from a large geographical area. *Dendrochronologia*, 165-179.

Lambert G.-N., Bernard V., Doucerain C., Girarclos O., Guibal F., Lavier C., Szepertisky B. (1996): French regional oak chronologies spanning more than 1000 years. In Dean J.-S, Meko D.-M., Swetnam T.-W. (Eds.), Tree Rings, Environment and Humanity : Relationships and Processes., Proceedings of International Conference, Tucson, Arizona, 17-21 may 1994, *Radiocarbon*, 821-932.

Mille P. (1993): L'usage du bois vert au Moyen Age : de la contrainte technique à l'exploitation organisée des forêts. In Collardelle M., (Ed.), l'Homme et la Nature au Moyen Age, paléoenvironnement des sociétés occidentales, actes du Ve Congrès international d'archéologie médiévale tenu à Grenoble, Paris, Errance, 166- 169.

Murray S. (1997): The Collapse of 1284 at Beauvais Cathedral. In Courtenay L.-T. (Ed.), The Engineering of Medieval Cathedrals, coll. " Studies in the History of Civil Engineering ", Brookfield, Ashgate, 141-168.

Perouse de Montclos J.-M. (1991) : La charpente à la Philibert de l'Orme, réflexions sur la fortune des techniques en architecture. In Guillaume J. (Ed.), Les chantiers de la Renaissance, actes des colloques de Tours de 1983-1984, coll. " De architectura ", Université de Tours, Centre d'études supérieures de la Renaissance, ed. Picard, Paris, 27-50.

Simpson W.-G. (1992): Notes on innovations in structural engineering and carpentry practice in North-West Europe, 1150-1400. In *Medieval Europe, Technology and Innovation.* York, University of York, 61-67.

Taupin J.-L. & Hoffsummer P. (2002): Etudes de cas, la cathédrale de Beauvais. In Hoffsummer P. (Ed.), Les charpentes du XIe au XIXe siècle, typologie et évolution en France du Nord et en Belgique coll. " Cahiers du Patrimoine ", n°62, Monum, Editions du Patrimoine, Paris.

Webb G.-E. (1983): Tree-rings and telescopes, the scientific career of A.E. Douglass, Tucson, The University of Arizona Press.

Dendroarchaeology of late-neolithic timber in the Federseebasin

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Time and space

Lake Constance and the moors around the Federsee have yielded numerous and well-known archaeological settlements mostly from the stone-age and the bronze-age. Among the most prominent features of these settlements are the many well preserved timbers. While the bronze-age timbers of both regions and those from the stone-age at lake Constance have been intensively studied by A. Billamboz (Billamboz 2006 a, b) those of the late Neolithic in the Federseebasin have not yet been studied in detail (Map 1). This is the project of a doctoral thesis soon to be finished at the University of Mainz. The aims are of course the dating and chronology-building and an analysis of the ecological and economical framework of the settlements. These are important aspects since the late-neolithic shows striking and hitherto unexplained features in the archaeological and pollen-record. Although we have found several settlements, the pollen-data widely lack cereals as well in on-site- and off-site-data. At earlier centuries the archaeological evidence clearly corresponds to the amount of cereal-type pollen (Liese-Kleiber 1995). So obviously something has changed in the economy at the same time that also witnesses the introduction of cart and wheel. The findings of more than 8000 timbers from the late-neolithic gave the opportunity to search for explanations and mechanisms of cultural behaviour in response to environmental change and to promote our knowledge of the dating, settlement-dynamics and thereby also the demography.
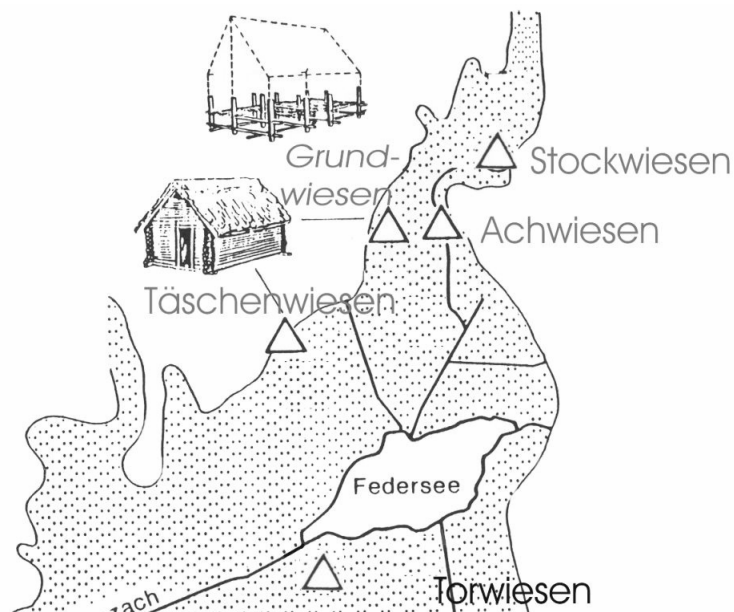
Map 1: The late-neolithic settlements in the Federsee-basin.

Difficult analyses

The material was not optimal since it turned out to be mainly made up of short tree-ring-curves of ash (*Fraxinus excelsior*), beech (*Fagus sylvatica*) and alder (*Alnus glutinosa*) as well as many species of minor importance like birch (*Betula sp.*), poplar (*Populus sp.*), willow (*Salix sp.*) and others. Moreover the curves were often quite dissimilar. Due to the restricted length of the curves statistical cross-dating was not reliable and the cross-dating was carried out visually. The measurements were sometimes hindered by the bad state the samples were in. Farmers had drained the peat-meadows in which the remains were embedded and thus the preservation was often poor. In many cases it was either impossible to achieve thin-sections or surfaces to measure the samples or the outer millimeters were heavily damaged so that the last rings were not measurable. In several cases it was helpful to soak the samples in resin like Melamin. After the resin has hardened it is sometimes possible to achieve thin sections and surfaces that can be measured.

The example of 'Alleshausen-Grundwiesen'

Material and methods

The settlement of Alleshausen-Grundwiesen yielded a complex stratigraphy with many building-structures one on top of the other as well as next to one-another (Fig.1). This stratigraphy is characterised by a thick dung-layer (layer 107) that covers large parts of the settlement (Schlichtherle 2004).
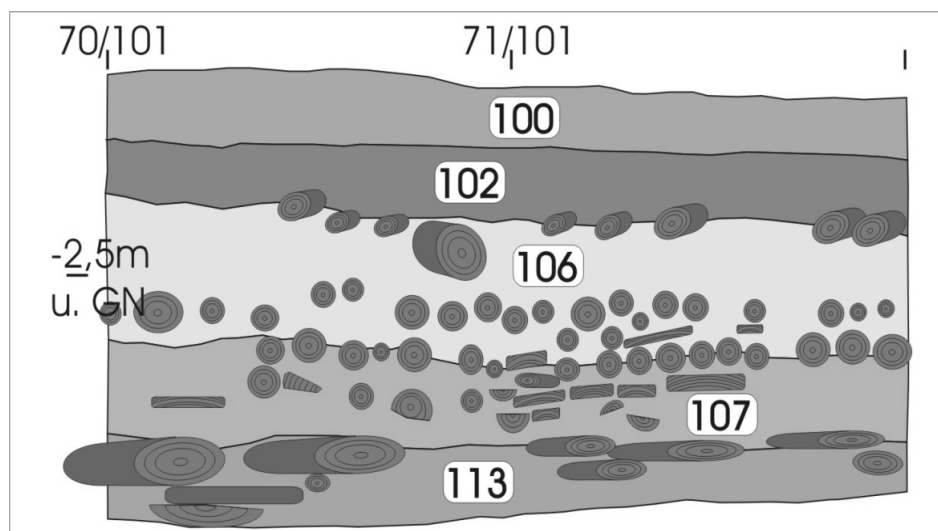
Figure 1: Example from the stratigraphy of Alleshausen-Grundwiesen with different archaeological layers (numbered) and wooden remains of the architecture.

At first, it turned out to be impossible to build a reliable chronology from this material. In an interdisciplinary fusion of archaeological and dendrochronological methods the archaeological identification of 'closed finds' (an ensemble of things that have been layed down at the same time) was used to define small groups of timber among which to look for similarities of the tree-ring curves. The visually cross-dated curves were averaged into small chronologies for single buildings. The stratigraphic sequence of the houses provided the

relative dating and important information for the cross-dating of the short building-chronologies. Thus it was possible to construct preliminary floating chronologies for the site for beech, alder, ash and birch. These curves were build with sometimes as few as 20 year-rings (Fig.2). All these synchronisations are of the dating-level 'C', meaning that they are rather proposals of the most probable synchronisation relying on external information (see Billamboz 1998, 164).
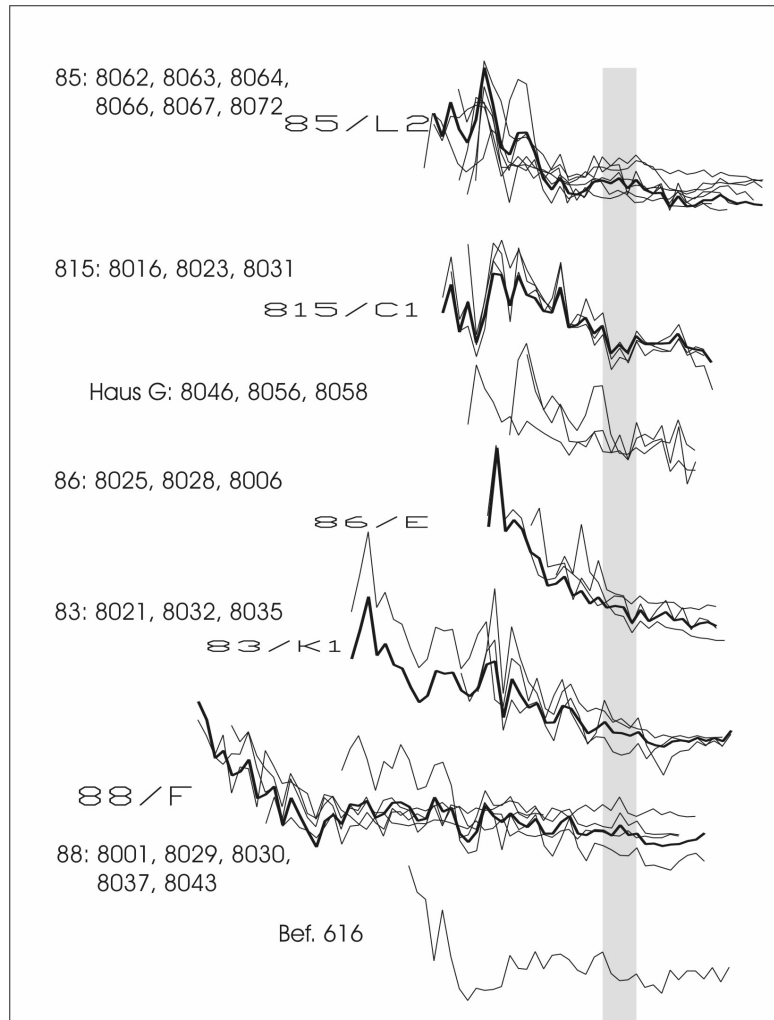
Figure 2: An example of short building-internal chronologies in stratigraphical order.

Results

It turned out that the small and lightly-built houses were in use for only very few years and in some cases in fact were probably rebuilt every year. For houses that were rebuilt within three years lay one on top of the other, with the lower house bearing traces of repairs. This had already been hypothesized by the excavator H. Schlichtherle since the houses have often just a size of some 4x4m and no plaster on the thin walls thus being hardly a place to stay during winter.

The dung-layer mentioned above yielded many thousands of twigs of which over 80% consist of ash (Maier 2004), while ash made up only about 3% of the timber.

Discussion

The identification of the species already hinted at a main-function of Alleshausen-Grundwiesen as a specialized seasonal settlement where cattle was kept and fed with ash-leaves. For this reason the ash trees were spared and not cut for timber. But the interpretation as a seasonal camp dependant on another village – probably larger and more permanent – depended mainly on the dendrochronological result of permanently rebuilt seasonal houses. This is the first time in archaeology such a second-order settlement was found although alike phenomena have been sometimes theoretically postulated (Schibler et al 1997, 347).

The example of Seekirch-Stockwiesen
Material and methods

This settlement was mainly built of ash and beech, where the ashes were primarily used for posts and the beech for the floors. The felling-dates revealed intensive recycling of old wood and a short inhabitation of less than ten years. The beeches showed a remarkable feature in their rings (Fig.3).
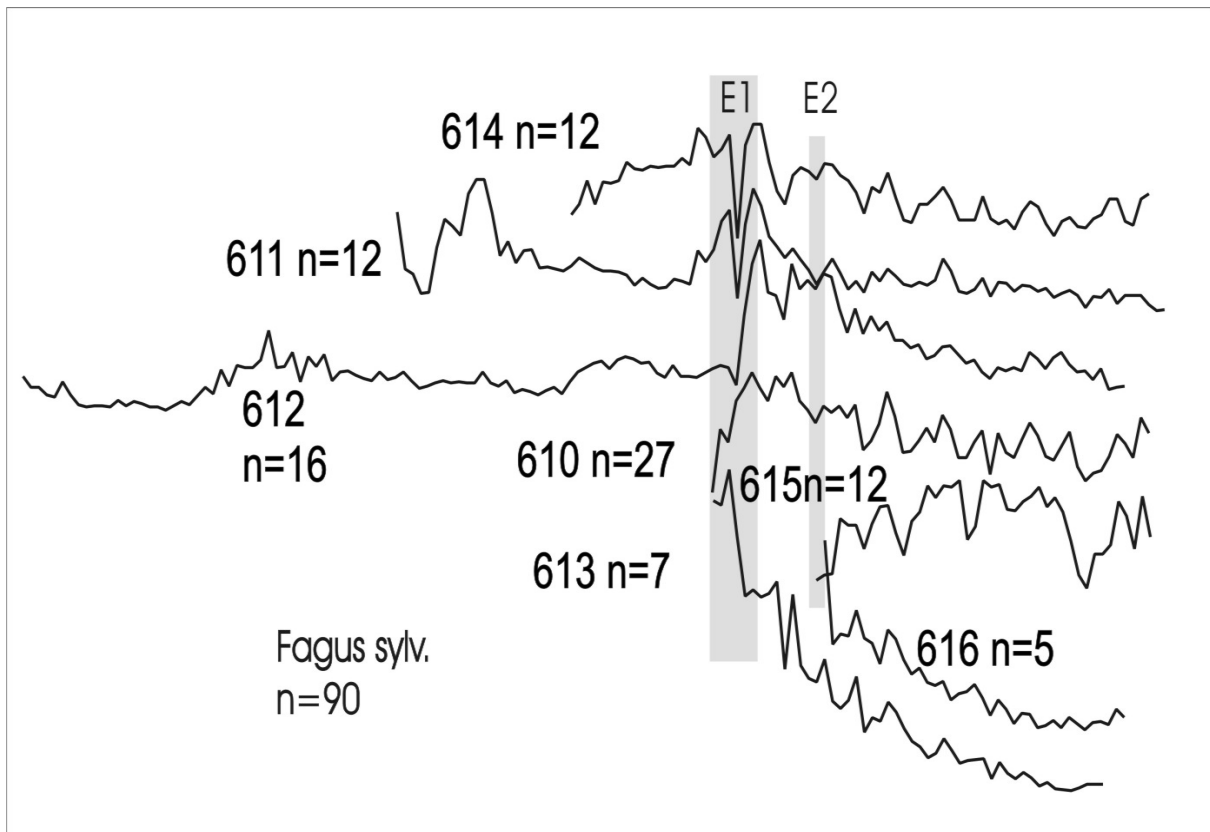
Figure 3: The dendro-groups of beech in the settlement Seekirch-Stockwiesen. Event 1 marks the first germination-phase and growth recovery, event 2 the second germination-phase.

After the dendrotypological sorting two groups could be identified that showed very narrow rings over a prolonged period of time. The trees of one of these groups (DG 612) suddenly and synchronously recovered and from this year onwards show rather normal and mostly undisturbed age-trends (event 1) although the mean ring-width is still very low (~0.5mm).

The other group shows some asynchronous recovery within the five preceding years (DG 611). Synchronously to the recovery several groups of younger trees begin their growth. The largest dendro-group DG 610 shows a moderate and also mostly undisturbed age-trend with narrow year-rings, while the dendro-group 613 shows a more pronounced trend with wide rings in the first years. About ten years later two more dendrogroups (DG-615 and DG616) begin their growth synchronously – again one of them with a steep age-trend and the other one without (event 2). Synchronous to the first germination and recovery-phase in beech, as well the ashes as the alders start to grow. Furthermore they both show a second germination-phase some ten years later which is again synchronous to the beginning of the beech-dendro-groups DG615 and DG616.

To evaluate the quality of the chronology and the difference between the growth before and after event 1 the eps of the mean-chronology of all beech-dendro-groups was calculated (Fig.4). It is clear, that the visually constructed chronology has a strong common signal after event 1 in the relative year 100 but a poor one before.
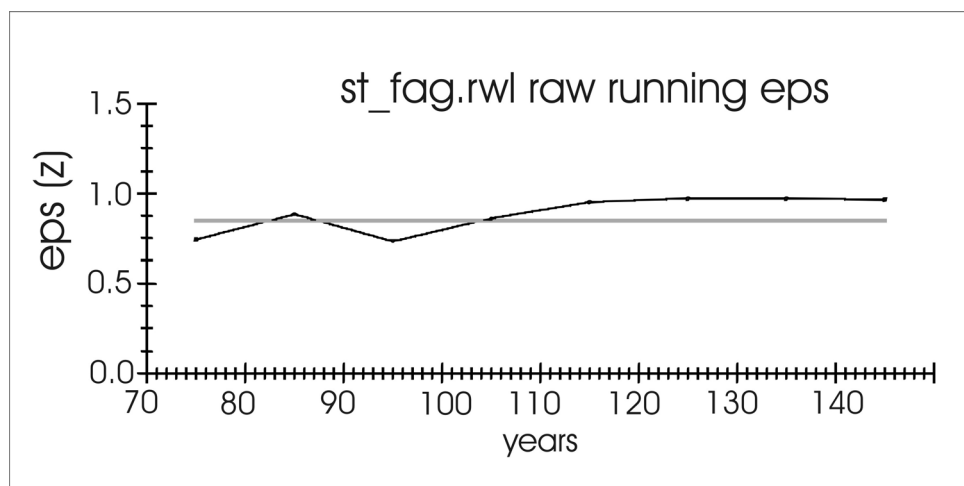
Figure 4: The eps of the beech-chronology of the Stockwiesen-settlement

Discussion

The event 1 is very probably of anthropogenic origin. The strong negative pointer year in the relative year 100 is not a late-frost event, since thin-sections of beech-samples show no traces of collapsed vessels. The straight and branch-free shape of the stems shows that they have grown in a dense stand of juvenile trees (Peters 1997, 59, 70f.), whose growth has been triggered by the same event. It appears unlikely that a storm-event should be able to destroy

enough dominant trees in several stands on different soils to explain a massive rejuvenation-phase in different species. Furthermore several individuals start their recovery earlier and some of the young trees (dendro-group 613) exhibit tree-rings whose cumulative growth-curves resemble oak-coppice-shoots in having conspicuous wide rings in the juvenile wood (Haneca et al. 2006) (Fig. 5). This is why this combination of features is interpreted as the traces of an athropogenic event.

Cumulative tree ring curves of beech-dendrogroups from Seekirch-Stockwiesen
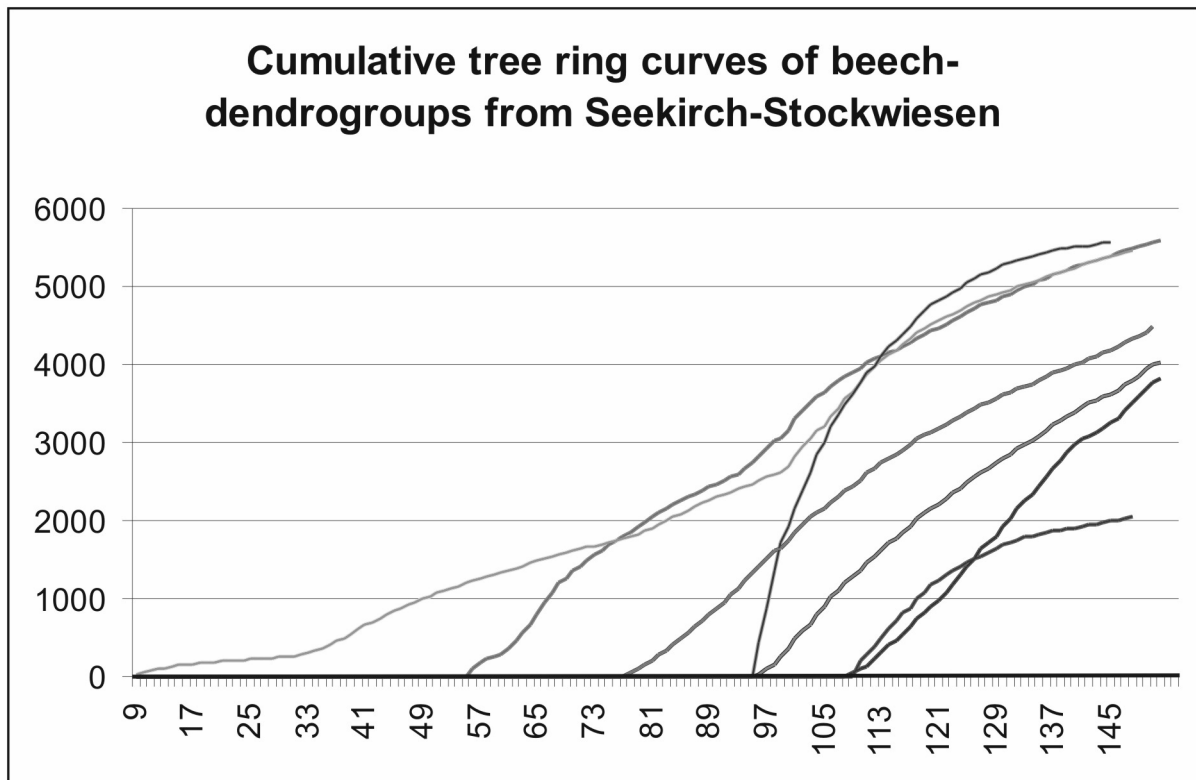
Figure 5: Cumulative growth-curves of the dendro-groups of beech. Groups 613 and 615 show a distinct trend resembling those of coppice-shoots.

It is not yet clear, of what kind this anthropogenic impulse was. Further anatomical studies are being carried out searching for features that shed some light on the ecological conditions and thus on the economic processes.

The typical anatomical reaction to light-shortage of dwarfed-individuals from the undergrowth as a lower vessel-density, lower vessel-diameter, lower ring-width and few flat fibre-cells at the ring-boundary in the late-wood that are also poorly lignified (Schweingruber & Schöne 1999) have been found in thin-sections of both beech and ash.

Interpretation

The event 1 is the result of some anthropogenic economic activity that in a short time but not completely synchronously changed the growth-conditions of the undergrowth on larger spaces both on wet and dry soils. Possible explanations are the removal of the dominant trees to induce strong growth of weeds, grass and young trees that were needed as cattle-fodder or else the sudden release from grazing. Other interpretations are possible and currently more analyses are being carried out in order to find the most probable explanation. The analysis of this succession, mirrored in the tree-rings, will hopefully give more answers concerning the economic structure of the people in the late-neolithic in the Federsee-basin.

Up to now the studies already showed that there existed different kinds of settlements that differed in respect to their durability, the repeated inhabitation, the economic specialisation and use of woodland.

References

Billamboz, A. (2006a): Jahrringuntersuchungen in der Siedlung Forschner und weiterer bronze- und metallzeitlichen Feuchtbodensiedlungen Südwestdeutschlands. Aussagen der angewandten Dendrochronologie in der Feuchtbodenarchäologie. [Preprint on CD-Rom] To be published in: Die Früh- und mittelbronzezeitliche ‚Siedlung Forschner' im Federseemoor. Befunde und Dendrochronologie. Siedlungsarchäologie im Alpenvorland. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg.

Billamboz, A. (2006b): Dendroarchäologische Untersuchungen zur Besiedlungs- und Landschaftsentwicklung im Neolithikum des westlichen Bodenseegebietes. Akten des Kolloquiums Umwelt – Wirtschaft – Siedlungen im 3. vorchristlichen Jahrtausend Mitteleuropas. Offa 2006.

Billamboz, A. (1998): Die jungneolithischen Dendrodaten der Pfahlbausiedlungen Südwestdeutschlands als Zeitrahmen für die Einflüsse der Michelsberger Kultur in ihrem südlichen Randgebiet. In: J. Biel u.a. (edts.), Die Michelsberger Kultur und ihre Randgebiete. Probleme der Entstehung, Chronologie und des Siedlungswesens. Materialh. Arch. Baden-Württemberg 43 (Stuttgart 1998), 159-168.

Haneca, K., Boeren, I., Van Acker, J., Beeckman, H. (2006): Dendrochronology in suboptimal conditions: tree rings from medieval oak from Flanders (Belgium) as dating tools and archives of past forest management. Vegetation History and Archaeobotany 15 (2): 137-144.

Liese-Kleiber, H. (1995): Pollenanalysen in der neolithischen Siedlungslandschaft des nördlichen Federseemoores. Untersuchungen im Umfeld der jungsteinzeitlichen Siedlung Ödenahlen. In: Die neolithische Moorsiedlung Ödenahlen. Siedlungsarchäologie im Alpenvorland III. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 46: 255-284.

Maier, U. (2004): Archäobotanische Untersuchungen in jung- und endneolithischen Moorsiedlungen am Federsee. In: Ökonomischer und Ökologischer Wandel am vorgeschichtlichen Federsee. Archäologische und Naturwissenschaftliche Untersuchungen. H. Schlichtherle/A. Feldtkeller/U. Maier/R. Vogt/E. Schmidt/K.-H. Steppan (eds.), *Hemmenhofener Skripte 5*: 71-159.

Schibler, J. et al. (1997): Ökonomie und Ökologie neolithischer und bronzezeitlicher Ufersiedlungen am Zürichsee. Ergebnisse der Ausgrabungen Mozartstrasse, Kanalisationssanierung Seefeld, AKAD/Pressehaus und Mythenschloss in Zürich. 381p.

Schlichtherle, H. (2004): Große Häuser – kleine Häuser. Archäologische Befunde zum Siedlungswandel am neolithischen Federsee. In: Ökonomischer und Ökologischer Wandel am vorgeschichtlichen Federsee. Archäologische und Naturwissenschaftliche Untersuchungen. H. Schlichtherle/A. Feldtkeller/U. Maier/R. Vogt/E. Schmidt/K.-H. Steppan (eds.), *Hemmenhofener Skripte 5*: 13-55.

Schweingruber, F. H., Schöne, B. R. (1999): Verzwergte Laubhölzer; anatomische und morphologische Besonderheiten sowie ökologische Bedeutung. Schweizerische Zeitschrift f. Forstwesen 150 (4) 1999, 132-141.

Oak dendrochronology studies in the Basque Country

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Introduction

Arkeolan is a historical-archaeological study and research centre situated in Irun, in the Basque Country, on the border between France and Spain. It was created in 1989 as a non-profit organization and one of its main objectives is to have the professional nature of archaeological research formally recognised. Arkeolan has been a pioneer in carrying out studies on mining and Roman settlements, the medieval and post-medieval iron and steel industry, archaeological topography in medieval towns, urban fortifications, mountain fortresses and cemeteries and town planning documents. It has also created typology databases and has undertaken experimental archaeology, museum projects, etc. A team comprising archaeologists, historians, biologists, documentalists and topographers are active in this company.

Figure 1: Wooden structure of the Roman port of Oiasso (Irun)

Background

The interest in dendrochronology arose from the excavation in 1992 of the Roman port of Oiasso in Irun. In this site, a great number of wood remains were recovered from numerous excavations (Fig. 1) and were conserved in excellent conditions due to a water-saturated anaerobic environment. The possibility of dating these wood remains accurately by means of dendrochronological analysis encouraged *Arkeolan* to focus its efforts on creating its own laboratory with the aim to establish a reference chronology for the area. Oak (*Quercus robur, Quercus petraea* and its numerous hybridisations) was chosen as a reference species, due to its use in all kinds of structures for centuries. With the objective established, a series of

consultations were held with researchers from the field, in order to obtain advice regarding training, equipment, etc. Dr. Emilia Gutierrez of the University of Barcelona was eventually the person to become involved in the continuous training, collaboration and advisory processes, as well as putting us into contact with another researcher, José Xabin Lizeaga Rika, who performs dendrochronological studies on oaks in the south of Navarre.

Description of the territory of Gipuzkoa

Our first efforts focused on locating living old trees in the territory of Gipuzkoa. While the Basque Country is predominantly mountainous, the high population density and its distribution mean that both rural and urban environments coexist. Therefore, urban dynamics will strongly affect the features of the rural environment. Centuries-old forest exploitation, which has been regulated since the Middle Ages, must be added to this fact. The woods were originally exploited by the inhabitants for building purposes and for firewood. However, the great demand for raw material for ironmongeries and naval constructions, put great pressure on the woods, so that in the mid 19th century the mountains were almost bare. As a result of these dynamics, all that is left today of the great oak and beech forests that formerly covered almost the entire territory are a few small woods with old trees, and young specimens that are the product of reforestation. In addition, the old trees have been affected by the practice of pollarding or by their position in areas of transition between rural and urban environments. The pollarding practice was very common and consisted in the pruning of the main branches to obtain firewood for the ironmongers. The main consequences of this practice are the lack of protection of the higher part of the tree and the formation of large hollows and wood rot inside the trunk. This is reflected in the ring-width series by significant reductions in ring width due to the loss of the leaf mass and therefore drastic unnatural growth reduction.

First steps and methodology

In the above context, locating individual specimens that were appropriate for dendrochronological analysis seemed a very complicated task. However, in 1998 a series of sampling campaigns were carried out following analysis of vegetation maps, consultation with the forest ranger service and conversations with experts in the rural environment and its history. Since the aim was to establish a regional chronology and bearing in mind the complicated orography of the territory, which comprises an endless number of valleys and mountains, we had to obtain samples from different coastal and inland environments. For this reason different locations were chosen for each campaign (Fig. 2). Samples were obtained by using 30 and 40 cm long Pressler borers at a height of 1.30 metres. Whenever possible, two or three samples of each specimen were obtained in order to compile an average ring-width series for each individual. Growth rings were identified and measured using a LINTAB measurement stage, comprising a semiautomatic measurement table, a binocular magnifier and a cold light source, connected to a computer using the TSAP program and the utilities package available from the ITRDB (COFECHA, ARSTAN, ITDRB VIEW, etc), which were used for data storage and subsequent processing.

The series obtained were standardized with the aim of eliminating individual growth trends. Whenever possible, a mean series of samples from a single tree was obtained. The crossdating process was carried out initially between series from a single area with the aim to construct different local chronologies, and in a second phase, series from other areas were introduced in order to test the possibility to construct a regional chronology.

Figure 2: Location of sites where living trees were sampled.

Initial results

In accordance with the tree features and samples obtained, it was possible to distinguish several groups:

Group 1

These were remains of seriously deteriorated pollarded trees. Samples of fifteen to twenty specimens were obtained from each location with great difficulty due to the presence of large cavities and rotten parts inside the trunks.

While series of over 200 rings from almost all the locations were studied, we only succeeded in synchronising the last 125-150 years. This was due to the growth reduction caused by pruning, which greatly complicates the crossdating process.

The series applying to the Agorregi and Iturrarán locations situated in Pagoeta Natural Park in Aia are included in this group. Samples from the Olaberria Valley in Irun, the Santa Lucía de Berezao Valley in Oñate and individual specimens located in the Jauregi district of Hernani are also included here.

Group 2

Specimens collected around "caseríos", typical Basque farm houses, are included in this group, as oaks were formerly used to mark the boundaries between properties and acorns were used as pig feed. These specimens are 100 to 200 years old and are seriously deteriorated. However, the samples display complacent growth due to their location in ideal growth areas. The fact that these are mostly smaller groups of trees meant that fewer samples were collected in these cases and only about ten specimens could be sampled.

Group 2 specimens were collected around Caserío Erreista in Aia, Caserío Tximista and Martitxenea in Irun, and Laurgain in Aia. This group included 100 year old trees, such as those from Presalde, in Zestoa, which correlated well with both the inland and coastal trees. Therefore, they proved to be essential for the construction of a regional chronology. Another peculiar case was that of the specimens sampled in Punta Mendata, Deba. These trees are located on very sloped land close to the sea. Due to their position they are frequently battered by strong winds, which results in growth series that did not synchronize well between specimens,. Finally, on land belonging to the Lazkaomendi caserío, a great number of oaks were sampled. Despite the fact that they were not excessively large, we decided to sample them anyway because they were situated on relatively high ground. The series obtained proved to be of great quality, free of human-induced compression and providing specimens around two hundred years old.

Group 3

The specimens from this group are located in parks or semi-urban environments, and include very large trees planted in an orderly fashion. The series obtained from these trees display good synchronisation, and the age of the sampled specimens varies from 100 to 150 years. Trees collected at Manterola in Aia, Parque del Duque in Lazkao and San Martín de Oñate belong to this group.

Group 4

This group comprises larger forest patches in natural environments, which probably did not undergo human intervention. They were sampled because of these features even though very old specimens were not found. Unfortunately, only in two cases, those of Gaztinari Haundi in Lazkao and Urdiain in Alsasua (Navarra), sufficiently long series were obtained that enabled us to construct chronologies. At the first location, the specimens did not reach the 150 year mark, whereas at the second site, samples of around two hundred years were found. However, they were not correlated with the chronologies obtained from other sites. In the cases of Arditurri of Oiartzun, Valle de Jaizubia and Endara in Irun, Justiz in Hondarribia, and Leizaran in Andoain, the samples were around 50 years old and the series were not of particular interest. At present, we are analysing samples from living trees and stumps from new locations in the north of Navarre, such as Donamaría, Legasa and Labaien, which are of interest due to their location on fairly high ground, in land with very little substrate.

As a result of these campaigns, we have succeeded in compiling more than ten local chronologies, both of inland and coastal areas, and a regional chronology comprising more

than 70 series, covering the period from 1835-2002, with which the majority of the specimens sampled in Guipuzcoan territory present a high correlation.

It proved particularly difficult to construct the regional chronology for a relatively small area of ca. 2000 square kilometres, since the different local chronologies only gave correlations with nearby locations. As a result, the inland series failed to synchronise with the coastal series. When comparing individual series, samples from Presalde and Zestoa displayed correlations with both coastal and inland groups. Therefore, the regional chronology was compiled of individual curves from specimens displaying the same growth trends as the rest. In an initial comparison between the ring width and the available climatic data, the influence of temperature on growth appeared to be greater than that of rainfall. It was also observed that the growth trends recorded on the inland location series tended to be less pronounced in the series of coastal locations.

Sampling

For the moment, the limited length of the established regional chronology did not enable us to date any building or archaeological wood samples. This is also due to the fact that in buildings pertaining to the end of the 19th and beginning of the 20th centuries a lot of pine wood was used due to its low cost. Furthermore, most oak wood items display clear evidence of re-use.

In addition to the collection of samples from living trees, an additional stock of wood appropriate for tree-ring analysis was collected from renovation, demolition and excavation work on all kinds of buildings and structures. It should be pointed out that it was relatively easy for us to access all these structures due to joint work with the team of archaeologists from the Arkeolan centre. As a result, at the beginning of the year 2004 there were over 1,500 samples in the laboratory inventory, of which approximately 800 were from living trees, some 500 from construction woods and a further 200 from archaeological sites. While most of them are slices from beams and posts, construction wood cores were also obtained from items that were not replaced during renovation. In addition, slices of archaeological items that had been retrieved in excavations were also collected. Unfortunately, although relatively large sections were obtained, they offered rather short series (no more than 50 or 60 rings) due to very large ring widths. However, it was only possible to compile floating chronologies of each deposit and absolute dating was not possible.

The qualitative leap

In 2004, *Quercus faginea* specimens that proved to be over 300 years old were collected in Alava, a region in the south with continental climate features, such as more pronounced temperature and humidity variations. Therefore a more intense sampling campaign was carried out in this region. Isolated samples located among large areas of *Pinus sylvestris*, and small homogeneous *Quercus f.* woods situated in areas with very little substrate were chosen. Most of the 130 samples obtained were between 250 and 400 years old. The series did not display anthropic growth alterations, even in the case of the small forest patches, which have been subject to traditional pruning regulated by local people,.

Figure 3: Typical Q. faginea stand at Ribera Alta (Araba)

As a result of crossdating and synchronization of these series, a local chronology comprising over 90 series was obtained. This chronology covered the period from 1640 to 2003 and was highly correlated with some of the chronologies established previously by this laboratory for the territory of Gipuzkoa. Furthermore, high correlations were observed for another chronology, established for oaks stands about 100 km away in the south of Navarre (Joxe Xabin Lizeaga Rika pers. com.), with "t" values of more than 9.

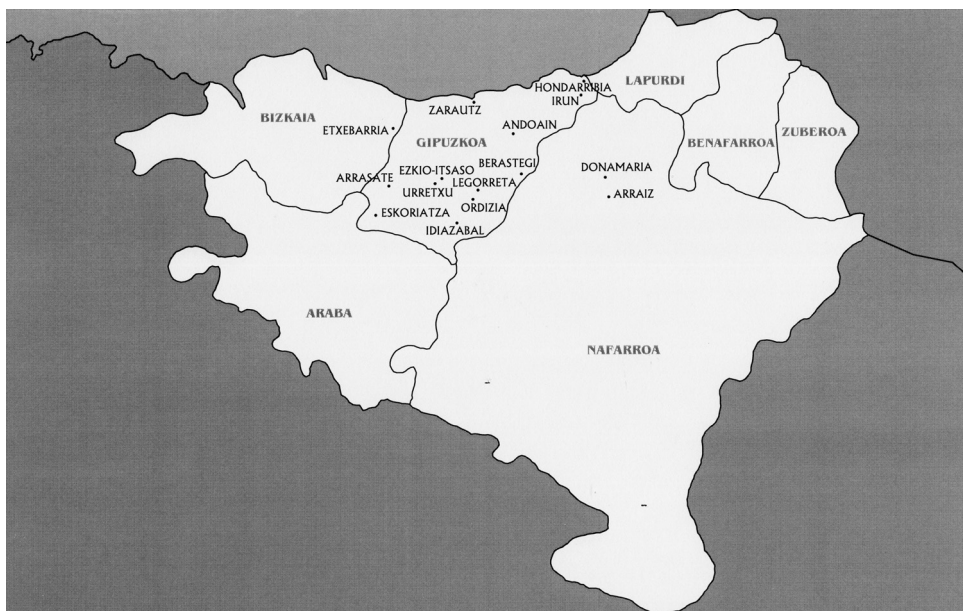*Figure 4: Location of some of the historic timbers successfully dated.*

During the same year, samples were collected from a demolished house in Arraiz (the Xabattenea house), a small village situated in the north of Navarre. Many of these samples exhibited more than one hundred rings and one of them had over three hundred rings. These samples synchronized well with the reference curve and resulted in a floating chronology for

the period from 1384-1690. Furthermore, this significant synchronisation was repeated for the same dates with the chronology from the south of Navarre, which confirmed its validity. This allowed a reference curve for building wood to be created to date several other samples; however, reused wood still posed a problem. In some cases it was only possible to date the samples that presented sufficiently long ring series. Still, in some cases the dendrochronological analysis provided numerous dates. An example of this is the case of a relatively modern building located in Urretxu, Gipuzkoa. The building is located in a street in which sampling was already carried out on several other buildings. However, these former sampling campaigns did not reveal any pieces of interest. From this particular building, over thirty samples were collected and analysed. The results revealed that the first floor had been built immediately after a documented fire that had devastated the village in 1658, and that the building was subsequently extended with a floor in the first half of the 18th century.

Current situation and future prospects

To date, we have over 2,300 samples stored in our laboratory, from living trees, construction wood and archaeological items. In addition, we have a chronology of living specimens of *Quercus f.* and a reference chronology has been established with samples of *Q. robur* and *Q. petraea* covering the period from 1384-1782. This chronology is constantly revised and improved in terms of the availability of dated series. There is no doubt that it will be possible to extend it into the past when we manage to synchronise some of the stored samples, which are expected to be older, as suggested by documents.

Furthermore, a "caserío" or Basque farmhouse sampling campaign has been initiated. The construction of these houses begins in the 15th century, a period in which many wooden structures have been erected, almost always using oak.

At this moment we are revising the work of the past few years in collaboration with Professor Emilia Gutierrez of the University of Barcelona, in order to carry out an up-to-date filtering of the series with a special interest in assessing its potential to begin climatic studies, as for the moment we have only addressed the analysis of significant years and their frequency.

The extension of the reference chronology back in time appears quite feasible, as quality samples from "caseríos" display high correlations for dates of the 15th century. This suggests that the sample depth of the curve for these periods could be improved. We are also working on a draft project whose aim is the intensive sampling of the Alava territory's tower-houses, of which the history goes back to the 13th century. On the long term, regarding the future with optimism, the aim would be to extend the curve until there is a reliable overlap with the already dated samples from Roman times.

In conclusion, dendrochronological studies in the Basque Country are an arduous and costly task, but not an impossible one. The difficulties caused by the complacent growth of trees can be overcome. In the case of living trees, it can be overcome by extending the sampling areas to neighboring areas in which minor climatic changes take place, but in which there are common growth trends. In the case of building wood, this can be done by systematic sampling of all kinds of structures liable to contribute woods of interest due to their assumed age and the collection of a large number of samples from each deposit. This to overcome the

fact, that many of them will be rejected due to their limited number of rings. Therefore, the collaboration of the institutions is essential when it comes to collecting information (i.e. joint work with the forest ranger service in order to locate living specimens and with heritage officials for obtaining news of any demolition or renovation work that might offer the chance to collect samples of interest).

Figure 5: Medieval wooden structure recovered at Hondarribia and successfully dated.

References
Baillie, MGL. (1982): Tree-ring dating and archaeology. Croom Helm. 274 pp.
Cook, ER. & Kairiukstis, LA. (1992) : Methods of dendrochronology. Kluwer Academic Publishers. 394 pp.
Fritts, HC. (1976): Tree rings and climate. Academic Press. 567 pp.
Jozsa, L. (1988): Increment core sampling techniques for high quality cores. Forintek Canada Corp. 26 pp.
Kaennel, M. & Schweingruber, FH. (1995): Multilingual Glossary of Dendrochronology. Paul Haupt Publishers. 467 pp.
Phipps, RL. (1985): Collecting, preparing, crossdating and measuring tree increment cores. U.S. Geological Survey, Water-Resources Investigations Report 85-4148. 48 pp.
Schweingruber, FH. (1993): Trees and wood in dendrochronology. Springer-Verlag. 402 pp.
Schweingruber, FH. (1996): Tree rings and environment. Dendroecology. Paul Haupt Publishers. 609 pp.

SECTION 2

CLIMATOLOGY

Finding best regression approach for description of climate-growth relationships by floating time spans of varying width

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Introduction

Climate growth relationships – actuality and research needs

Mathematical description of the climate-growth system (acc. to Fritts 1976) is a central topic of tree ring research. Already Douglass, the founder of dendrochronology understood tree ring width series as proxy series for climatic data. Since the beginning, numerous attempts were undertaken to investigate and to describe climate-growth relationships. Recently heat and drought during the summer of 2003 attracted the public interest to the problems of climate change and forests' long-term vitality. Effects of long lasting heat and drought are seen to be potential threats for the continuity of the existing forests. Additionally and simultaneously to increasing climatic stress we have to ascertain that the enduring deposition of eutrophying substances and the increase of carbon-dioxide concentration may cause hypertrophic growth rates and therefore raise demands for water supply. Forestry in Germany as well as in Europe is faced to the difficulties that the environmental conditions of forests continuity are changing rapidly and that the knowledge to set adaptive silvicultural measures into action is not available at the required extent.

Summarizing all facts and needs of the current situation, it can be concluded that the elaboration of quantified knowledge on the effects of climatic elements on tree growth in an all-embracing breadth is of outstanding importance.

Knowledge of the effects of climatic elements on tree growth – fields of lacking knowledge

To solve the task mentioned above open fields of lacking knowledge must be appointed:

- ranges and limits of adaptability of tree species against the background of more and more extreme climatic courses,
- climatic sensitivity of our main tree species in various regions, their local climates and soil conditions,
- modification of climatic sensitivity of a tree species by local site conditions,
- changing of competition dynamics in mixed forests against the background of climate change,
- composition of forest structures which can react plastically to climatic stress (far-reaching adaptability; mixed species; diversification of risks).

To complete these fields it is necessary to explain the preponderant portion of variance in tree ring series and to possess appropriate techniques to decompose the climatic signal in tree ring index series.

Analysis of the climate-growth system and mathematical description of climate-effect relationships

The following considerations start with the availability of tree ring index series. The methods used therefore, that means the linear aggregate model of tree ring series (Cook 1985), trend calculation and elimination, the detrending and standardisation are assumed to be known and will no further discussed here.

The tree ring index value of a certain year is a result of all the environmental factors acting on the tree stand during the whole year. In any mathematical attempt to analyse climate-effect relationships these year-related values of tree ring index are faced by climatic variables which are available for all days within the year. Owing to the impracticality to apply daily data, methods of data pooling must be applied, otherwise the problem would be unmanageable. The general criterion for such a data-pooling method would be that time spans inside the year (length and position) must be found which correspond to the real climatic demands of the trees. Monthly variables (precipitation sums or averaged temperatures) are accounted to be not fully appropriate to analyse climate-growth-relationships.

Currently wide spread methods to analyse Climate-Effect Relationships:

Single factor analysis:
Values of a climatic variable of a few months assumed to be important for tree growth are summarised (seasonalised) and compared to tree ring widths. Choice of variables and limits of the seasons are defined by the experience of the scientist.

Single year analysis:
A discontinuous method which investigates the climatic course in event years and pointer years.

Year to year comparison:
The increment of the current year is compared with the average of 10 preceding years. The applied climatic variable here is the De Martonne-index.

Multiple regression analysis:
Numerous approaches are referred for instance by Fritts (1976).

Response functions (Fritts 1976):
The substantial methodical progress consists in a control of the multicollinearity between climatic variables by PCA and in the reduction of the number of predictors by use of eigenvectors. The high number of primary variables, mostly low portion of explained variance and sometimes a complicated interpretability of the results are to be mentioned as disadvantages. Schweingruber (1993) dealing with the response-function method stated: Climate-growth relationships cannot be static.

Bootstrapped Response function (Guiot 1991); Evolutionary and Moving Intervals (Biondi & Waikul 2004):
Advantages: enhanced reliability and robustness of parameters; time dependent changes of impact strength of predictors can be shown.

State-space models; Kalman filter technique (Visser & Molenaar 1988, van Deusen & Koretz 1988):

Time series is understood as a state-space. The advantage of this method is that time-variant impact strength of variables on ring width is the determining theoretical assumption. Unfortunately there is no updated software for modern operating systems available.

Common to all mentioned continuous statistical procedures above is that the choice of variables is done by the authors, according to their background of ecological experience. Mostly monthly limits are preset. Therefore the real climatic demands of trees cannot be fully hit. The conclusion from this situation is that a new procedure must be developed which objectifies climatic data pooling and variable selection.

Development of the method of 'floating time spans of varying width'

The task consists in the determination of position and width of intra-annual time spans which explain the variance of tree ring index series at the best possible rate. Preferably few restrictive constraints should be adopted.

Realisation:

Basic climatic data (temperature, precipitation) in daily resolution were supplied by the German Weather Service (DWD) for the period from 1951 till 2003. These data were proofed for errors and homogeneity by the Potsdam Institute for Climate Impact Research (PIK). As most suitable weather station is chosen the one which is closest to the particular sample plot (horizontal and altitudinal distance).

All climatic variables included in the model are relative values related to the averaged cumulative yearly course obtained from the period from 1951 till 2003. The following predictive variables are applied:

- $X1$: relative precipitation balance;
- $X2$: $X1^2$; preliminary investigations have shown a potential nonlinearity;
- $X3$: relative temperature balance;
- $X4$: $X1 \times X3$; temperature and precipitation within a period are mostly intercorrelated; interaction term $X1 \times X3$ is used to compensate the effects of intercorrelation.

The time range to search for the optimal time span starts with 1 April and ends with 31 October. This range covers more than the vegetation period. Assuming a minimum width of time span of 21 days 194 different positions within the superior time range have to be proofed. The width of the time span will be increased by one day until the maximum width of 183 days (a half year) is reached. Applying this width of time span, 32 different positions have to be proofed. Altogether a very high, but finite number of combinations (18,419 cases) from time span width and position is produced. The optimum time span for calculating climatic variables is identified by '*complete enumeration*' of all these combinations. For each case a multiple regression analysis is calculated and its results are evaluated. As a criterion to evaluate and compare quality of all obtained solutions, the coefficient of determination is used at first. As regression analyses is applied here on time series, the synchrony of

measured series and modelled series must be kept. Therefore the coefficient of Gleichlaeufigkeit is calculated additionally. Sensitivity of tree ring index series is an important property and reflects in which size climate acts on tree growth. The magnitude of this impact strength must be reproduced by the regression model. A ratio of sensitivity of modelled series divided by the sensitivity of the measured series is calculated and used as a third control parameter.

In the following, the chronology "Ebersberg Forest" (tree species: Norway spruce *(Picea abies)*, level II plot, Bavaria) is used as an example to demonstrate the methods and the workflow of the purpose-built computer program. After a first search-run within the range between 1 April and 31 October the time span from 17 August to 3 October is found to fit best the tree ring index series (Fig. 1).
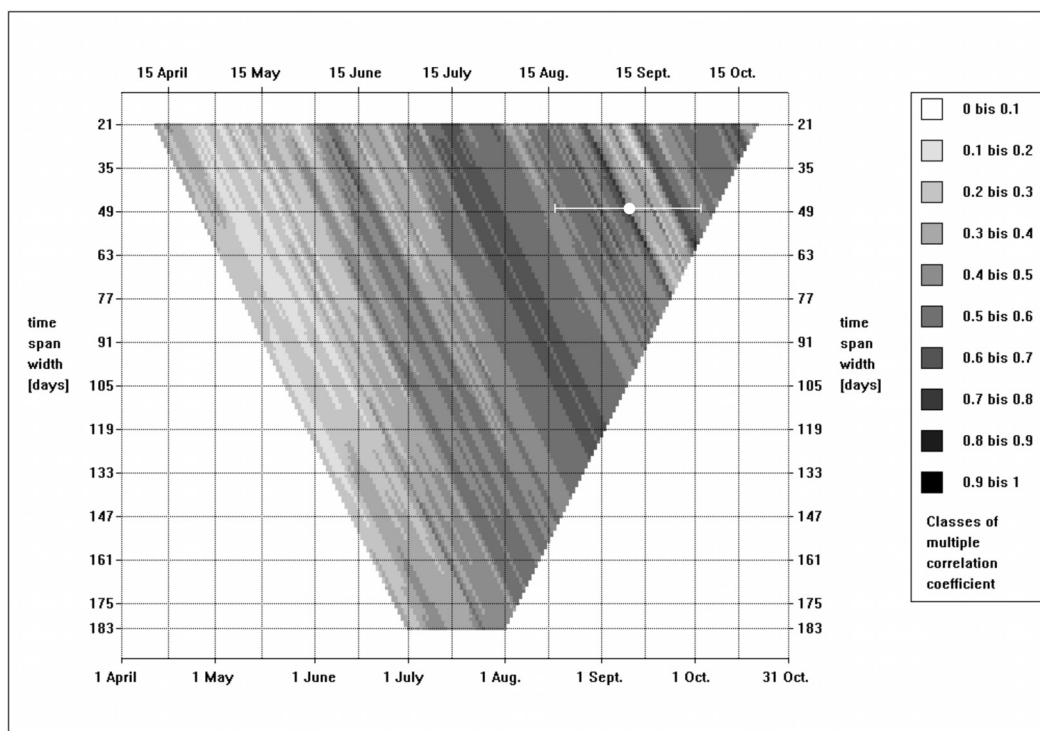
Figure 1: Results of a first searching run within the vegetation period; each rectangle indicates with its position the dated middle of a time span and with its grey level the class of multiple correlation coefficient

53,09% of the variance is explained by the four variables (mentioned above) within this time span and by the tree ring index value of the preceding year. This additional predictor is included only during the very first run and acts as a proxy value instead of the physiological initial state just before the beginning of the running year. Evaluating this initial result it has to be presumed that not only this first found time span is important for tree growth during vegetation period but other time spans may also be important and may probably enlarge the portion of explainable variance. That is why the search-run is repeated under recurrent use of the predictors of the already found time span. This step – the repetition of the search-run under inclusion of the already found time spans with their predictors – is carried out until the remaining time gaps within the range from 1 April till 31 October are smaller than 21 days (minimum time span width). The result of such a repeated search within vegetation period is shown in Figure 2.
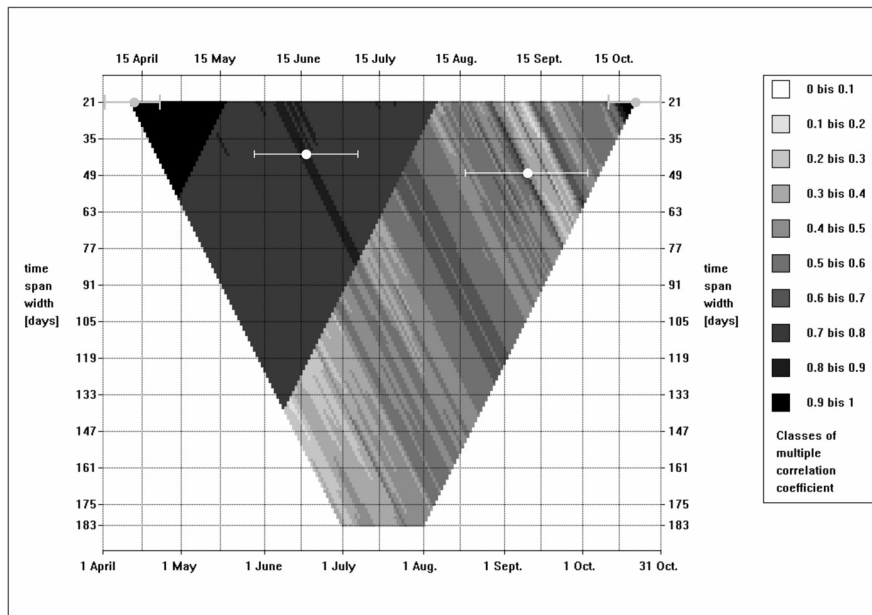
Figure 2: Results of repeated search within the vegetation period; four time spans are found and indicated by fat white points (dated middle) and by white bars (limits of the time spans)

The preponderant portion of variance, often nearly completely, is explained. However, the sufficiency and significance of the regression model at this stage is restricted. Growth rate of a running year is not only the result of factors acting in this vegetation period, but is preconditioned by preceding events, at least by the weather conditions during late winter and spring. A second time range is defined therefore from 1 December till 31 March. Here a last searching run with time spans of widths from 21 days till 84 days is carried out (Fig. 3).
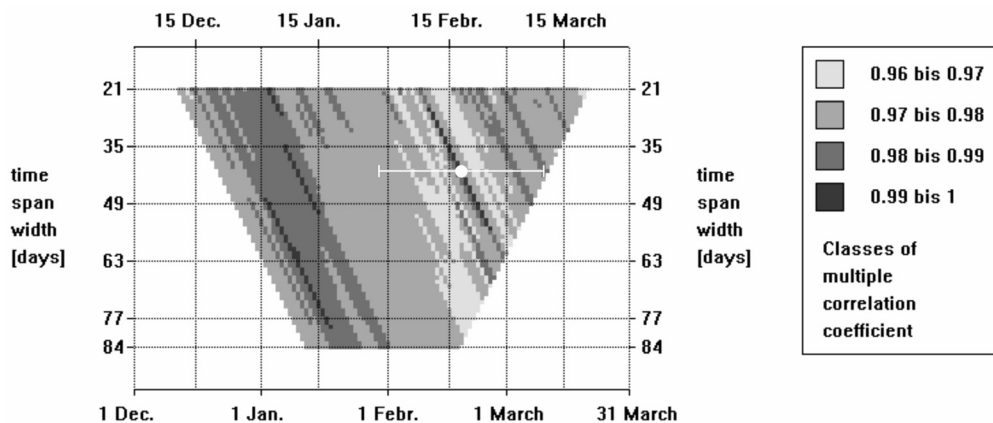
Figure 3: Results of the last search within the second time range, the winter and spring time

After that a full regression model with the maximum number of predictors exists. The next step consits of the application of an interactive backward selection strategy, because it is to assume that not all of the included predictors will score the significance level. Therefore a t-test is applied and all predictors which fail the test will be excluded and the reduced regression model will be recalculated. This stepwise reduction is done until the model includes only significant predictors. All steps of building up the regression model and the following backward selection are recorded (number of predictors, coefficient of determination, sensitivity, Gleichläufigkeit, Akaike information criterion) and summarized to a graph (Fig. 4).
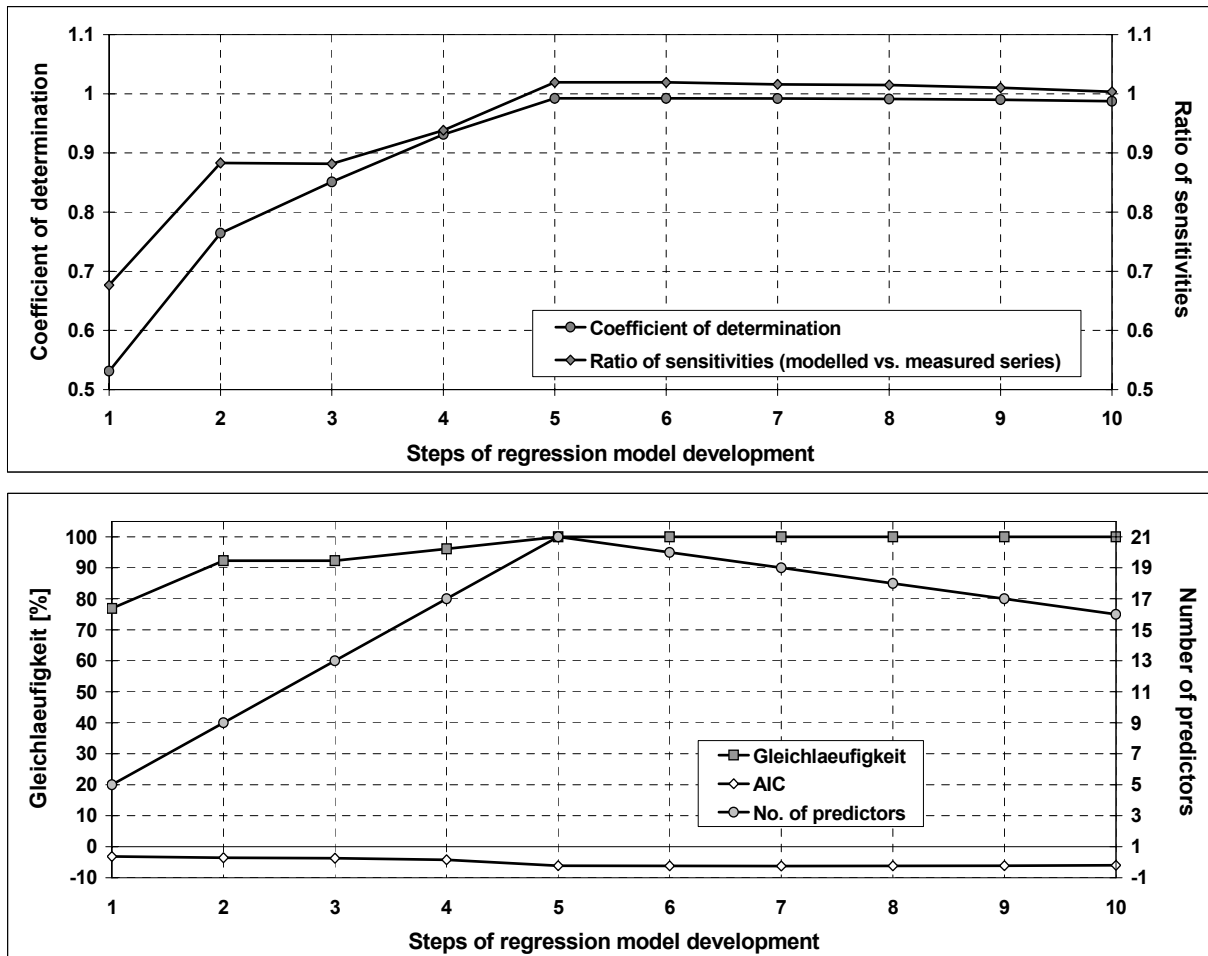
Figure 4: Built up (steps 1 to 5) and backward selection (steps 6 to 10) of the regression model; Number of predictors drops down from 21 to 16. Coefficient of determination, Gleichlaeufigkeit and ratio of sensitivities nearly keep their level during backward selection.

One of the most interesting questions is to ask for the impact strength of the found predictors within their time spans. To answer this question the following statistical parameters for each predicting variable are calculated:

- mean
- mean+standard deviation
- mean-standard deviation
- absolute maximum
- absolute minimum

To investigate the impact strength of one predictor the values of all the other variables in the model are preset to their mean and for the predictor under investigation the corresponding values of mean+standard deviation, mean-standard deviation, absolute maximum and absolute minimum are applied successively. In this way the corresponding tree ring index values are generated from regression model. Because tree ring index values *(TRI)* of the time series oscillate around the mean of 1,0 they can be transformed into relative growth deviations*(RGD)*: $RGD_t = 100\% \cdot (TRI_t – 1,0)$. This procedure is applied for all included predictors and displays simultaneously a complete analysis of model sensitivity (Fig. 5).
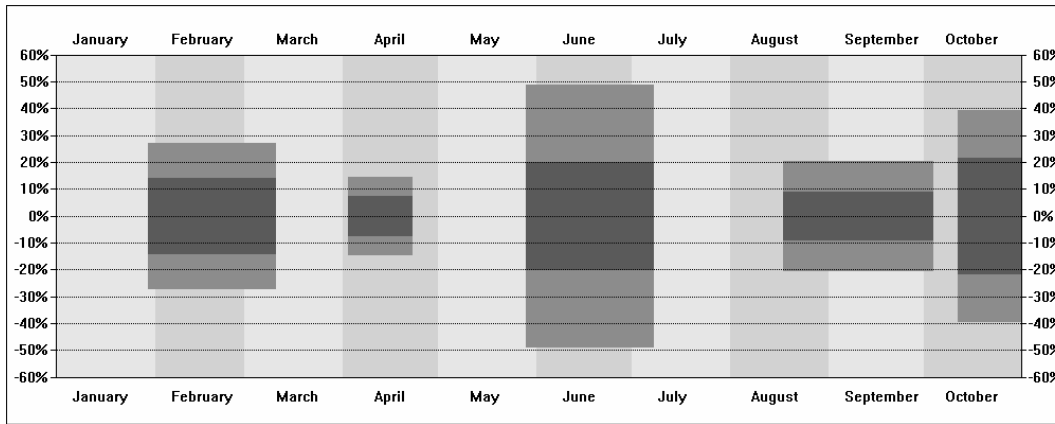
Figure 5a: mean relative precipitation balance
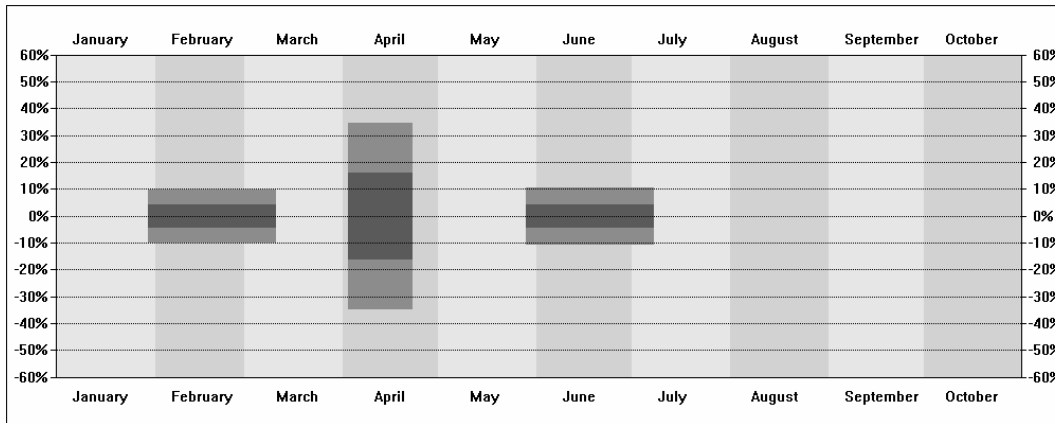
Figure 5b: mean relative precipitation balance - quadratic
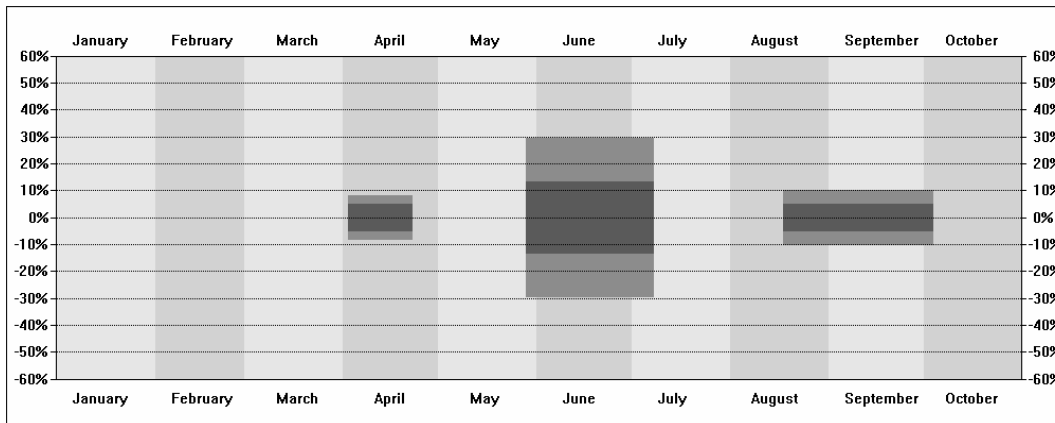
Figure 5c: mean relative temperature balance
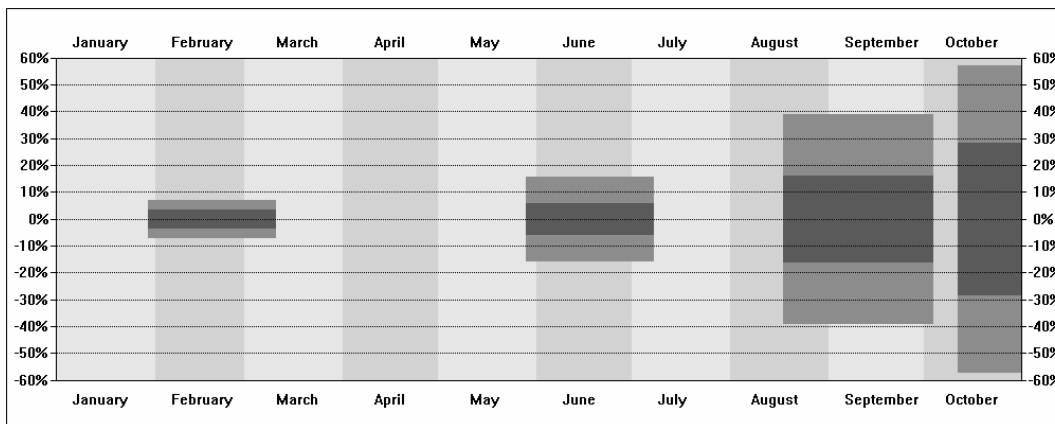
Figure 5d: interaction terms, products of mean relative precipitation and temperature balance

Figure 5: Impact strength and position of the found climatic predictors; vertical axis: relative increment deviation [%] caused by the climatic variables; dark-grey bars: increment deviations caused by the predictors changing between mean + standard deviation and mean – standard deviation; mean-grey bars: increment deviations caused by the predictors changing between absolute minimum and maximum values.

Other graphs for further information include a comparison of time series of original (measured) and modelled tree ring index values (Fig. 7) and the residuals related to the predictor variables (Fig. 8).
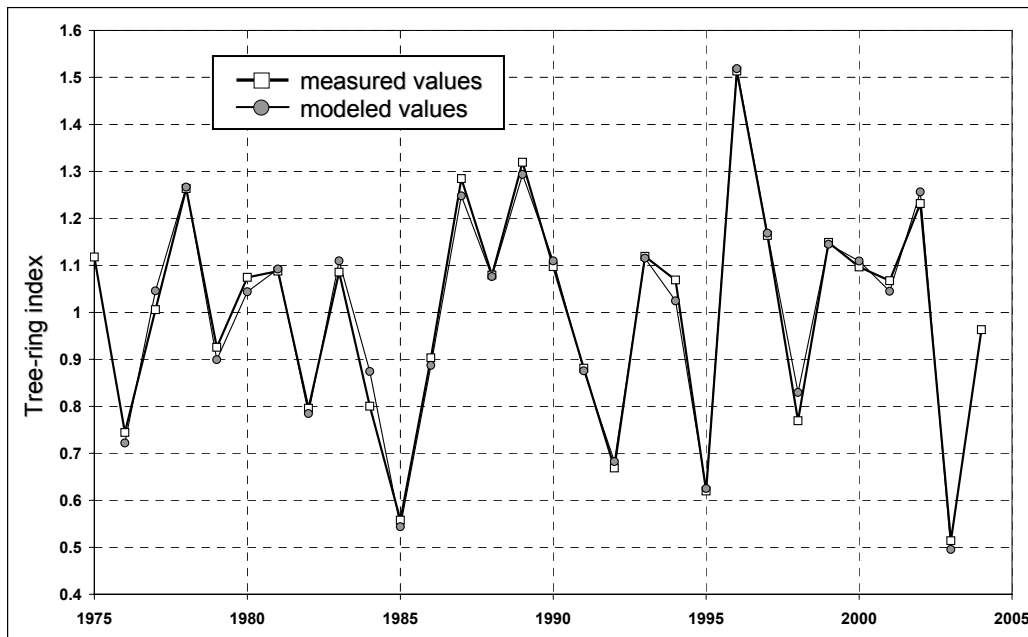
Figure 7: Comparison of the time series of measured and modelled values of tree ring index

What can this method perform? - Discussion

Tree ring index series can be reproduced by the model with high degrees of fidelity, especially if time series length is below 35 years. Variables included into the model are chosen by a self-controlling algorithm. Therefore the choice of variables is objectified. Found intra-annual time spans of climatic variables correspond to the real demands of the trees.

The multiple application of the described method to many different time series and tree species can enlarge our knowledge about the climate-growth system substantially. Especially the information about position and width of time spans wherein climatic elements are important for tree growth can improve our knowledge on the growth process. The results can also adjust some of our perceptions. In this sense it can be understood as a learning tool. Otherwise the regression model works not dynamically. If time series are too long or if environmental condition change rapidly the fidelity of results is lowered.

Application and generalisation of the results obtained from multiple use of the new method

The mode of action of climatic influences on tree growth can be compared between

- tree species growing under comparable environmental conditions such as soil properties, water supply, elevation, deposition, etc.,
- differenced site conditions including deposition of pollutants at the same tree species (numerous combinations),
- different regions with their different local climates at the same tree species,
- pure stands of a tree species and mixed stands with this species and other mixtures of species.
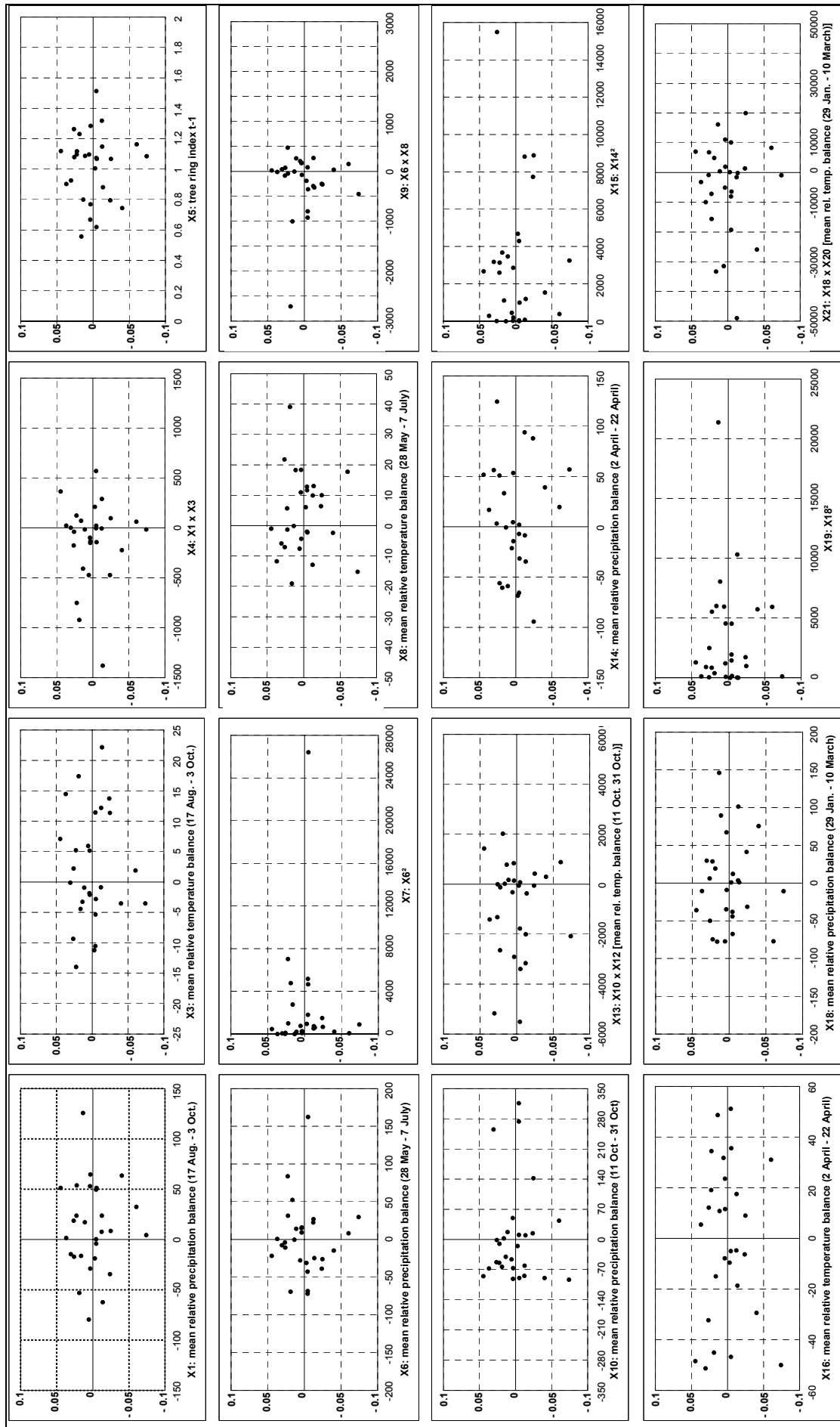
Figure 8: Residuals of the regression model related to all 16 included predictors; The predictors X2, X11, X12, X17 and X20 were excluded during backward selection because they failed the t-test.

If all the modifying effects of these causation complexes on impact strength of climate on tree growth are known, then we are able to forecast how tree and stand growth go on under conditions of progressive warming and different scenarios of precipitation supply.

The algorithm presented here produces satisfying results within the analysed time series range but it doesn't work dynamically. Time (state) dependent changes of the effect of climatic variables – that's the reality of the climate-growth system – cannot be performed. An algorithm which combines the advantages of objectifying of climatic data pooling and variable selection with moving and evolutionary intervals (pseudo-dynamic approach) or the state-space model (dynamic approach) would be appropriate to the true nature of the climate-growth system.

References

Biondi, F. and Waikul, K. (2004): DENDROCLIM2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. Computers & Geosciences 30: 303-311

Cook, E.R. (1985): A Time Series Analysis Approach to Tree-Ring Standardization. Unpublished Ph.D. Dissertation. University of Arizona, Tucson, AZ, USA

Fritts, H.C. (1976): Tree Rings and Climate. Academic Press, London, New York, San Francisco, 567p.

Guiot, J. (1991): The bootstrapped response function. Tree-Ring Bulletin 51: 39-41

Schweingruber, F.H. (1993): Jahrringe und Umwelt: Dendroökologie. Erweitertes Scriptum zur Vorlesung Dendrochronologie am Botanischen Institut der Universität Basel. Birmensdorf: Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft: 474

Van Deusen, P.C., Koretz, J. (1988): Theory and programs for dynamic modelling of tree rings from climate. USDA Forest Service, General Technical Report SO-70: 18

Visser, H., Molenaar, J. (1988): Kalman Filter Analysis in Dendroclimatology. Biometrics, Vol. 44, No. 4:. 929-940

Tree growth - climate response in relation to habitat type in spruce stands of the Borecka Primeval Forest

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Introduction

The annual growth of a tree depends on several factors with climate usually being among the most important. However, under similar climatic conditions, other features that affect the formation of tree-rings and cause variation in the ring-width can be observed. Habitat type determined by, for example, site fertility (e.g. biomass production) or moisture content (water available for the plants) can be such a factor. Habitat conditions may sharpen or soften the climate influence on tree growth due to its variability. Sites with high moisture content in the soil may contain enough water to reduce unfavourable effects of low precipitation or high temperature (and hence increased transpiration). Under the same climatic conditions, trees on drier sites may suffer significant decrease in growth or even stop growing. Understanding these relationships may be useful, in particular for the production of good quality wood.

The objective of this study was to investigate how spruce trees growing in different habitat conditions respond to the climate and to examine whether their reaction to extreme conditions is similar or varies depending on the habitat.

Material and methods

Measurements were carried out in mixed forest stands with Norway spruce (*Picea abies* (L.) Karst.) being the dominant species. The forest stands were located in the Borecka Primeval Forest (Borki forest district, Diabla Góra forestry) in north-eastern Poland. Trees from three different habitat types characterized by different moisture content (fresh, humid and mixed marsh deciduous forest) were collected. The distance between sampling plots was relatively small (ca 1-1.5 km) and therefore it can be assumed that the sites are subjected to the same mezo-climatic conditions.

In total 43 trees were sampled by taking Increment cores at breast height level using a Pressler borer. The cores were then prepared, scanned and measured to the nearest 0.01mm using the PRZYROST program.

Synchronization of the samples was checked with COFECHA (Holmes 1999, Grissino-Mayer 2001) and modified ZGODA (Bruchwald 2000) programs. Series that did not show significant synchronization and convergence with others were excluded. After selection of the samples, a total of 34 samples remained for further analysis. The DPL package programs (Holmes 1999) were used for the statistical analysis, while the CRONOL program was used to build standard and residual chronologies representing individual habitat types as well as the whole

area. The RESPO program was used to examine the relationships between the climate conditions and annual tree-growth. Mean monthly temperature and precipitation from October of the previous year to September of the current year (12 months) were used in the response function model. Finally, the author's program PYA which uses the idea of 'normalisation in a moving window' (Schweingruber et al. 1990) was used in the pointer year analysis. Event year values were calculated within 7–year windows. The threshold for negative or positive event years was set for 0.65. An individual year was considered a pointer year when at least 60 % of the trees showed the same kind of increment reaction (negative or positive event year).

Climate characteristics (monthly mean temperature and precipitation for the period 1951-2000) for the investigated area were obtained for a meteorological station in Suwałki (approximately 60 km eastwards) from the Institute of Meteorology and Water Management (IMGW) and from two Internet open sources (see references for URLs).

Results and discussion

Chronologies

Four chronologies covering the period 1875-2005 were constructed for the fresh, humid and marsh habitats, as well as for the whole area (a, b, c, d on Figure 1 respectively). The average ring width ranged from 2.36 mm (fresh habitat) to 1.43 mm (marsh) and decreased with increasing moisture content of the site. Standard deviation of raw measurement series varied from 0.70 mm (marsh) to 2.07 mm (humid type). Mean sensitivity values showed the same pattern as the average ring width and fall from 0.273 to 0.235.
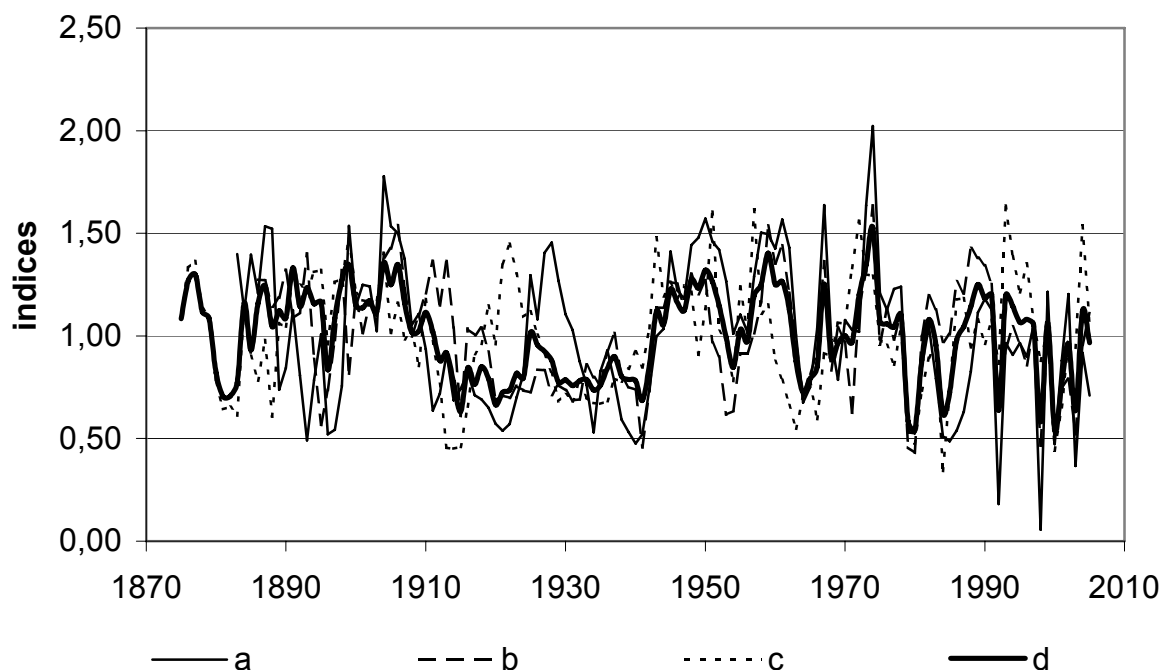
Figure 1: Standard chronologies of Norway spruce of Borecka Primeval Forest for fresh (a), humid (b) and marsh habitats (c) as well as the whole area (d)

Response to climate conditions

Analysis of the response of spruce trees to climate conditions showed that in Borecka Primeval Forest, climate determined less than half of the annual ring-width increment. Determination coefficients (R^2) reached only 40%. Koprowski (2003) obtained slightly higher results for this area. However, values of R^2 varied considerably when individual habitat types were investigated. Fresh and humid types showed a higher response to the climate variability with coefficient values of 57 and 45%, respectively. The formation of the annual rings in marsh habitats seemed not to be driven by climate in great extend as R^2 equals only 16%.

Results show that, as far as the whole area is concerned, warm conditions in September and pluvial in July are statistically the most important factors affecting tree-ring formation (Figure 2). Previous studies (Zielski, Koprowski 2001, Koprowski 2003) pointed out to March temperature and May-July or May-August precipitation as the main factors influencing growth of the tree rings. However, in those studies only fresh deciduous forest stands were analysed, which may cause this discrepancy.

Tree growth – climate responses were different for the different habitat types. The influence of temperature on tree growth was only significant for the the fresh habitat. No statistically significant relationships between temperature and growth were found for the humid and marsh sites. However, the fresh and humid sites share July as the most favourable month for growth due to relatively high precipitation. Again, no significant relationship between climate and tree growth was found for the marsh site.

Pointer years

Pointer years were identified for the period of 1900 to 2002 separately for each habitat type and for the whole area. In total 27 different pointer years were identified. Eleven of them were positive and 16 were negative (Tab. 1).

Table 1: Pointer years of spruce from Borecka Primeval Forest, 1900-2002

Pointer year	Whole site	Habitat type		
		fresh	humid	marsh
positive	1982 1974 1967	1982 1974 1967 1937 1925 1913	1988 1982 1974 1967 1959 1943 1937 1906	1993 1943 1904
negative	1992 1984 1980 1979 1964 1941	1998 1992 1980 1979 1965 1964 1941 1940 1921 1920	1998 1992 1980 1979 1971 1964 1954 1941	2000 1992 1984 1979 1966 1913
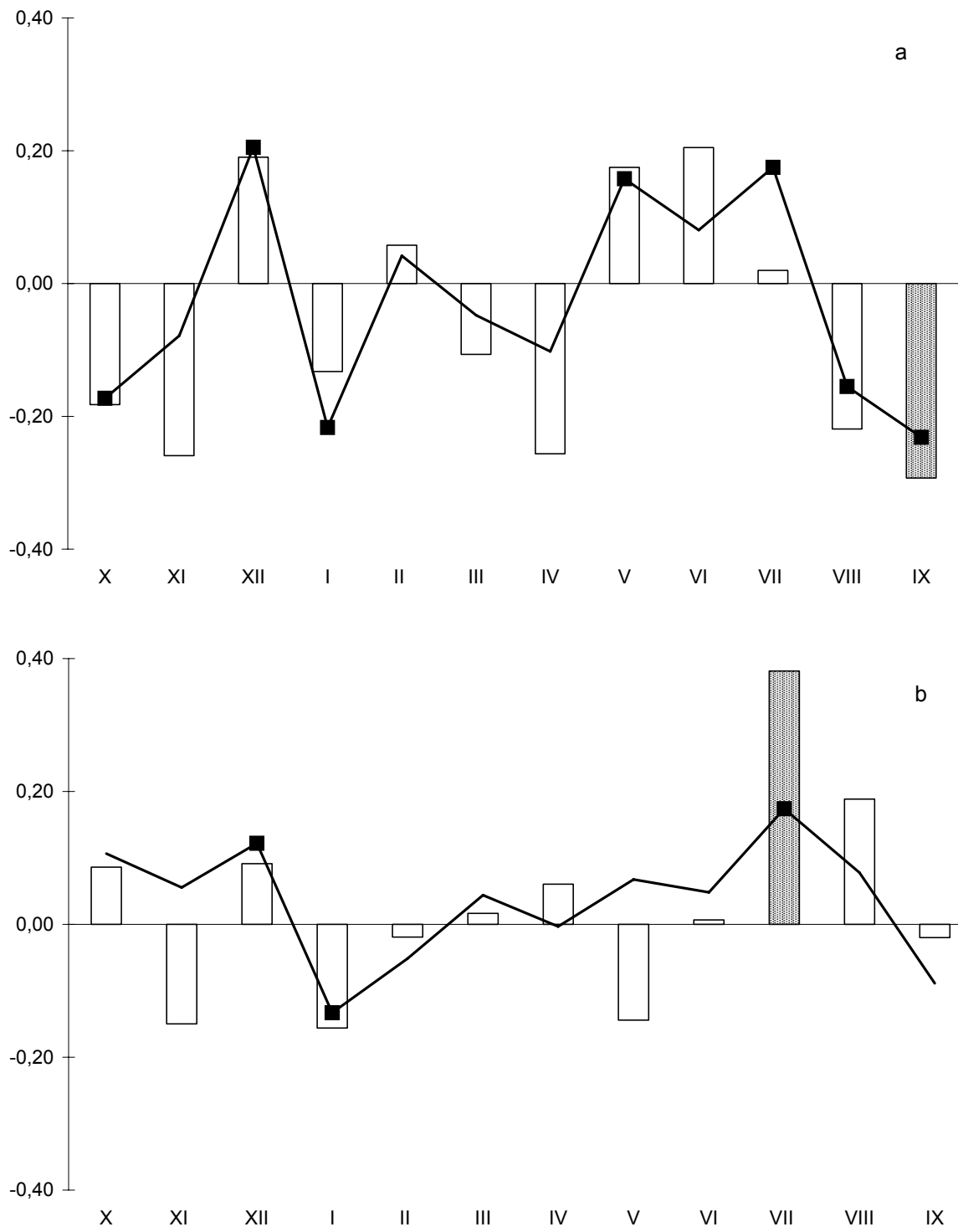
Figure 2: Relationship between increment pattern (residual chronology) and mean monthly temperature (a) and mean monthly sum of precipitation (b) in spruce stands of Borecka Primeval Forest. Bars represent coefficients of correlation and lines coefficients of regression. Hatched bars and squares show values significant at 0.05 level.

In general, fresh and humid habitat types reacted to extreme weather conditions in a very similar way. In both cases, 16 pointer years were detected; of which 9 are shared by both sites (3 positive and 6 negative). Particularly wide rings appeared in the years 1967, 1974 and 1982, while narrow rings appeared in 1941, 1964, 1979, 1980, 1992, and 1998. The marsh habitat showed not only lower sensitivity (less pointer years), but also a quite different pattern of the response to extreme weather conditions, in particular as far as positive pointer years are concerned. This indicates that this habitat type is much less climate-dependant than the other types. However, all sites, individually and as a whole, have two negative pointer years in common: 1979 and 1992. Very narrow rings in these two years were also identifies in neighbouring Olsztyńskie Lakeland (Koprowski, Zielski 2002) and Lithuanian (Vitas 2001, 2004) forest stands as well as in the whole boreal range of Norway spruce in Poland (Koprowski 2003). Similarly, the years 1967 and 1974 were distinguished as positive in Olsztyńskie Lakeland (Koprowski, Zielski 2002) and north-eastern Poland (Koprowski 2003). However, none of the pointer years (positive or negative) from more distant sites in southern Norway (Muter, Bednarz 2003) were present in Borecka Primeval Forest. This confirms that spruce trees from the Baltic region responds to extreme climate conditions homogeneously within small regions.

Conclusions

Annual growth of Norway spruce in Borecka Primeval Forest is dependent on both climate and habitat type. However, the latter factor affects the climate- tree growth responses to a great extent and causes significant differences in tree growth between the habitats. Results of the pointer year analysis show that despite those differences, climate- tree growth relationships of Norway spruce from the examined region resemble the general pattern obtained for the whole boreal range of Norway spruce in north-eastern Poland. The differences that were found in this study should be the starting-point for the further examination of relationships between tree growth, climate and various habitat types.

Acknowledgements

References

Bruchwald, A. (2000): Dendroskale sosny dla różnych regionów Polski. *Przestrzenne zróżnicowanie wzrostu sosny.* 92-104. [in Polish]

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

Holmes, R.L. (1999): Dendrochronology Program Library (DPL) Users Manual. LTRR University of Arizona, Tuscon

Koprowski, M. (2003): Dendrochronologiczna analiza przyrostów świerka pospolitego (*Picea abies* (L.) Karsten subsp. Abies) na wybranych stanowiskach w Polsce, PhD thesis, 120 [in Polish]

Koprowski, M., Zielski, A. (2002): Lata wskaźnikowe u świerka pospolitego [Picea abies (L.) Karsten] na Pojezierzu Olsztyńskim. *Sylwan* 2002/11: 29-39 [in Polish]

Muter, E., Bednarz, B. (2003): Klimatyczne uwarunkowania przyrostu na grubość świerka (*Picea abies* (L) H. Karst) z regionu Parku Narodowego Ormtjernkampen w Norwegii. *Sylwan* 2003/3: 47-56 [in Polish]

Schweingruber, F.H., Eckstein, D., Serre-Bachet, F., Bräker, O.U. (1990): Identification, presentation and interpretation of event years and pointer years in dendrochronology. *Dendrochronologia* 8: 9-38.

Vitas, A. (2001): Drought of 1992 in Lithuania and consequences to Norway spruce. *Baltic Forestry*. Vol. 7, No. 2(13) : 25-30.

Vitas, A. (2004): Tree rings of Norway spruce (*Picea abies* (L) Karsten) in Lithuania as drought indicators dendroecological approach. *Polish Journal of Ecology*. 52: 210-210

Zielski, A., Koprowski, M. (2001): Dendrochronologiczna analiza przyrostów świerka pospolitego na Pojezierzu Olsztyńskim. *Sylwan* 2001/7: 65-73 [in Polish]

http://www.pogpol.chilan.com/wiel/OP.12195.htm

http://data.giss.nasa.gov/cgi-bin/gistemp/gistemp_station.py?id=635121950000&data_set=1&num_neighbors=1

Climatic response of multiple tree-ring parameters from the Spanish Central Pyrenees

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Introduction

There are many studies showing that tree-ring data are highly useful for the assessment of past climatic variations. Annually resolved proxy time-series that extend several centuries back in time and reach into the 21st century, are, however, exceptionally rare. Temperature sensitive ring-width datasets of millennial length are restricted to a mere handful of geographic regions at high northern latitudes or higher elevations.

The paucity of long-term temperature sensitive tree-ring records is greatest in the mid to low-latitudes, and there are even less records if additional parameters (e.g., density) besides tree-ring width are demanded. Critical consequences are that *(i)* too few data exist to distinguish spatial patterns of climatic extremes, particularly prior to AD 1400 (D'Arrigo et al. 2006), *(ii)* large-scale reconstructions of temperature indicate substantial divergence in their amplitude (Esper et al. 2005), and *(iii)* the restriction to ring width data complicates benchmarking annual extremes (Büntgen et al. 2006a, b), as ring width measurements reflect only a short portion of high summer conditions with the tendency of containing some information of the previous year (Frank and Esper 2005). For the southern European region, detailed knowledge of the climatic signal preserved in different tree-ring parameters is limited. Previous dendroclimatological studies from the Pyrenees are based on ring width data from living trees only (Camarero et al. 1998; Gutiérrez 1991; Rolland and Schueller 1994; Ruiz-Flaño 1988; Tardif et al. 2003).

Here we seek to understand the potential of multiple tree-ring parameters for palaeoclimatic reconstructions in the western Mediterranean region. We have developed the first tree-ring dataset of living and dry-dead timberline wood from the Central Spanish Pyrenees that both extends into the 21st century and meanwhile reaches back prior to AD 1000 (with 58 series from three sites reaching back to AD1500). Five annualized tree-ring parameters were measured: tree-ring width, maximum latewood density, minimum earlywood density, earlywood width and latewood width, herein abbreviated as TRW, MXD, MID, EWW and LWW. Their climatic signal was assessed by comparison with regional temperature and precipitation data.

Data and methods

Tree-ring data and detrending

Three climatologically and partly ecologically similar high-elevation timberline sites: Gerber, Sobrestivo and Port de Cabus (hereinafter GER, SOB and CAB) were considered. Living and

in situ dry-dead (i.e., preserved on dry ground) pine (*Pinus uncinata* Ram.) trees of all age-classes were sampled. *Pinus uncinata* Ram. is a shade-intolerant species, most dominant within the sub-alpine Central Pyrenees between 1,600-2,500 m asl.

The GER site (42°38'N, 1°06'E) is located in the northern part of the National Park 'd'Aigüestortes I Estany de Sant Maurici' within an altitudinal range of 2,200-2,450 m asl. The SOB site (42°41'N, 0°06'E), ~70 km west of GER is located between the National Park 'de Ordesa y Monte Perdido' and the French border within an altitudinal range of 2,350-2,450 m asl. The CAB site (42°30'N, 1°25'E), ~50 km east of the GER site is located at the border between Spain and Andorra within an altitudinal range of 2,350-2,450 m asl (Figure 1). While GER and SOB are characterized by wide talus-slopes, CAB is less steep and dominated by an open-forest grassland.
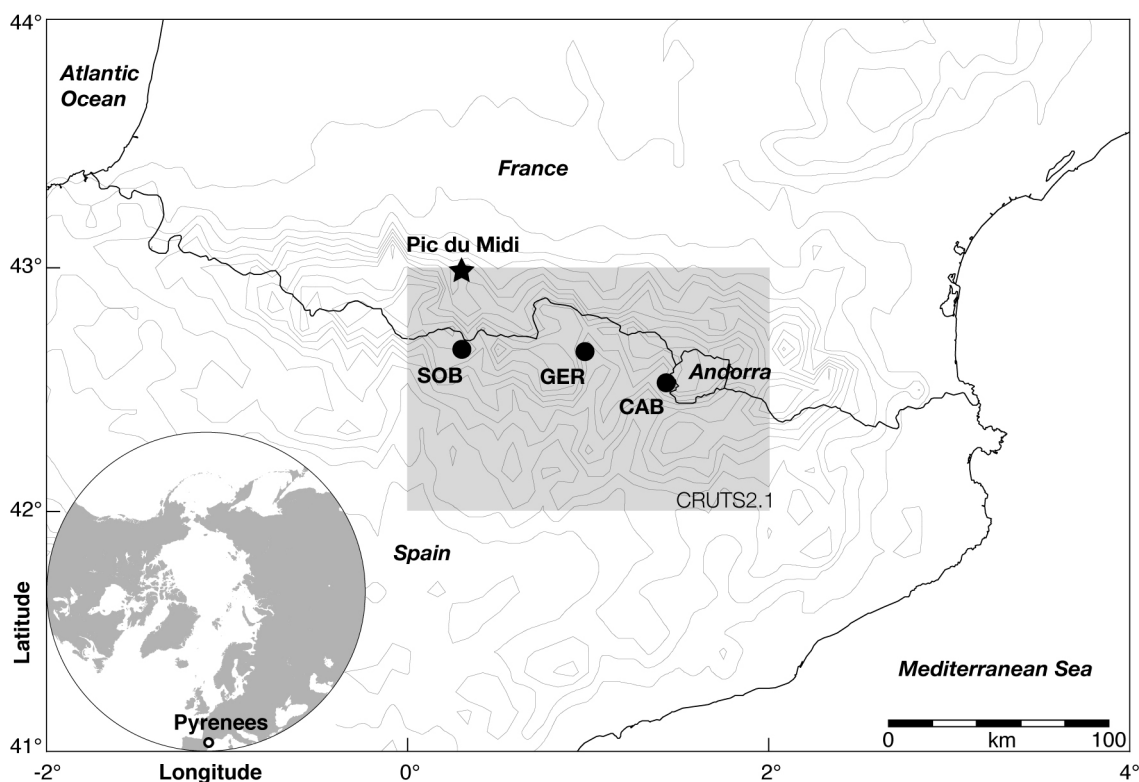
Figure 1: Location of the three timberline sites Gerber (GER), Sobrestivo (SOB), and Port de Cabus (CAB) in the Spanish Central Pyrenees. The inset map shows the location of the Pyrenees in a larger-scale context.

Generally two cores were taken from each tree using an increment borer. 62 (141) core samples from living (dead) trees were collected at GER, 26 (32) were collected at SOB, and 17 (25) were collected at CAB, respectively. Although full site control of the dry-dead material existed, the coring location (i.e., stem height) within relict trees often remained unclear, as advanced levels of wood decay yielded to sparse stem leftovers. However, as pines growing near the timberline commonly produce large amounts of resin that preserves the wood by hindering the growth of fungi long after a tree has died (e.g., Grudd et al. 2002). Consequently, dry-dead material herein considered, though often not more then small stem remains, has a wide age range, with the oldest germination date being in the AD 920s. For

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this study, 303 core samples of all age-classes, i.e., segment length ranges from 11-732 years, were selected for MXD measurements (Figure 2). Wood was processed using a WALESCH 2003 X-ray densitometer with a resolution of 0.01 mm, and brightness variations transferred into g/cm³ using a calibration wedge (Eschbach et al. 1995). High-resolution density profiles were then utilized to obtain the five tree-ring parameters: TRW, MXD, MID, EWW and LWW (Schweingruber et al. 1978).

A Site	TRW (mm)	MXD (g/cm³)	MID (g/cm³)	EWW (mm)	LWW (mm)	MSL (years)	Series (cores)	Period (after truncation <5)
GER	0.82	0.63	0.33	0.64	0.19	208	203	924 (1260)-2005
SOB	0.75	0.66	0.32	0.59	0.16	235	58	1499 (1517)-2005
CAB	0.72	0.60	0.33	0.56	0.17	213	42	1377 (1479)-2005
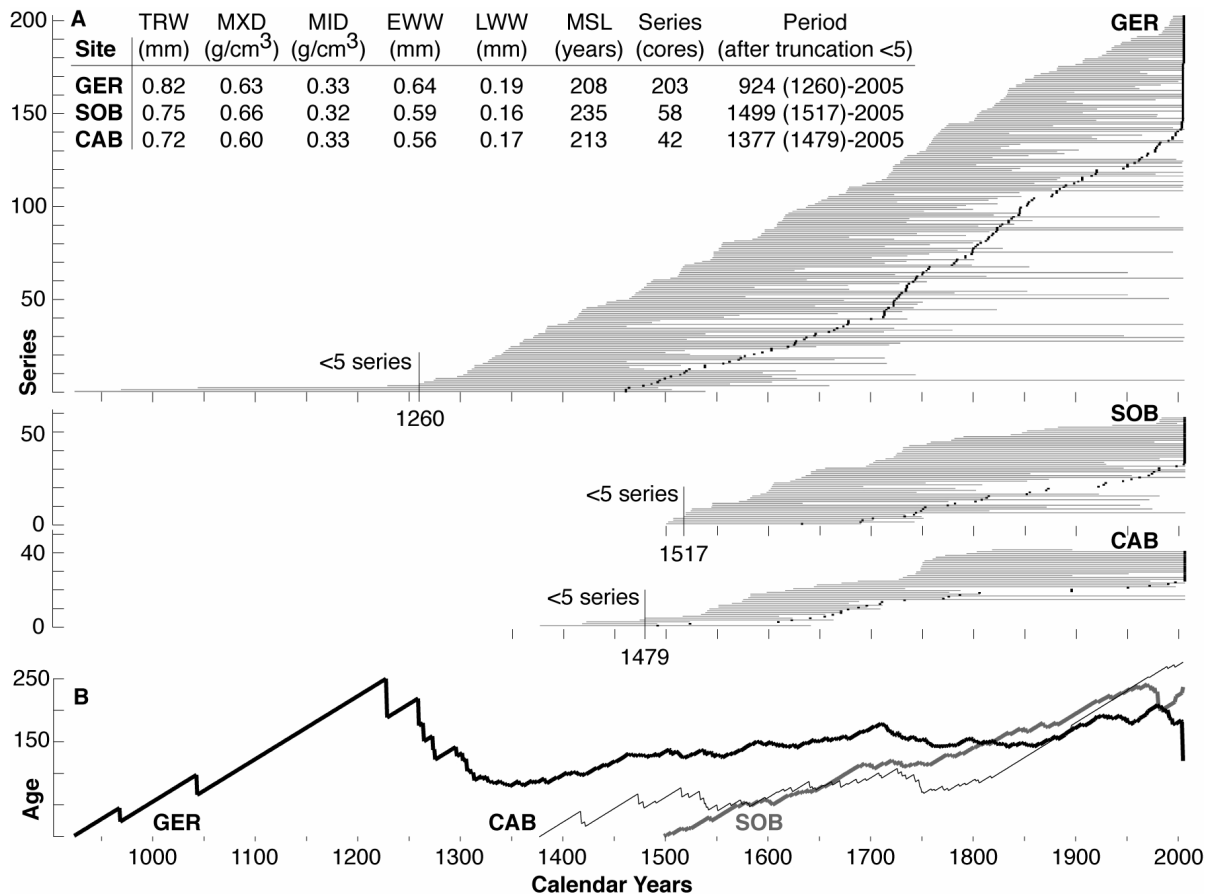
Figure 2: A) Temporal distribution of the 203 Gerber (GER), 58 Sobrestivo (SOB), and 42 Port de Cabus (CAB) core samples. Note the reduction in sample size <5 series prior to AD 1260, 1517 and 1479, respectively. Black dots denote potential sample distribution if series are ordered by their outermost ring. B) Mean cambial age of the GER, SOB and CAB samples for each calendar year. The inset table compares the five individual tree-ring parameters and chronology characteristics on a site-by-site level.

To remove non-climatic, age-related growth trends from the raw measurement series (Fritts 1976), though allow variations from inter-annual to multi-decadal length to be preserved, individual series standardization was applied using ARSTAN (Cook 1985). Indices were calculated as ratios from relatively stiff 300-year cubic smoothing splines (Cook and Peters 1981). For details see Cook et al. (1995) and Esper et al. (2003), for example. For chronology development, series were averaged using a bi-weight robust mean. The variance in the mean chronology was stabilized using methods described by Osborn et al. (1997). Signal strength of the chronologies was assessed using a 'moving window' approach of the inter-series correlation (*Rbar*), and the expressed population signal (*EPS*; Wigley et al.

1984). *Rbar* is a measure of common variance between single series, independent of the number of measurement series. *EPS* is an absolute measure of chronology error that determines how well a chronology, based on a finite number of trees, estimates the theoretical population chronology from which it has been drawn. *EPS* quantifies the degree to which this particular sample record portrays the theoretical population chronology.

Meteorological data

For growth/climate response analyses, records of monthly minimum and maximum temperatures from the Pic du Midi mountain observatory (Pic du Midi de Bigorre: 2,862 m asl, 43°04'N, 0°09'E) were used. See Bücher and Dessens (1991) and Dessens and Bücher (1995, 1997) for details. A dataset of gridded (0.5°x0.5°) monthly temperature means and precipitation sums was further considered (CRUTS2.1; Mitchell and Jones 2005). Mean values from 15 grid-boxes covering the 42-43°N and 0-2°E region were utilized.

Local climate conditions of the GER site were estimated from three nearby high-elevation instrumental station records: *Bonaigua* (2,263 m asl, 42°40'N, 1°06'E), *Sant Maurici* (1,920 m asl, 42°34'N, 1°00'E), *Estany-Gento* (2,120 m asl, 42°30'N, 1°00'E). The mean annual temperature with respect to the 1961-90 period is ~4.3°C, with the lowest (-2.5°C) and highest (13.1°C) monthly values measured in January and July, respectively. The mean annual precipitation is ~1250 mm, evenly distributed throughout the year, which is likely due to the study's location in commonly prevailing air masses of maritime origin, and the existence of convective summer precipitation during periods of persistent high-pressure influence from the Azores-high.

Results

Growth-trends

Raw measurement series of each of the five parameters were age-aligned on a site-by-site basis (considering pith-offset estimation), and their mean growth trends, the so-called regional curves (RCs) estimated (Figure 3). Resulting RCs depict the common growth trend of a given species, parameter and site. Increased variance towards the series outermost ends is induced by low sample replication. While the RCs estimated for TRW, EWW and LWW resemble negative exponential functions, i.e., high values during the juvenile phase (~50 years) followed by an exponential decrease, the RCs derived from MXD describe a somewhat generalized linear decline. After a short juvenile period of high densities until ~25 years, RCs for the MID parameter are nearly horizontal.

Surprisingly, the greatest between site differences are found for MXD, whereas the other parameters show rather similar growth trends at each site. Age-aligned MXD values from the CAB site show almost no juvenile increase following a horizontal line with a relative low mean. Note that the other parameters derived from CAB, though, show a clear juvenile growth pattern, indicating that only little to no pith offset is given. Although MXD values from the GER and SOB sites show a slight juvenile increase, their linear trends are nearly flat, however, characterized by different mean values.
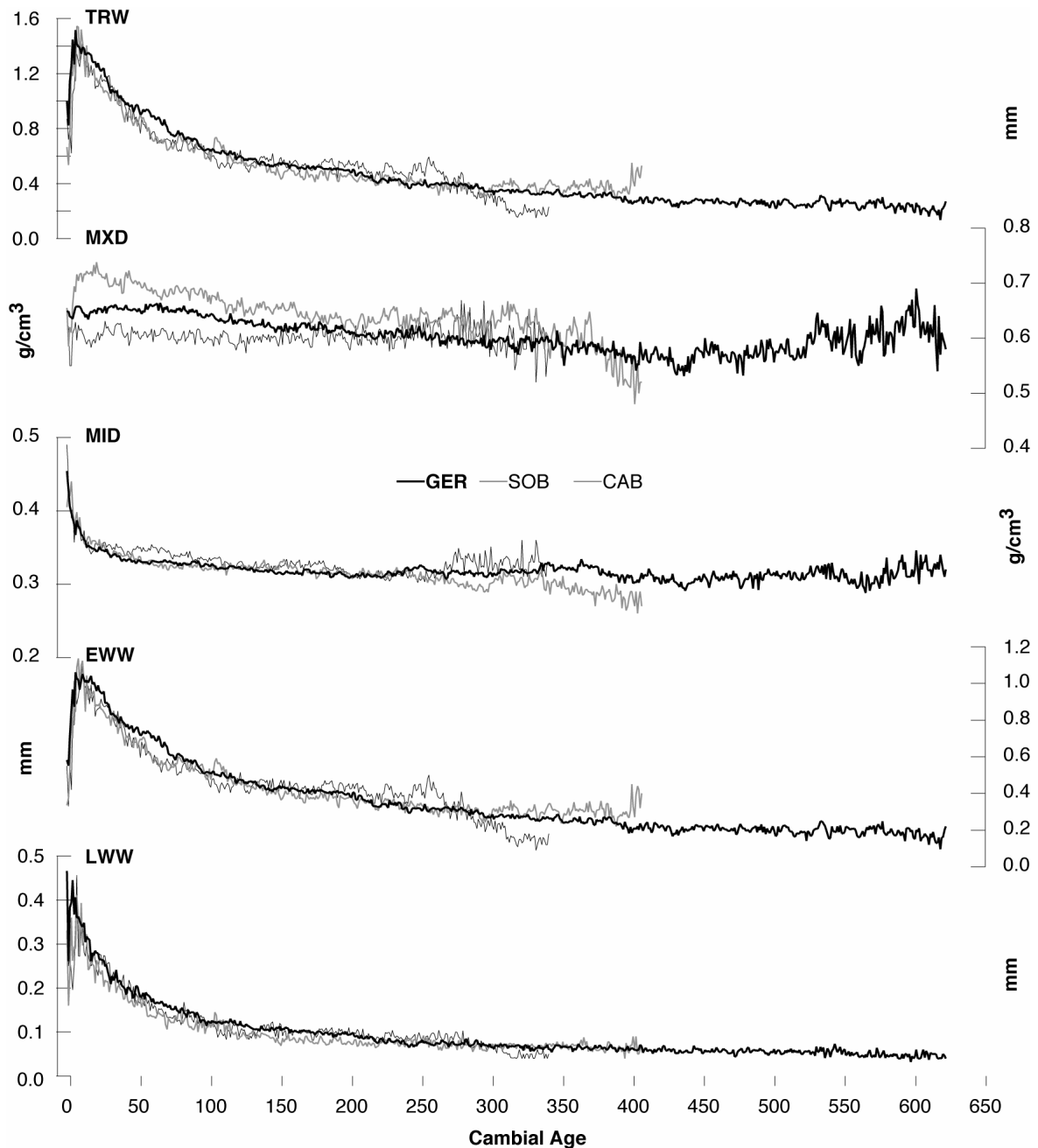
Figure 3: Mean growth trends of the five parameters after age-aligning all series by cambial age (considering pith-offset estimation) on a site-by-site basis. Regional curves are truncated at 5 series.

Chronology characteristics

Visual comparison of the 20-year low-pass filtered site chronologies (using individual 300-year spline detrending) illustrates some common decadal-scale variability in the TRW, MXD, EWW and LWW series, but less agreement with MID chronologies (Figure 4). Distinct decadal-scale depressions are recorded around 1600 AD, 1700, in the 1820s and 1970s in the TRW, MXD, EWW and LWW chronologies that coincide with the timing of solar minima (Luterbacher et al. 2001; Wanner et al. 1995), and/or periods of increased volcanic activity (Oppenheimer 2003). Similar TRW and MXD responses to solar and volcanic forcing are reported from the European Alps (Büntgen et al. 2006a), Tatra Mountains (Büntgen et al.

2006b) and Canadian Rockies (Luckman and Wilson 2005), for example. In contrast, the MID chronologies show increased values during these periods.
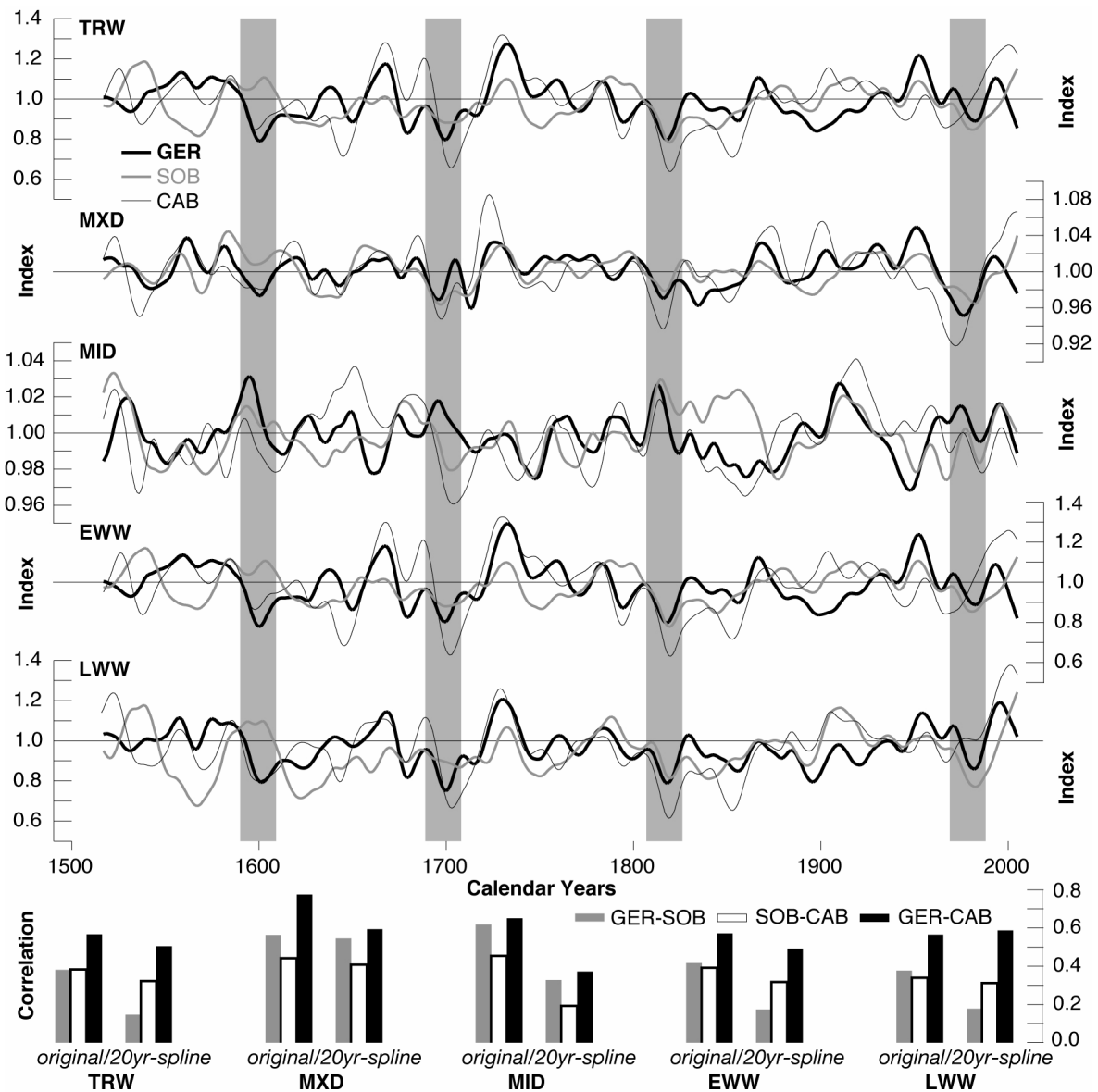
Figure 4: Site chronologies (GER = black; SOB = grey; CAB = light grey) of the five parameters after standardization using fixed 300-year smoothing splines. Series are 20-year low-pass filtered, truncated at <5 series and shown over their common 1517-2005 period. Grey shadings denote periods of common decadal-scale growth depressions in the TRW, MXD, EWW and LWW series. Bar plots denote intra-parameter correlations between the three sites GER, SOB and CAB, using the original (left) and low-pass filtered (right) chronologies.

Correlations between chronologies of the same parameter, but from different sites, show highest agreement between the GER and CAB data. Such inter-site correlations are most significant for MXD, followed by MID, and generally lower for all three 'width' parameters (Figure 4). While inter-site coherency of the 'density' chronologies is strongest between the original chronologies and tends to decrease after 20-year low-pass filtering, coherency of the 'width' chronologies is equally distributed amongst inter-annual and multi-decadal frequency.

Interestingly, lowest correlations are obtained between the smoothed TRW, EWW and LWW chronologies from GER and SOB, most likely reflecting the parameters high degree of unexplained mid-frequency variability, in comparison to MXD.

First order autocorrelation is lowest for MXD, followed by slightly higher values for MID (Table 1). LWW, EWW and particularly TRW, however, show significant first order autocorrelation, reflecting biological persistence in radial growth (Frank and Esper 2005a). Hence, there is a tendency of overestimating decadal-scale variability when using TRW measurements for reconstructing past environmental conditions, as the 'target's' autocorrelation is lower. Out of all five parameters, the lowest autocorrelation is derived from GER, whereas increased values obtained from SOB and CAB are fairly similar. *Rbar* and *EPS* statistics of the SOB site are generally lower than those of the GER and CAB sites. Robust *EPS* statistics for the GER chronology most likely result from the high sample depth, whereas stable *EPS* statistics for the CAB chronology most likely result from open forest-grassland site conditions, which result in less between tree competition and physical stress (e.g., rock fall). Signal strength of the SOB chronology, however, possibly suffers from low replication and the severe talus-slope site condition (e.g., increased rock fall activity). Such indicators of chronology signal strength are relatively high for the MXD, TRW and EWW records, compared to lower values obtained for the MID and LWW chronologies.

Table 1: Chronology characteristics of the five parameters on a site-by-site basis using the 1517-2005 common period. AC_1 refers to the records autocorrelation lagged by one year. Rbar and EPS are mean value statistics from using 30-year windows lagged by 50%.

	TRW			MXD			MID			EWW			LWW		
	GER	SOB	CAB	GER	SOB	CAB	GER	SOB	CAB	GER	SOB	CAB	GER	SOB	CAB
AC_1	0.41	0.54	0.63	0.00	0.22	0.19	0.12	0.28	0.28	0.38	0.48	0.61	0.25	0.48	0.48
Rbar	0.26	0.21	0.32	0.29	0.15	0.35	0.14	0.13	0.16	0.26	0.21	0.32	0.17	0.17	0.22
EPS	0.95	0.86	0.87	0.96	0.80	0.89	0.91	0.76	0.72	0.96	0.86	0.87	0.93	0.83	0.80

With respect to the common signal reported from the three site chronologies and to provide a more comprehensive regional-scale approach, five records (TRW, MXD, MID, EWW, LWW) were averaged using all 303 measurement-series available. These resulting mean parameter chronologies reflect growth patterns of the Central Pyrenees, and thus are most suitable for the comparison with climate data. For the 20th century where maximum proxy replication is given and instrumental measurements of monthly temperature means and precipitation sums are most reliable, a detailed examination on inter-annual growth variations of the five parameters was conducted (Figure 5).
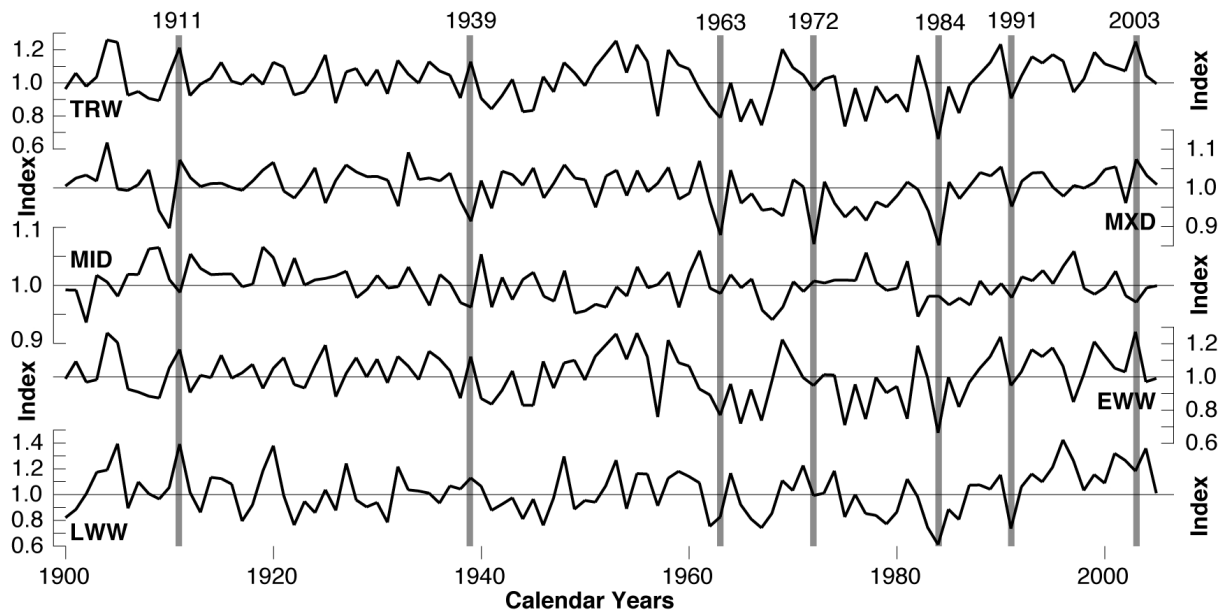
Figure 5: Mean series of the five parameters after averaging the three sites chronologies standardized using fixed 300-year smoothing splines. Grey shadings denote common extremes in annual growth variations.

Due to the applied individual spline detrending, vital inter-annual to multi-decadal scale variability was preserved, whereas potential longer-term trends were consequently removed. Indices are relatively stable from 1900 to ~1940, followed by a slight increase until ~1955 and small depressions ~1965 and ~1975. An increase is observed over the last 30 years with a peak in 2003. These decadal-scale fluctuations are distinct in the 'width' chronologies, but less pronounced in the 'density' records. A positive pointer year in 1911 is reported from all parameters with the exception of MID, which shows a negative anomaly. A similar pattern occurs in 2003 where all parameters show a positive pointer year, but a low value is found for MID, and also for LWW. Annual growth depressions common to all five parameters are found in 1963 and 1991 (most likely due to volcanic eruptions), whereas MID shows relatively stable values in 1972 and 1984, and all other parameters indicate negative anomalies. In 1939 the three 'width' parameters show a positive value, whereas the two 'density' parameters show a negative anomaly.

Correlations between the mean TRW, EWW, LWW and also the MXD chronologies are significant (p <0.01), whereas no significant correlations are found for the MID chronology (Table 2). Correlations between the five parameters computed over the 1901-2002 period (which is used for comparison with meteorological data) remain stable even if the full period 1517-2005 is used.

Table 2: Correlation matrix of the five mean parameter chronologies as introduced in figure 5. Correlations in the upper right part of the matrix refer to the 1901-2002 period of overlap with the instrumental data, while correlations in the lower left derive from the full 1517-2005 period common to all chronologies after truncation <5 series.

		TRW	MXD	MID	EWW	1901-2002 LWW
	TRW		0.44	-0.10	0.98	0.67
	MXD	0.36		0.26	0.39	0.41
1517-2005	**MID**	-0.18	0.06		-0.18	0.25
	EWW	0.98	0.36	-0.25		0.49
	LWW	0.73	0.30	0.13	0.59	

Growth/climate response

Growth/climate response analysis between the five mean parameter chronologies and minimum, mean, and maximum temperature and precipitation data was undertaken (Figure 6). Correlations were computed over the common period 1901-2002, using an 18-month window from May of the year prior to tree growth until current year October, along with various seasonal means.

MXD revealed generally significant (p <0.01) response to monthly March, May and August, and various seasonal temperature means of the current year. May-September temperatures yielded the highest correlation. MXD correlations with current year June and July temperatures, along with those of the previous year and precipitation sums of all target windows were found to be not significant (p <0.01). Even though, this generally derived response pattern (monthly May and August, seasonal May-September) of the MXD parameter exists for all temperature records, highest correlations are gained from maximum, and lowest correlations from minimum temperatures. Detailed information on the potential of reconstructing regional-scale maximum summer temperatures back into medieval times using MXD data is provided in Büntgen et al. (in review). A nearly similar MXD response to maximum growing season temperatures is further reported from the Canadian Rocky Mountains (Luckman and Wilson 2005; Wilson and Luckman 2003). A comparable pattern of MXD formation, i.e., during the early and late vegetation period with less vitality in between, is reported from a larch network from nearby timberline sites in the Swiss Alps (Büntgen et al. 2006a), from a multi-species network across the Alpine arc (Frank and Esper 2005), the Tatra Mountains in the northwestern Carpathian region (Büntgen et al. 2006b), and from hundreds of sites along the northern latitudinal timberline (Briffa et al. 2002). An altitudinal/latitudinal modification of the absolute growing season length, however, must be considered, when comparing results from different geographical settings.

MID revealed a somewhat similar monthly response pattern as described for MXD, with lower significance, though. Remarkable differences, however, are the significant (p <0.01) negative response of MID to July and all high summer seasonal temperature means, complimenting the inverted correlation results as described above.

TRW, EWW and LWW correlations with minimum, mean and maximum temperatures and precipitation sums are not significant, or show only slightly coherence. The first month that shows significant, and at the same time highest correlations (*p* <0.01), independent of the parameter and temperature data considered, is May. A similar relationship between radial growth and May temperatures of several high-elevation *Pinus uncinata* TRW sites from the Central Spanish Pyrenees has been observed by Tardif et al. (2003), however, they also describe some effect of previous November temperatures on tree growth.
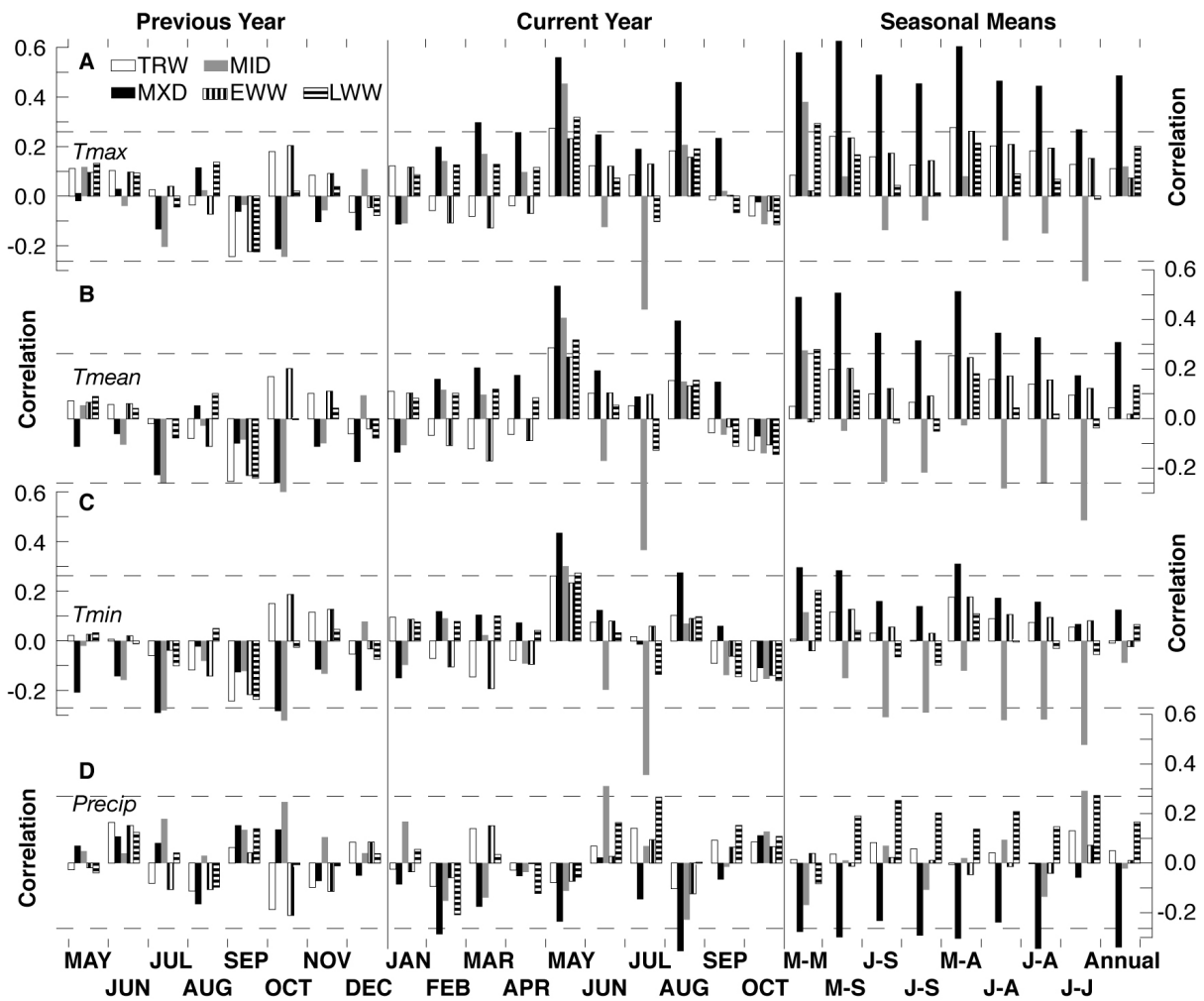
Figure 6: Growth/climate response of the five parameters using A maximum temperatures, B mean temperatures, C minimum temperatures, and D precipitation sums. Correlations are computed from previous year May to current year October over the 1901-2002 common period. Horizontal dashed lines denote the 99% significance levels, corrected for lag-1 autocorrelation. Temperature data derive from the Pic du Midi station, and precipitation data from the CRUTS2.1 gridded dataset, using the mean of 15 grid-boxes that cover the 0-2°E and 42-43°N region. Seasonal abbreviations refer to March-May, May-September, June-September, July-September, May-August, June-August, July-August, June-July, respectively.

Discussion and conclusions

We have presented a new collection of living and dry-dead wood from three timberline sites in the Central Spanish Pyrenees resulting in a composite dataset spanning the AD 924-2005

period. For each site chronology five parameters were measured and compared with regional-scale climate data. While MXD revealed a distinct positive response to May-September temperatures, MID showed a distinct negative response to July and June-July mean temperatures. All other parameters showed no or little response. Even though the dataset utilized, the methods applied and the climate response derived demonstrate the capability of high-elevation *Pinus uncinata* MXD data to robustly reconstruct variations in maximum summer temperatures, several limitations remain.

Even though, all relict material from the three sampling sites is compiled, robust replication still ceases to exist before AD 1500. When sampling dry-dead material, variable degrees of wood decay complicate knowing the stem's coring location. Sometimes samples were collected far from the base of a tree or at unknown heights, hindering the exact dating of the tree's germination date, and potentially introducing some bias in the climatic signal preserved. The individual spline detrending applied, restricts the final chronologies to reflect inter-annual to multi-decadal variations and eliminates potential lower frequency information. To gain a somewhat distinct summer temperature signal, capable for the assessment of past variations, extensive measurements of MXD are required, as TRW revealed a diminished growth/climate response. It appears that only trees growing under severe timberline conditions maintain a temperature signal, whereas radial growth at lower elevation reflects a mixed signal likely to be dominated by changes in precipitation. A reduced number of long and homogenized instrumental station data reflecting climate conditions of the high-elevation sampling sites, further hinders comparison, calibration and verification over longer periods.

Our analysis demonstrates that MXD is the strongest proxy for the reconstruction of past summer temperature variations in the Central Spanish Pyrenees, whereas all other parameters expressed only a weak signal at best. This study, however, also showed that differences independent of the parameter exist between the three sites. To gain insight into such local-scale variability and at the same time allow regional-scale conclusions to be drawn, future research will need to consider *(i)* the update of existing and *(ii)* development of new MXD chronologies covering the entire Pyrenees from the Mediterranean Sea in the east to the Atlantic Ocean in the west. New samplings should be focused at *(iii)* high-elevations and possible compile *(iv)* dry-dead and sub-fossil wood.

References

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E.A. (2002): Tree-ring width and density around the Northern Hemisphere: Part 1, local and regional climate signals. *The Holocene* 12:737-757.

Bücher, A., Dessens, J. (1991): Secular trend of surface temperature at an elevated observatory in the Pyrenees. *Journal of Climate* 4:859-868.

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

Büntgen, U., Frank, D.C., Kaczka, R.J., Verstege, A., Zwijacz-Kozica, T., Esper, J. (2006b): Growth/climate response of a multi-species tree-ring network in the Western Carpathian Tatra Mountains, Poland and Slovakia. *Tree Physiology* (in press).

Büntgen, U., Frank, D.C., Grudd, H., Verstege, A., Nievergelt, D., Esper, J. (in review): Eight centuries of Pyrenees summer temperatures from tree-ring density. *Climate Dynamics.*

Camarero, J.J., Guerrero-Campo, J., Gutiérrez, E. (1998): Tree-ring growth and structure of Pinus uncinata and Pinus sylvestris in the Central Spanish Pyrenees. *Arctic and Alpine Research* 30:1-10.

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

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

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

D'Arrigo, R., Wilson, R.J.S., Jacoby, G.C. (2006): On the long-term context for late 20th century warming. *Journal of Geophysical Research* 111, D03103, doi:10.1029/2005JD006352.

Dessens, J., Bücher, A. (1995): Changes in minimum and maximum temperatures at the Pic du Midi in relation with humidity and cloudiness, 1882-1984. *Atmospheric Research* 37:147-162.

Dessens, J., Bücher, A. (1997): A critical examination of the precipitation records at the Pic du Midi observatory, Pyrenees, France. *Climatic Change* 36:345-353.

Eschbach, W., Nogler, P., Schär, E., Schweingruber, F.H. (1995): Technical advances in the radiodensitometrical determination of wood density. *Dendrochronologia* 13:155-168.

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

Esper, J., Wilson, R.J.S., Frank, D.C., Moberg, A., Wanner, H., Luterbacher, J. (2005): Climate: Past Ranges and Future Changes. *Quaternary Science Reviews* 24:2164-2166.

Frank, D.C., Esper, J. (2005): Characterization and climate response patterns of a high elevation, multi species tree-ring network for the European Alps. *Dendrochronologia* 22:107-121.

Fritts, H.C. (1976): Tree rings and climate. Academic Press, London, pp 567.

Grudd, H., Briffa, K.R., Karlén, W., Bartholin, T.S., Jones, P.D., Kromer, B. (2002): A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. *The Holocene* 12:657-665.

Gutiérrez, E. (1991): Climatic tree growth relationships for Pinus uncinata Ram. in the Spanish pre-Pyrenees. *Acta Oecologia* 12/2:213-225.

Luckman, B.H., Wilson, R.J.S. (2005): Summer temperatures in the Canadian Rockies during the last millennium: a revised record. *Climate Dynamics* 24:131-144.

Luterbacher, J., Rickli, R., Xoplaki, E., Tinguely, C., Beck, C., Pfister, C., Wanner, H. (2001): The Late Maunder Minimum (1675-1715) – A key period for studying decadal scale climate change in Europe. *Climatic Change* 49:441-462.

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

Oppenheimer, C. (2003): Climatic, environmental and human consequences of the largest known historic eruption: Tambora volcano (Indonesia) 1815. *Progress of Physical Geography* 27/2:230-259.

Osborn, T.J., Briffa, K.R., Jones, P.D. (1997): Adjusting variance for sample-size in tree-ring chronologies and other regional-mean time-series. *Dendrochronologia* 15:89-99.

Rolland, C., Schueller, F. (1994): Relationships between mountain pine and climate in the French Pyrenees (Font-Romeu) studied using the radiodensitometrical method. *Pirineos* 143/144:55-70.

Ruiz-Flaño, P. (1988): Dendroclimatic series of Pinus uncinata R. in the Central Pyrenees and in the Iberian System. A comparative study. *Pirineos* 132:49-64.

Schweingruber, F.H., Fritts, H.C., Bräker, O.U., Drew, L.G., Schär, E. (1978): The X-ray technique as applied to dendroclimatology. *Tree-Ring Bulletin* 38:61-91.

Tardif, J., Camarero, J.J., Ribas, M., Gutiérrez, E. (2003): Spatiotemporal variability in tree growth in the Central Pyrenees: Climatic and site influences. *Ecological Monographs* 73:241-257.

Wanner, H., Pfister, C., Brázdil, R., Frich, P., Frydendahl, K., Jónsson, T., Kington, J., Rosenørn, S., Wishman, E. (1995): Wintertime European circulation patterns during the Late Maunder Minimum cooling period (1675–1704). *Theoretical and Applied Climatology* 51:167-175.

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

Wilson, R.J.S., Luckman, B.H. (2003): Dendroclimatic Reconstruction of Maximum Summer Temperatures from Upper Tree-Line Sites in Interior British Columbia. *The Holocene* 13:853-863.

Dendrochronological investigations on *Juniperus procera* from Ethiopian dry afromontane forests

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Introduction

Within the dry afromontane forests of the Ethiopian highlands, *Juniperus procera* dominates from 2300 to 3200 m asl, where the mean annual rainfall ranges from 500 to 1100 mm. This tall (up to 50 m), evergreen forest tree is the only tropical African juniper and is indigenous to the East African tropical highlands. Its timber is strong and highly valuable; after seasoning the wood is very durable, immune to fungal attacks, termites or wood-borers (Gardner 1926, Pohjonen and Pukkala 1992). Therefore, juniper is the most preferred multipurpose tree in Ethiopia for construction, furniture, firewood, fencing and medicinal uses (Chaffey 1982), and holds as well a strong symbolic and religious meaning. The juniper dominated woodlands once covered a large part of the country. However, as a consequence of long-lasting and persistent human influence, they have been considerably depleted and are now reduced to some isolated patches (Negussie 1995, Nyssen et al. 2004).

To support conservation, restoration and sustainable use of the remaining woodlands more information is needed on growth pattern and population dynamics of *Juniperus procera*. Moreover, in the context of an increasing concern about global climate change, this study was an opportunity to assess the potential of *Juniperus procera* for dendroclimatic investigations in this poorly documented region of the tropics (Verheyden et al. 2005). Classical dendrochronological methods were used to build up tree-ring chronologies for *Juniperus procera* trees from two Ethiopian highland forests, and to check whether these chronologies have the potential to serve as proxies to study past changes in climate.

Study sites

The two investigated sites are located 300 km apart from each other in the Ethiopian highlands (Fig.1). The Menagesha-Suba forest stretches on the southwest facing slopes of Mount Wechecha (8°97'N to 9°00'N, 38°35'E to 38°38'E; 2300 - 2900 m asl), an extinct volcano 45 km southwest of the capital city Addis Ababa. The Adaba-Dodola forest lies on the northern side of the Bale Mountains (6°50'N to 7°00'N, 30°07'E to 39°22'E; 2400 - 3100 m asl).

Figure 1: Map of Ethiopia with the two study sites.

Both woodlands are remnants of dry evergreen mountain forests dominated by *Juniperus procera*. Despite their conservation status as National Forest Priority Areas, repeated human interferences have led to heavy degradation and nowadays closed forest is only restricted to difficultly accessible areas. The climate is tropical alpine, with an average temperature of 10 °C to 16 °C, depending on the altitude, and a mean annual precipitation of 1200 mm. The climate records from the Holeta and Dodola stations, located in direct vicinity of the study sites, show a slight difference in the total amount of rainfall but a similar pattern in the annual distribution of precipitation (Fig. 2).
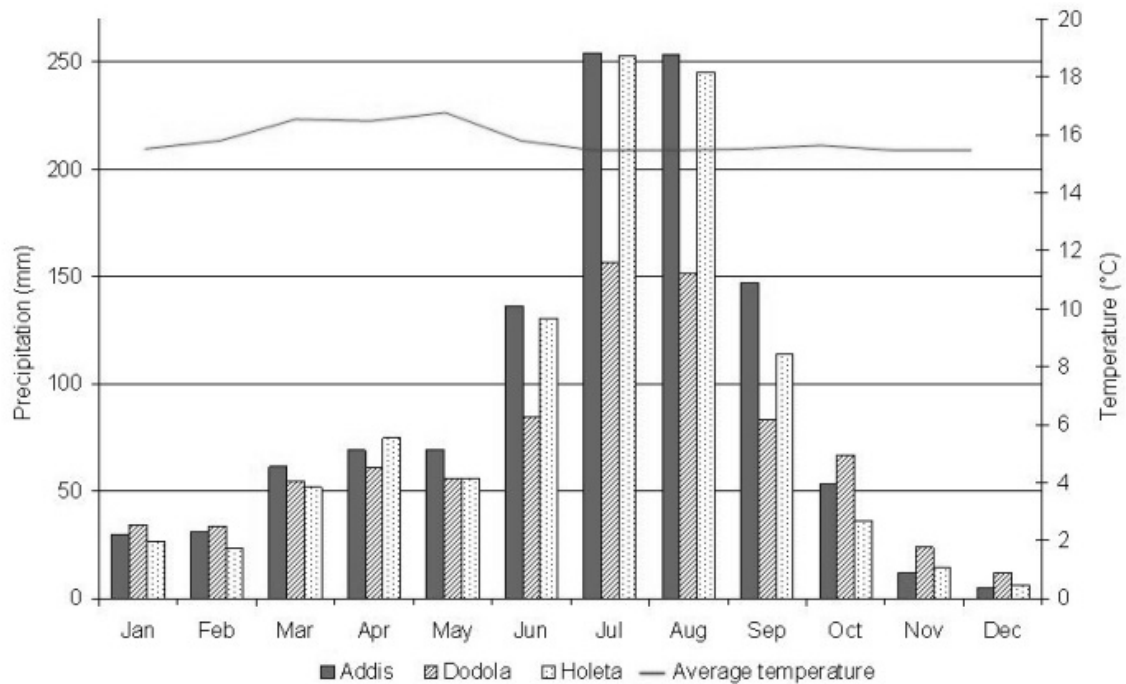
Figure 2: Climate diagram for Addis Ababa (09°03' N, 38°42' E; 2400 m asl), Adaba-Dodola and Holeta (closest weather station from Menagesha). Average values for the 13 common years with available data in the three sites (1972, 1975-1979 and 1996-2002).

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Both records reflect a bimodal distribution in rainfall with a main rainy season from June/July to September/October and a minor one from January/February to April/May.

Material and methods

Since juniper species are known to be problematic for dendrochronological studies (Esper 2000, Sigl et al. 2005), we mainly worked with whole stem sections from fallen trees or remains of recently cut trees: 11 stem discs were collected in Adaba-Dodola, from which two were planted at a known date. 11 stem discs and 26 increment cores from 13 living trees were collected in Menagesha-Suba. The stem discs were taken from stumps with a known felling date, between 30 and 50 cm above the ground; the two cores per tree were collected at breast height. The diameters of the sampled trees ranged from 16 to 46 cm.

All samples were air-dried. The stem discs were sanded until grit size of 800 and the 26 increment cores were mounted on wooden holders and hand-trimmed with a Stanley knife. From a first macroscopic inspection, distinct concentric growth bands were visible.

Tree ring widths were measured with a precision of 0.01 mm along four radii of the stem sections, using LINTAB (RinnTec) associated with TSAP (Rinn 1996). The time series were visually and statistically cross-dated to obtain mean tree-ring series for each juniper tree (Cook & Kairiukstis 1990, Stokes and Smiley 1996). We estimated the age of single trees after correction for missing rings due to sampling height. From this estimation and the measured ring widths, we developed diameter-age relationships for each individual. Linear regression was fitted to each of the accumulated growth curves to calculate mean growth rates for each tree. Tree-ring chronologies for the two sites, Adaba-Dodola and Menagesha-Suba, were constructed following a standard dendrochronological protocol: a 30-year spline was fitted to the single tree-ring records to remove any age-related trend in the series. Tree-ring indices were then produced by dividing each of the original tree-ring widths by the value of the fitted spline (Cook 1985, program ARSTAN http://www.ldeo.columbia.edu/res/fac/trl/public/publicSoftware.html). Subsequently, the 11 and 24 index series were averaged into two single site chronologies for *Juniperus procera* in Adaba-Dodola and Menagesha-Suba forests, respectively.

To evaluate the signal strength of both sites we calculated the Expressed Population Signal (EPS) for both chronologies, based on the average correlation between each site's tree-ring series (Wigley et al. 1984, Verheyden et al. 2005).

Response-function analysis (program DendroClim 2002, Biondi and Waikul 2004) has been carried out to assess the impact of changes in monthly mean temperature and the monthly sum of precipitation from September of the previous year till October of the observed year on the annual variation of tree-ring width during the period from 1905 to 2002.

Results and discussion

Wood of *Juniperus procera* appears light brown or golden, with clearly distinguishable, more reddish, heartwood (Fig. 3). Concentric tree rings are macroscopically visible: the late wood consisting of small and thick-walled tracheids appears darker than the early wood made of wider and thin-walled tracheids. The boundary between rings is marked by a flattening of the

tracheids, which become almost rectangular (Fig. 4a). Even so, measurement was hampered by the occurrence of wedging or partly missing rings, mostly due to low growth rates. Intra-annual variations appear in some growth layers, almost exclusively in the widest ones (Fig. 4b). They could often be related to a particularly clear bimodal pattern in the distribution of precipitations in the corresponding years, with a minor rainy season followed by a major one. However, these "double rings" do not appear in all trees simultaneously, which can possibly be related to different sensitivities of trees and/or site conditions. Studies focusing more specifically on this wood-anatomical pattern would clarify the relationship between juniper wood formation and environmental conditions with a high temporal resolution.

Figure 3: Stem disc of Juniperus procera with distinct growth layers.
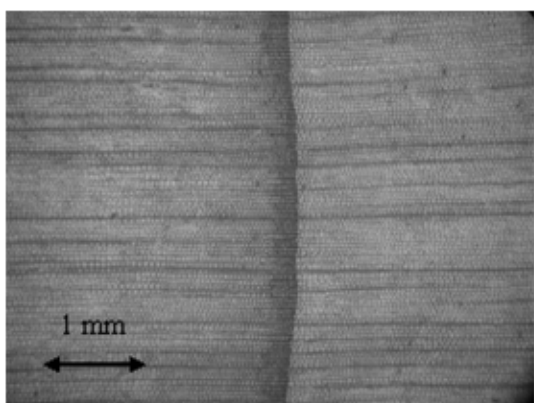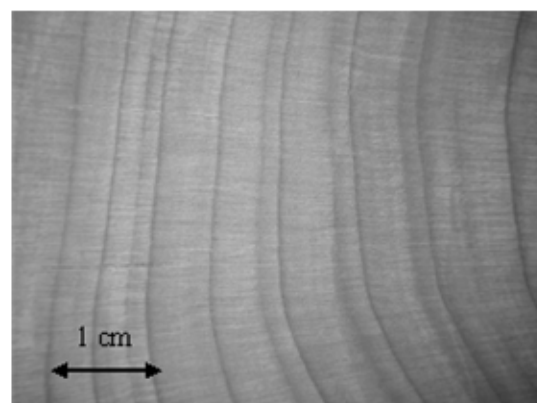
Figure 4a
Figure 4b

Figure 4: Ring boundary under binocular (4a) and "double-ring" pattern (intra-annual density variation) (4b).

The single radii of the 11 trees from Dodola and the 24 trees from Menagesha-Suba could be visually and statistically cross-dated and averaged into two site chronologies, running from 1900 till 2003 for Dodola and from1869 till 2004 for Menagesha. This is a first indication for the annual nature of growth rings (Worbes 1995, Stahle 1999).

The EPS values for Dodola and Menagesha are 0.74 (for the period 1939-2000) and 0.81 (for the period 1963-2000), respectively. They are slightly below the commonly accepted threshold of 0.85 (Wigley et al. 1984), but already suggest a fair level of synchronicity between the chronologies and the existence of a common factor influencing growth.
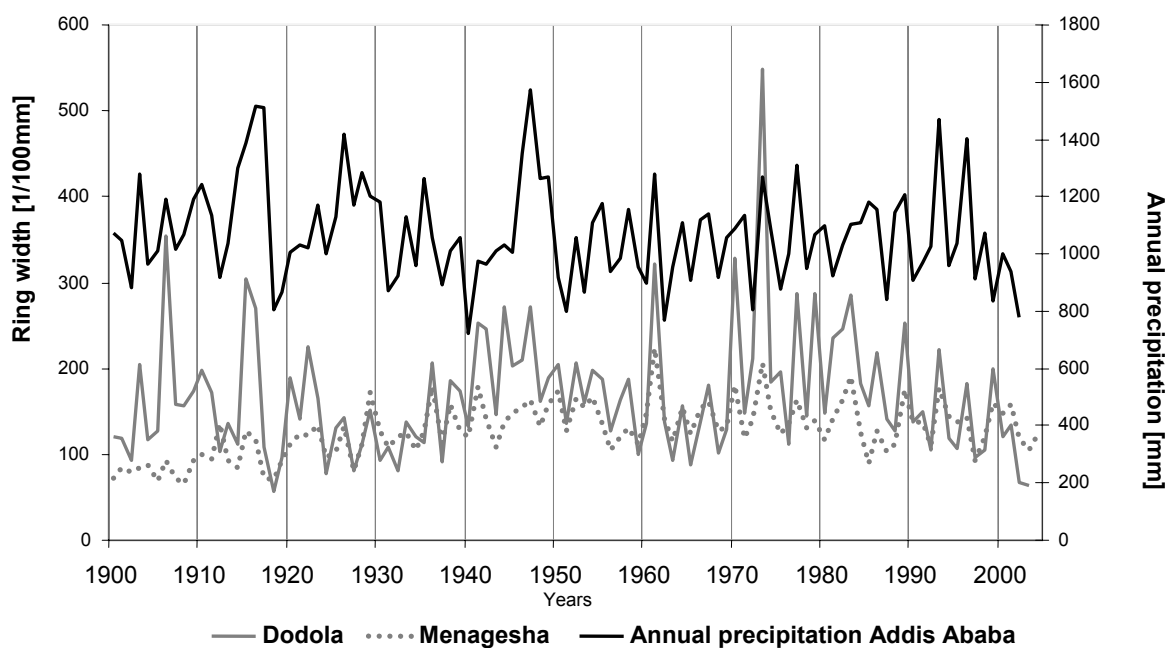
Figure 5: Master chronology of the sampled trees in both sites and record of annual precipitations from Addis Abeba.

Mean ring widths, expressing the growth rates of the trees, showed a huge variability. In Dodola, the mean annual growth rate amounts to 0.4 cm/year (minimum: 0.29, maximum: 0.51), being significantly higher than in Menagesha where it only reaches 0.26 cm/year (minimum: 0.13, maximum: 0.48). This can be the consequence of a higher amount and more equal distribution of rainfall in Dodola.

The high correlation between the two site chronologies (r=0.63), indicates that growth of the junipers in both areas is influenced by a common external factor (Fig. 5). In both sites the response-function analysis revealed that the annual growth was strongly related to the amount of precipitation, especially during the major rainy season when most of the rain falls, from July to September/October. Moreover, extremely wet or dry years could be clearly identified in tree growth. Once more, this points to a large-scale precipitation signal in the growth pattern of *Juniperus procera* in the Ethiopian dry afromontane forests (Fritts 1976). Temperature did not evolve as influencing factor. Other studies with the genus *Juniperus* were already successful for climate reconstruction (Bilham et al. 1984, Esper 2000, Bräuning 1999, 2001, Esper et al. 2002, Zhang et al. 2003). Juniper chronologies from the Ethiopian

highlands are hence extremely promising for reconstructing climate history and to evaluate the impact of future climate changes in this region. It is of high relevance in this area where extreme climatic events such as drought periods can have disastrous economic and social consequences.

References

Bilham, R., Pant, G. B., Jacoby, G. C. (1984): A preliminary study of ancient trees in the Hunza Valley and their dendroclimatic potential. In: K.J. Miller, ed., *The International Karakoram Project.* Vol. 2 Proceedings. Cambridge University Press, Cambridge, United Kingdom: 599-606.

Biondi, F., Waikul, K. (2004): Dendroclim2002: A C++ program for statistical calibration of climate signals in tree ring chronology. *Computers and Geosciences* 30: 303 - 311.

Bräuning, A. (2001): Climate history of the Tibetan Plateau during the last 1000 years derived from a network of juniper chronologies. *Dendrochronologia* 19(1):127-137.

Chaffey, D. R. (1982): South-west Ethiopia forest inventory project. A reconnaissance inventory of forests in south-west Ethiopia. Addis Ababa, Forestry and Wildlife Conservation and Development Authority.

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

Cook, E. R., Kairiukstis, L. A. (1990): Methods of Dendrochronology: applications in the environmental sciences. Kluwer academic publishers, London. 408 pp.

Esper, J. (2000): Long-term tree-ring variations in *Juniperus* at the upper timber-line in Karakorum (Pakistan). *The Holocene* 10(2): 253-260.

Esper, J., Schweingruber F. H., Winiger M. (2002): 1300 years of climatic history for Western Central Asia inferred from tree-rings. *The Holocene* 12(3): 267-277.

Fritts, H. C. (1976): Tree rings and climate. New York Academic Press, New York, USA. 567 pp.

Gardner, B. A. (1926): East African Pencil Cedar. *Empire Forestry Journal* 5: 39-53.

Negussie, A. (1995): A monographic review on *Juniperus excelsa*, Alemaya University of Agriculture, Faculty of Forestry: 39.

Nyssen, J., Poessen J., Moeyersons J., Deckers J., Haile M., Lang A. (2004): Human impact on the environment in the Ethiopian and Eritrean highlands – a state of the art. *Earth-Science Reviews* 64: 273-320

Pohjonen, V., Pukkala, T. (1992): *Juniperus procera* Hocht. ex Endl. in Ethiopian forestry. *Forest Ecology and Management* 49: 75-85.

Rinn, F. (1996): TSAP (Time series Analysis and Presentation) Version 3.0. Heidelberg, Germany.

Sigl, M., Strunk, H., Barth, H.-G. (2005): Dendroclimatic investigations in Asir Mountains – Saudi Arabia, Preliminary report. TRACE Vol. 4 – Proceedings of the Dendrosymposium 2005, April 21st-23rd 2005, Fribourg, Switzerland: 92-98.

Stahle, D. W. (1999): Useful strategies for the development of tropical tree-ring chronologies. *IAWA Journal* 20(3): 249-253.

Stokes, M., Smiley, T. (1996): An Introduction to Tree Ring Dating. The University of Arizona Press, Tucson, Arizona.

Verheyden A, De Ridder F., Schmitz N., Beeckman H., Koedam N. (2005): High-resolution time series of vessel density in Kenyan mangrove trees reveal a link with climate. *New Phytologist* 167(2): 425-35.

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

Worbes, M. (1995): How to measure growth dynamics in tropical trees - a review. *IAWA Journal* 16: 337-351.

Zhang, Q. B., Cheng G. D., Yao T. D., Kang X. C., Huang J. G. (2003): A 2,326-year tree-ring record of climate variability on the northeastern Qinghai-Tibetan Plateau. *Geophysical Research Letters* 30(14), DOI: 10.1029/2003GL017425, Art. 1739.

Updating the Tyrol tree-ring dataset

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Tyrol collection and use in palaeoclimatology

The Tyrol dataset is a collection of 71 *Picea abies* ring width measurement series from the Stubaital and Oetztal in Austria. It was sampled in the 1970s (Lamprecht 1978, Siebenlist-Kerner 1984) – the outermost ring is 1975 – and extended back into the 14th century. Despite this limited length, the collection and derived chronologies have been used in recent publications dealing with millennium-long, hemispheric scale temperature variations (D'Arrigo et al. 2006, Esper et al. 2002, Osborn & Briffa 2006), indicating the relevance of these data in reconstructing large-scale climate variability. The data were considered despite the early end date (1975) limiting the calibration period by about 30 years, i.e. recent decades of instrumental data could not be used for climate signal analysis.
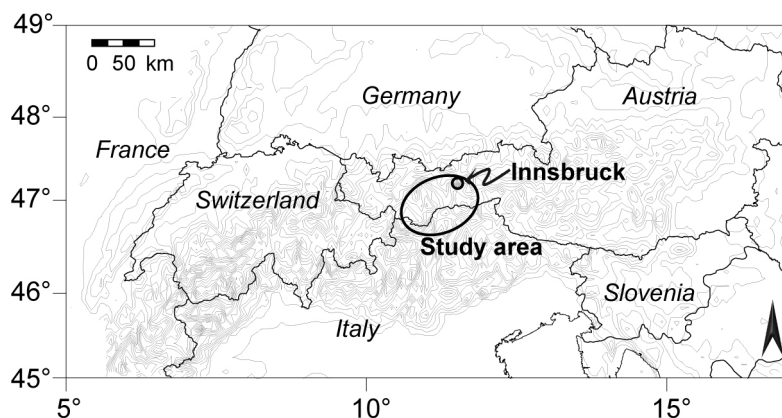
Figure 1: Map showing the study area in Tyrol in the central Alps.

We here describe efforts of updating this relevant dataset. These include extending the collection back in time and updating it during recent decades. We review the common variance of the various sub-samples combined in the Tyrol compilation, and describe some initial assessment of the climate signal. Interestingly, past efforts to reconstruct larger scale temperature variations considered only the tree-ring width (TRW) data fraction of the Tyrol collection. The original and now updated datasets contain both TRW and density measurements, however. So, here we focus on the maximum latewood density (MXD) measurements and compare their climate signal with that found in TRW.

Table 1: Characteristics of the sub-samples combined in the Tyrol dataset.

Sub-sample	Oetztal (rec.)	Stubaital (rec.)	Oetztal (hist.1)	Oetztal (hist.2)
Number	46	13	58	110
Period	1688-2003	1745-1975	1324-1869	1028-1870
Period (>4 series)	1715-2003	1784-1975	1382-1858	1053-1810
MSL [yrs.]	195	171	108	111
MTRW [mm]	1.30	0.96	1.12	1.15
MMXD [g/cm^3]	0.81	0.73	0.79	0.83
Rbar (TRW)	0.57	0.66	0.46	0.43
Rbar (MXD)	0.64	0.78	0.61	0.53

MSL is the mean segment length, MTRW the mean tree-ring width, MMXD the mean maximum density, and Rbar the inter-series correlation calculated using Cofecha.

Extending and updating the existing record

Samples combined in the Tyrol dataset are from the Oetztal and Stubaital, two neighbouring valleys south of Innsbruck in western Austria (Fig. 1). The original dataset as developed in the 1970s was composed of *Picea abies* samples from living trees spanning the 1745-1975 period and material from relict wood spanning the 1324-1869 period (Fig. 2). After truncation at a replication of 5 samples the collection covered 1382-1975 (Lamprecht 1978).

We now updated this record by integrating 46 measurement series from living trees in the Oetztal and 110 measurement series from historic material from the Oetztal/Stubai Alps and adjacent areas (Nicolussi 2002), thereby tripled the size of the original collection. Inclusion of data resulted in an extension back to 1028 (1053 after truncation at n>4) and an update through 2003. Relevant characteristics, including mean segment lengths, growth rates, and densities of the original and new sub-samples are listed in Tab. 1.
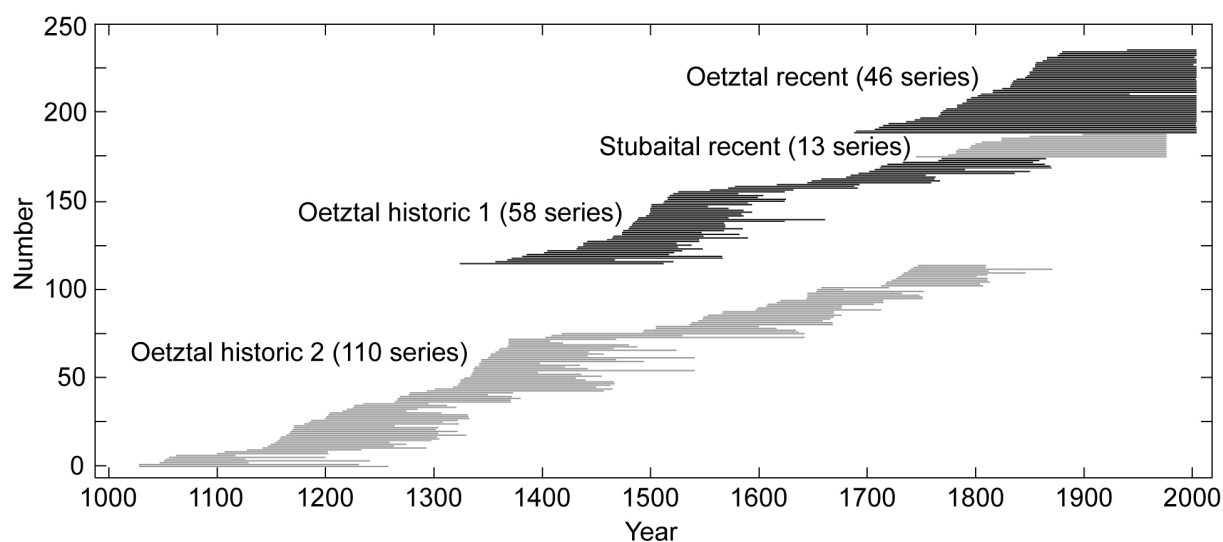
Figure 2: Replication of the original 'Stubaital recent' and 'Oetztal historic 1', and newly measured 'Oetztal recent' and 'Oetztal historic 2' sub-samples integrated in the Tyrol dataset. Each bar represents one measurement series, and 1-2 of these series represent individual trees.

To assess the common variance of the various sup-samples and provide a visual impression of the newly composed Tyrol collection, we power transformed (Cook and Peters 1997) the

TRW and MXD measurement series, standardized the data by calculating residuals from 300-year splines, and developed mean chronologies of the sub-samples using the robust mean (Fig. 3). Cross-correlations between these sub-sample chronologies ranged 0.22-0.54 for TRW and 0.65-0.87 for MXD (see Tab. 1 for overlap between the truncated chronologies), indicating a much stronger common signal in the density data. Lowest correlations for both TRW and MXD were recorded between the original Stubaital recent and Oetztal historic 1, and highest correlations between the Oetztal recent and Oetztal historic 1 sub-samples. The substantial range in correlation between the TRW and MXD chronologies is consistent with the Rbar results obtained for the various sub-samples (Tab. 1), even though differences were smaller on the level of individual measurement series.
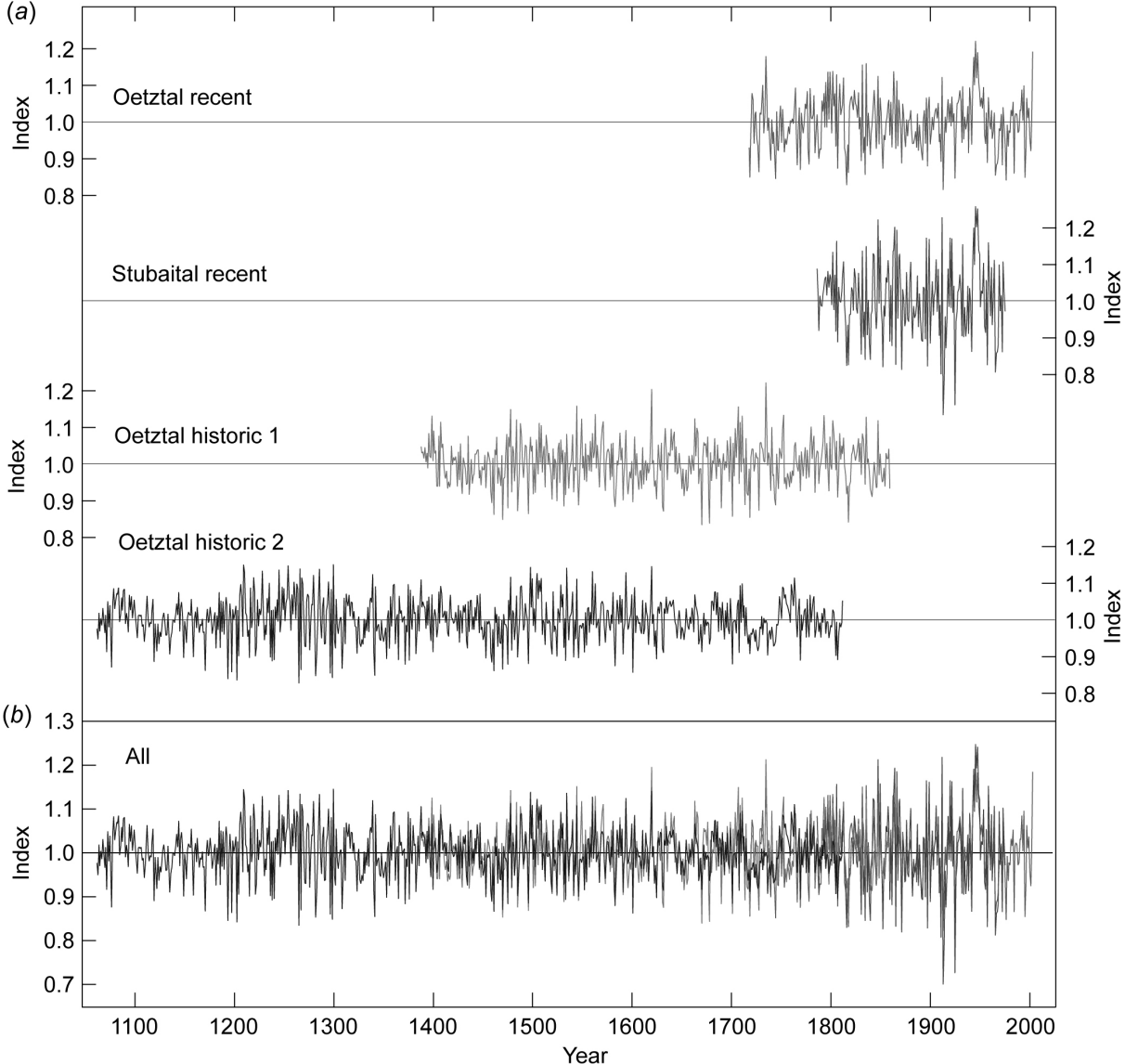
Figure 3: 300-year spline detrended MXD chronologies separated by sub-sample (a) and plotted together (b). Oetz. rec. vs. Stub. rec. TRW/MXD chronologies correlate at 0.54/0.87 (1784-1975 period), Oetz. rec. vs. Oetz hist. 1 at 0.28/0.71 (1715-1858), Stub. rec. vs. Oetz. hist. 1 at 0.22/0.65 (1784-1858), and Oetz. hist. 1 vs. Oetz. hist. 2 at 0.40/0.68 (1382-1810).

Climate signals

Comparison with high elevation temperature data (Auer et al. 2005) revealed a stronger climate signal in the MXD chronology (Fig. 4). Maximum response was found to Aug-Sep mean temperatures (r = 0.66, 189 years). The correlation pattern of the TRW data is less clear and reached maximum values with Jun-Jul mean temperatures (r = 0.43). These results and the significances of the updated Tyrol collection for palaeoclimatic studies are supported by the fit between the linearly modelled and target instrumental data (Fig. 4b).
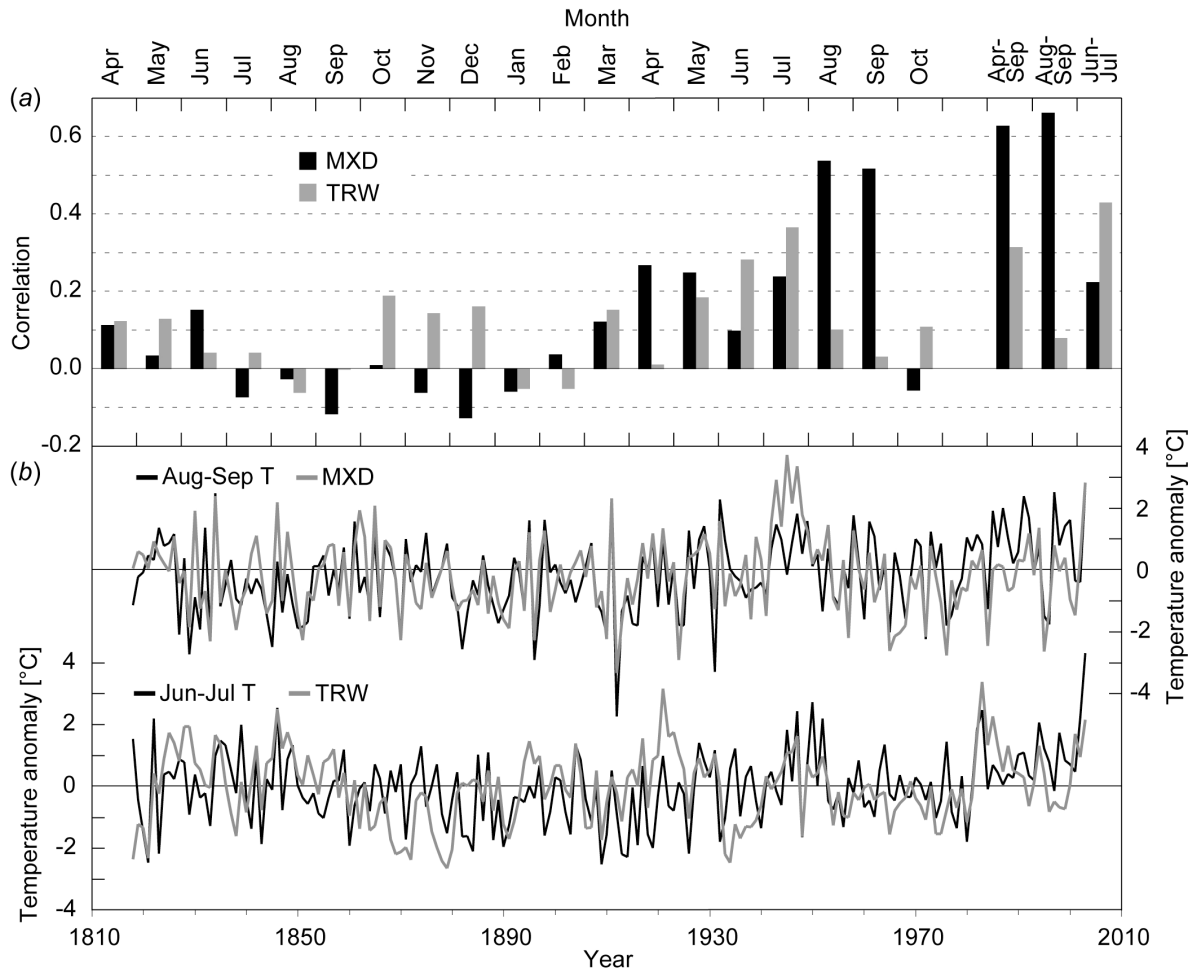
Figure 4: (a) Correlation of the TRW and MXD chronologies with previous to current year monthly and seasonal high elevation temperature data. (b) Instrumental and modelled Aug-Sep and Jun-Jul mean temperatures over the period 1818-2003.

Discussion

A significant update of a widely used tree-ring dataset from Tyrol in Austria is presented. Inclusion of 156 new measurement series allowed extending the original record by about 300 years back to AD 1053. Investigation of the common variance in TRW and MXD data demonstrated significantly higher coherence for the density parameter. While these results suggested a stronger climate signal in MXD, this assumption was confirmed by comparison with high elevation instrumental records from the region. Our results suggest that future efforts in reconstructing past temperature variability should consider the MXD data from the Tyrol collection. To analyze the full spectrum of climate variations including long-term temperature changes, age-related standardization methods such as RCS (Esper et al. 2003)

could be evaluated. Also the combination of TRW and MXD data (Luckman and Wilson 2005) might help to better estimate past temperature variations and particularly the absolute amplitude of such variations (Esper et al. 2005a, 2005b). Future efforts should also reconsider the inclusion of the Stubaital sub-sample, which could possibly be removed and substituted with the newly measured samples from the Oetztal.

Acknowledgements

References

Auer, I., and 24 co-authors (2005) A new instrumental precipitation dataset for the greater alpine region for the period 1800-2002. *Int. J. Climatol. 25*: 139-166.

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

D'Arrigo, R.D., Wilson, R.J.S., Jacoby, G. (2006) On the long-term context for late twentieth century warming. *J. Geophys. Res. 111*: doi. 10.1029/2005JD006352.

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

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

Esper, J., Frank, D.C., Wilson, R.J.S., Briffa, K.R. (2005a) Effect of scaling and regression on reconstructed temperature amplitude for the past millennium. *Geophys. Res. Lett. 31*: doi. 10.1029/2004GL021236.

Esper, J., Wilson, R.J.S., Frank, D.C., Moberg, A., Wanner, H., Luterbacher, J. (2005b) Climate – past ranges and future changes. *Quat. Sci. Rev. 24*: 2164-2166.

Lamprecht, A. (1978) Die Beziehung zwischen Holdichtewerten von Fichten aus subalpinen Lagen des Tirols und Witterungsdaten aus Chroniken im Zeitraum von 1370-1800 AD. Diploma Thesis. Univ. Zurich.

Luckman, B. H., Wilson, R.J.S. (2005) Summer temperatures in the Canadian Rockies during the last millennium: a revised record. *Clim. Dyn. 24*: 131-144.

Nicolussi, K. (2002) Zur Verwendung von Holz als Baumaterial im Bereich von Tirol - Ergebnisse dendrochronologischer Untersuchungen. In: Hausbau im Alpenraum: Bohlenstuben und Innenräume. *Jahrbuch für Hausforschung 51*: 235-242.

Osborn, T.J., Briffa, K.R. (2006) The spatial extent of 20th-century warmth in the context of the past 1200 years. *Science 311*: 841-844.

Siebenlist-Kerner, V. (1984) Der Aufbau von Jahrringchronologien für Zirbelkiefer, Lärche und Fichte eines alpinen Hochgebirgsstandortes. *Dendrochronologia 2*: 9-29.

The potential for long-term climatic reconstructions in the Central Altay mountains from living and relict larch

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Introduction

In cold or arid regions wood from trees that lived hundreds or thousands of years ago may be so well preserved that it can be used to build campfires. The information stored in the annual rings of such stems can also serve as an invaluable archive of past climatic variations. The oldest material included in millennial-length, annually resolved reconstructions of past temperature (e.g., Mann et al. 1999, Esper et al. 2002, D'Arrigo et al. 2006) comes to a large extent from such relict material. However, these archives are exceptionally rare. No large-scale reconstruction currently includes tree-ring material from more than 6 locations at AD 1000 (D'Arrigo et al. 2006). Longer chronologies derived from living and relict material are known from Sweden (Grudd 2006), Mongolia (D'Arrigo et al. 2001), Spain (Büntgen et al. 2006), Alaska (D'Arrigo et al. 2004), and Siberia (Naurzbaev et al. 2002, Jacoby et al. 2000), for example. Herein we discuss the potential for a 1000-year regional temperature reconstruction in the Russian Altay mountains based on newly collected and measured relict material in conjunction with living samples.

A survey of the International Tree-Ring Data Bank rapidly reveals that the majority of tree-ring data represents annual ring-width (RW) measurements. This fact largely arises from the ease and speed of measurement, and the generally strong environmental signal related to this parameter. From certain environments and species, separate measures of earlywood and latewood widths may contribute to a better understanding of seasonal climate than ring-width alone (e.g., Meko & Baisan, 2001). It is also known that measures of maximum latewood density (MXD) of trees growing near the lower thermal limit of survival at the upper or latitudinal treelines are exceptionally sensitive indicators of growing season temperatures (Schweingruber et al. 1979, Briffa et al. 2002, Frank & Esper 2005). In comparison to RW, MXD tends to more faithfully record the inter-annual climate signal, possess less biological autocorrelation, and contain a climatic signal that is less dependent upon specific site ecologies.

With the goal of exploring parameter-specific climate responses, and to maximize reconstruction potential, we have limited the data included in this study to only those sites for which both RW and MXD measurements are available. The data from living trees were collected in the mid 1990's as part of the "Schweingruber network" (e.g., Briffa et al. 1996). The relict material was collected over the past decades, with the most recent samplings and measurements conducted by D.O. and A.K. Below, we present this dataset, show the relationships between the RW and MXD parameters within and between sites and detail the

climate response of the living data. We then discuss the critical transition between the living and relict material, which can be used to help ensure that these data reflect the same environmental forcing and when merged, yield a continuous estimate of the same climatic changes.
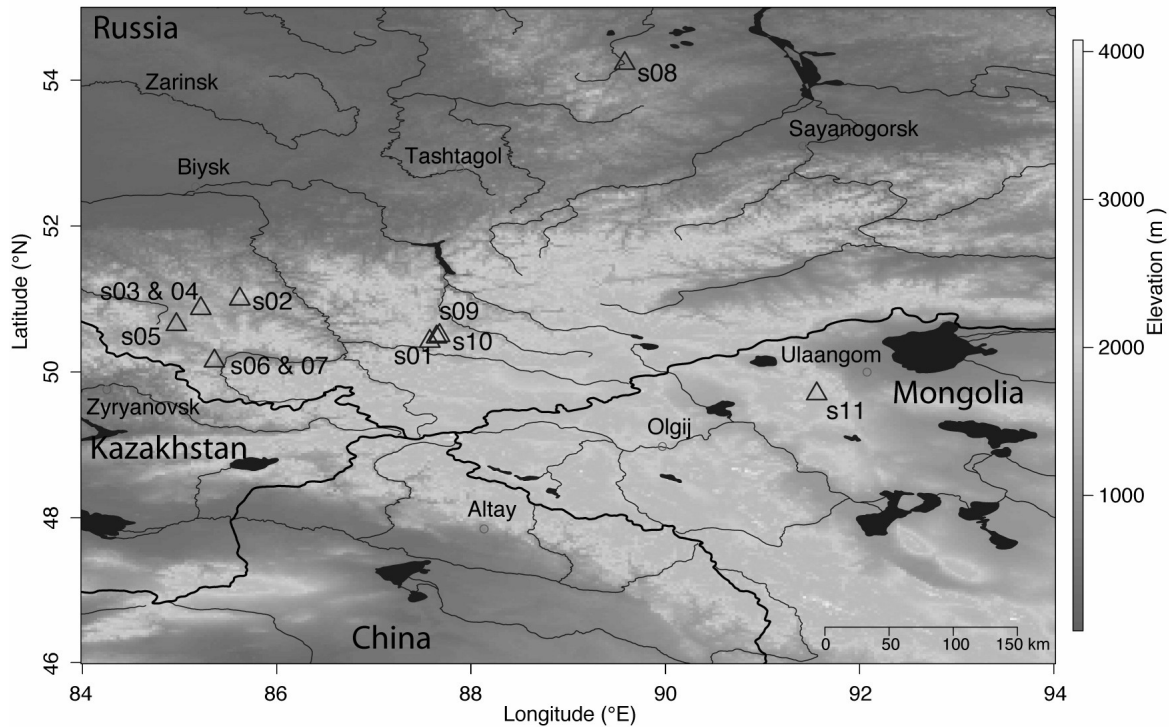
Figure 1: Map showing the location of the eleven living tree-ring sites concentrated in the Russian Altay mountains. For all sites both ring-width and maximum latewood density were measured. The relict material cover was primarily obtained in the same region as the living sites 1-7 and 9-10.

Data

Tree-ring series

The majority of the living tree sites considered are located between 85-88°E longitude and 50-51°N latitude, with the relict material coming from approximately the same region. This area represents the westernmost limit of the Altay mountain chain, which continues eastward in Russia and south-eastward in Mongolia. The majority of the sampled living trees and all of the relict material are larch. Many sites are located at or near the timberline (Fig. 1), and with one exception all sites are located above 1400 m a.s.l. In this area, treeline is located at about 2000- 2200 m a.s.l. The ring-width series of living trees span at least the past two centuries, with the oldest ring dated to 1570 AD (Table 1). The mean segment length (MSL, the number of years on a sample) at the living tree sites ranges from 137 years at Ust Koska Valley (s07) to 342 years at Ust Koska Hill (s06). The relict material has a generally higher MSL – a single sample has 807 measured rings. For all cores of living trees that failed to intercept the pith, the number of rings to the trees center were estimated (Fig. 2), with the average (maximum) estimated number of unmeasured rings to the pith being 26 (181) years. These data were not available for the relict material at the time of writing. During the course of sample preparation and measurement, in many cases, continuous data from the full radii

were not measured for reasons including breaks in cores, unsharp x-ray films, or exceptionally narrow tree-rings. Such gaps are illustrated in figure 2, but were estimated using data from other trees via the "gap-filling procedure" in the program ARSTAN (Cook 1985). The gap-filling procedure allows measurement series to be detrended as a single continuous series, thereby allowing the longest possible wavelengths of climatic related information to be preserved (Cook et al. 1995).

Table 1: Listing of the tree-ring chronologies site names, species, position, number of radii, maximum time span covered, the mean segment length, and the interseries correlations of the detrended measurements. LASI = Larix siberica, PCOB = Picea obovata, PISY = Pinus sylvestris, LAGM = Larix

Code	Name	Spec.	Lat. (°N)	Long. (°E)	Elev. (m)	Radii	Span	MSL	Rbar (TRW)	Rbar (MXD)
s01	Aktasch Valley	LASI	50.42	87.58	2000	30	1601 - 1994	287	0.41	0.39
s02	Ceminsky pass	LASI	51.00	85.63	1450	29	1611 - 1994	280	0.40	0.37
s03	Jablonsky Pass E.	LASI	50.87	85.23	1450	30	1636 - 1994	250	0.48	0.46
s04	Jablonsky Pass W.	LASI	50.87	85.23	1400	30	1761 - 1994	210	0.57	0.52
s05	Kirisky Pass	LASI	50.65	84.98	1500	30	1741 - 1994	229	0.54	0.53
s06	Ust Koksa Hill	LASI	50.15	85.37	1750	24	1581 - 1994	342	0.47	0.42
s07	Ust Koksa Valley	PCOB	50.15	85.37	1700	26	1775 - 1994	137	0.18	0.33
s08	Tyn Hill	PISY	54.23	89.58	650	30	1613 - 1994	214	0.45	0.26
s09	Ust Ulagan Bog	LASI	50.50	87.68	1950	24	1697 - 1994	269	0.48	0.42
s10	Ust Ulagan Lake	LASI	50.48	87.65	2150	24	1581 - 1994	229	0.42	0.47
s11	Turgen-charchira Mtn.	LAGM	49.70	91.55	2000	26	1570 - 1995	254	0.52	0.34
s12	Altay Relict	LASI	–	–	–	34	912 - 1812	315	0.43	0.49

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For chronology development, the age-trend was removed in all samples by taking ratios from 300-year cubic smoothing splines. In the rare cases, where the detrending curve went below zero, more flexible splines were used. This detrending will allow preservation of climatic information at annual to ca. centennial time-scales. The variance of the mean chronologies were stabilized for changes in both interseries correlations and sample replication (Frank et al. 2006, Frank et al. 2007).

Instrumental

The instrumental data used for comparison were taken from the CRU TS 2.1 0.5 x 0.5° gridded dataset (Mitchell & Jones 2005). This latest CRU release of high resolution land data contains a variety of climatic parameters at monthly resolution and maximally spans the 1901-2002 period. For this study we considered mean, minimum, and maximum average monthly temperatures, and total monthly precipitation. Climatic correlations were computed between tree-ring series and the grid-box data "covering" the site locations. Differences between the different gridboxes were for the most part rather minimal. For the purposes of this study, this dataset has the advantage of allowing comparison with many different climatic parameters, which are not easy to otherwise obtain. Disadvantages, however, include that in developing the gridded dataset, all station data were used without correction for possible inhomogeneities or trends arising from, for example, urban warming. This dataset was

designed more to allow assessment of the most likely climatic conditions at any point in space at any point in time. Thus the seasonal cycle is designed to be well captured, but long-term trends in these data are not necessarily fully reliable indicators for the surrounding natural climate conditions. This needs to be considered when interpreting results from proxy/climate calibrations.
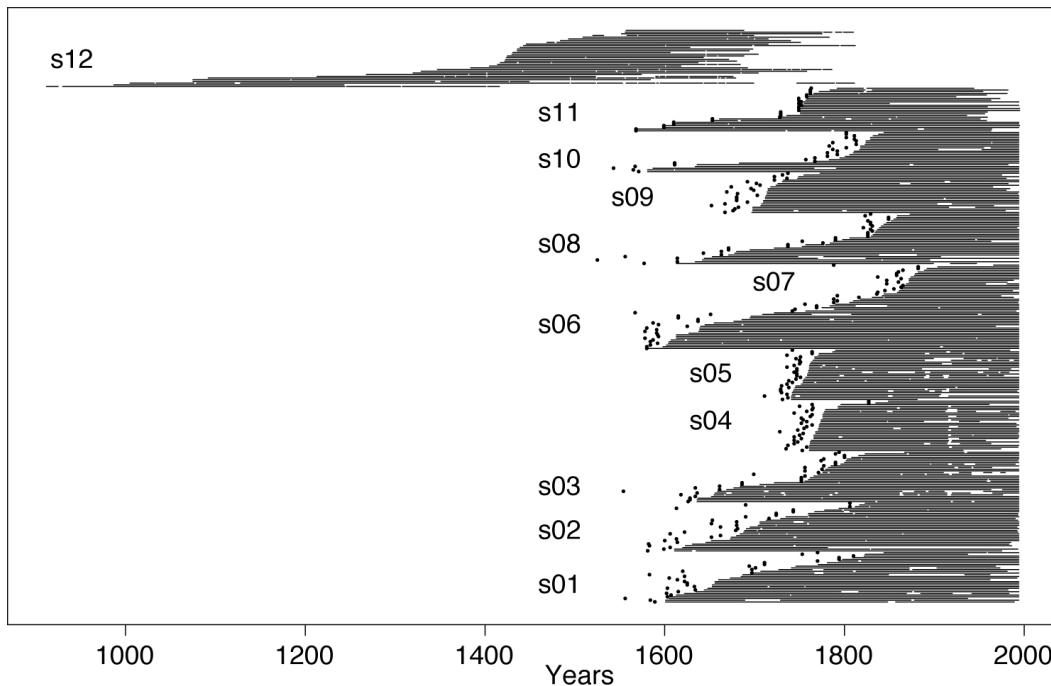
Figure 2: Beams showing the time spans covered by the individual measurement series ordered by sites. Gaps within beams reflect periods where no measurement data exists. Estimates of the years missing to the pith (pith-offset) are shown as black dots.

Results

Site chronologies

After detrending, the average interseries correlation (Rbar) of the RW and MXD sites chronologies were very similar at 0.45 and 0.42, respectively, indicative of an environmental factor commonly forcing tree-growth. At the different sites, the correlation of the RW and MXD chronologies derivied from the same trees tend to be highly correlated (Fig. 3). With the unsmoothed data, correlations over the full chronologies time spans range between 0.11 and 0.74, with a median correlation of 0.61. These correlations increase after 15-year smoothing to 0.28 – 0.82 for the range, and 0.67 for the median, and accordingly decrease after 15-year high-pass filtering to 0.00 – 0.68, and 0.58. It is unclear what fraction of this common low-frequency behavior is driven by the common climate signal, or if there is some intrinsic relationship between between RW and MXD, where for example, the low frequency trends are contained in the RW, and are subsequently found in the MXD data due to a lack of independence between these two parameters. Recent explorations in information shared between these two parameters has resulted in a new detrending method that better reveals the independent seasonal signal of RW and MXD measurements (Kirdyanov et al. 2006).
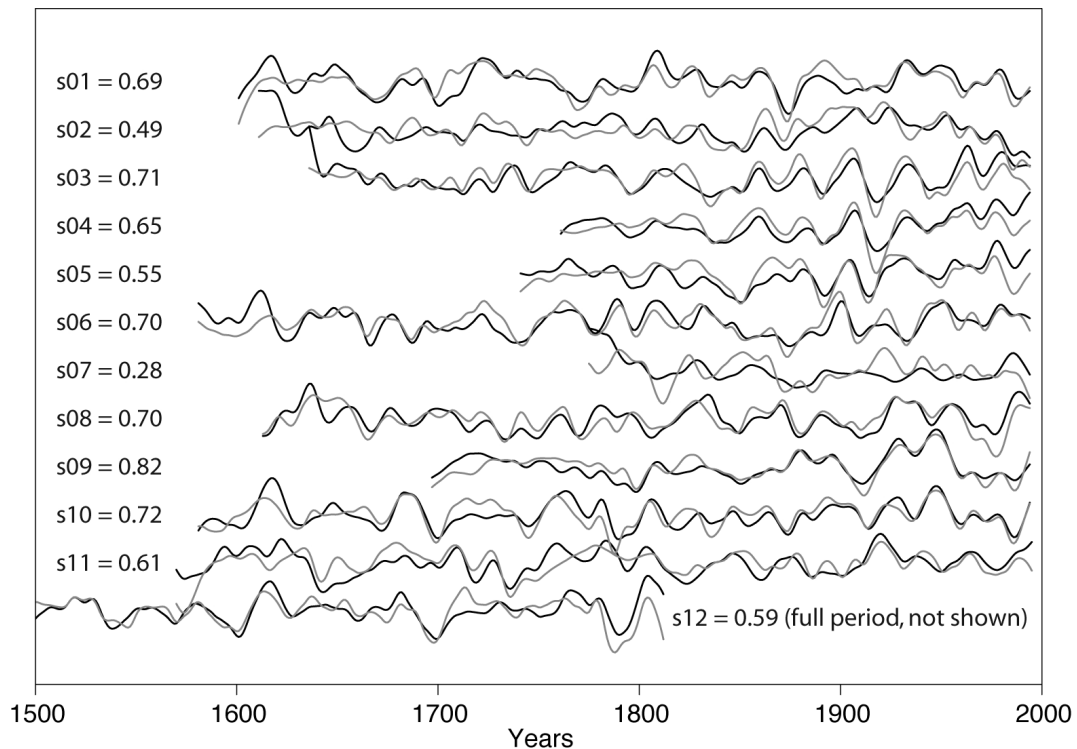
Figure 3: Decadal variation in the TRW (black) and MXD (grey) chronologies shown after smoothing with a cubic-spline with a 15-year frequency response threshold. Correlations between the smoothed TRW and MXD chronologies, computed over the full period, are shown for all 12 sites.

The common signal between the various RW site chronologies is displayed in figure 4. The RW chronologies, tend to have unspectacular correlations with the median site having an average correlation of 0.23 with the other sites. This figure increases for the MXD chronologies to 0.32. As expected, correlations are highest between sites that are geographically proximal and are of the same species. These considerations are more important for RW, than for MXD. Based on these analyses, we retained data from eight living tree sites (s01-s06 and s09-s10) for more detailed consideration of the climatic response and possible merging with the relict material. These sites are all Larix and are concentrated in the western most portion of the Altay mountains.

Climate response

Correlations between the eight retained RW and MXD chronologies with the four climatic variables considered are shown in figures 5 and 6, respectively. The RW response to all three temperature variables is quite similar, with generally highest correlations to June in the year of ring formation. Both significant ($p < 0.05$) positive and negative correlations are found to previous years conditions with particularly variable response during the winter. Four sites showing significant positive correlations with previous march temperatures. Of the seasonal means shown, correlations with average temperatures of the year prior to ring formation and for current June and July tend to be highest. Response to monthly and seasonal precipitation was generally found to be minimal, with the exception of four sites showing negative ($p < 0.05$) correlations to rainfall with the previous July.

In comparison to RW, the MXD response to the monthly and seasonal temperature variables is much stronger and more consistent between all of the sites. A positive temperature response maximum, beginning in May and ending in August is evident. Here different correlation levels to mean, maximum, and minimum temperatures are found, with the highest values obtained for the maximum monthly and seasonal temperature data. All eight of the chronologies show significant (p<0.05) response to May-August, June-August, and June-July maximum temperatures. In contrast, no more than six chronologies show p< 0.05 correlations with any minimum temperature seasonal mean. The response to mean temperatures (an average of maximum and minimum) is intermediate. Correlations between the MXD chronologies and precipitation during the summer of growth tend to be negative. This likely reflects the negative correlation between temperature and precipitation during these months. Three of the chronologies also show a significant (p < 0.05) correlations with precipitation from the preceding July.
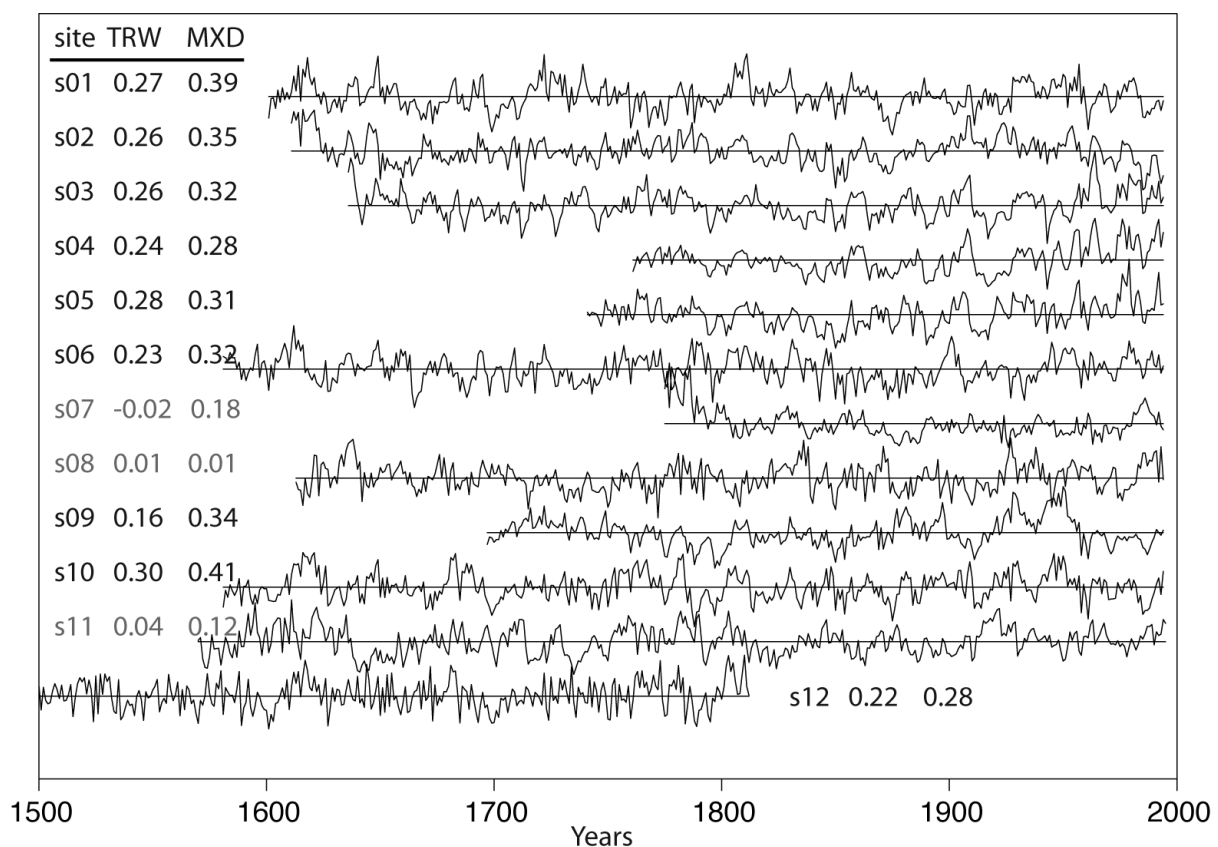
Figure 4: 300-year spline detrended TRW chronologies after normalization over their full lengths demonstrating the common signal. For the 12 sites the average correlation with the other sites over their individual overlap is shown for TRW (left) and MXD (right). Sites retained for further climate analyses are listed in black.
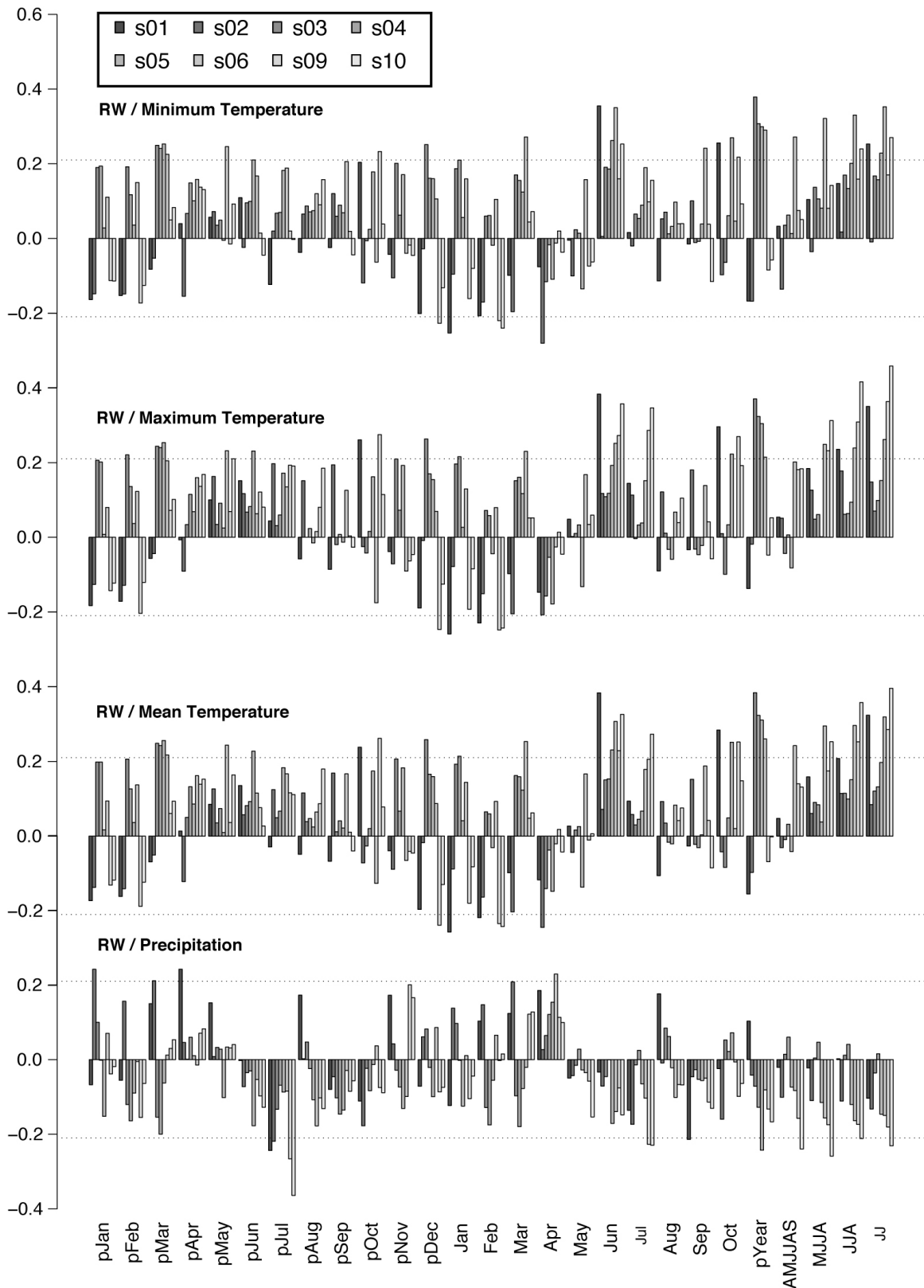
Figure 5: Correlations between RW chronologies and instrumental data over the 1901-1994 period. Approximate 95 % significance limit (after adjustment for lag1 autocorrelation using the mean autocorrelation of the tree-ring and instrumental data) is shown.
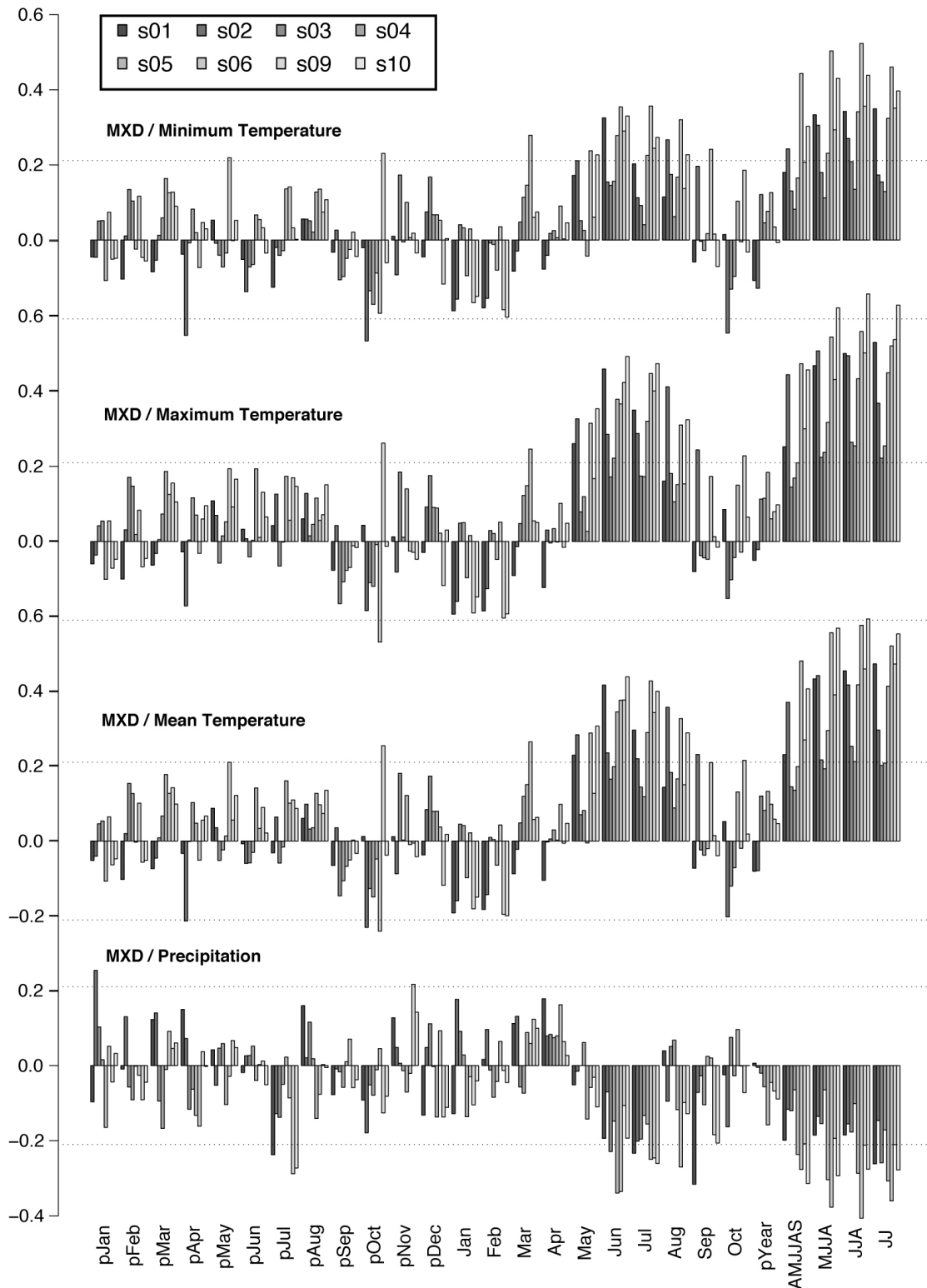
Figure 6: As for figure 5, but for MXD data.

Reconstruction potential

A new MXD chronology was computed as the variance stabilized bi-weight robust mean of the individual series from the eight retained sites with living trees and the relict material. Based on the climate response, average June-August maximum temperatures from a single representative grid-point (center 50.25°N, 86.75° E) were chosen for further comparison with

the MXD data. This Altay MXD composite was scaled to the mean and variance of the temperature "target" over the the 1901-1994 common period (Fig. 7). The MXD data explain 36% of the instrumental variance, and thus indicates high reconstruction potential from these tree-ring data.
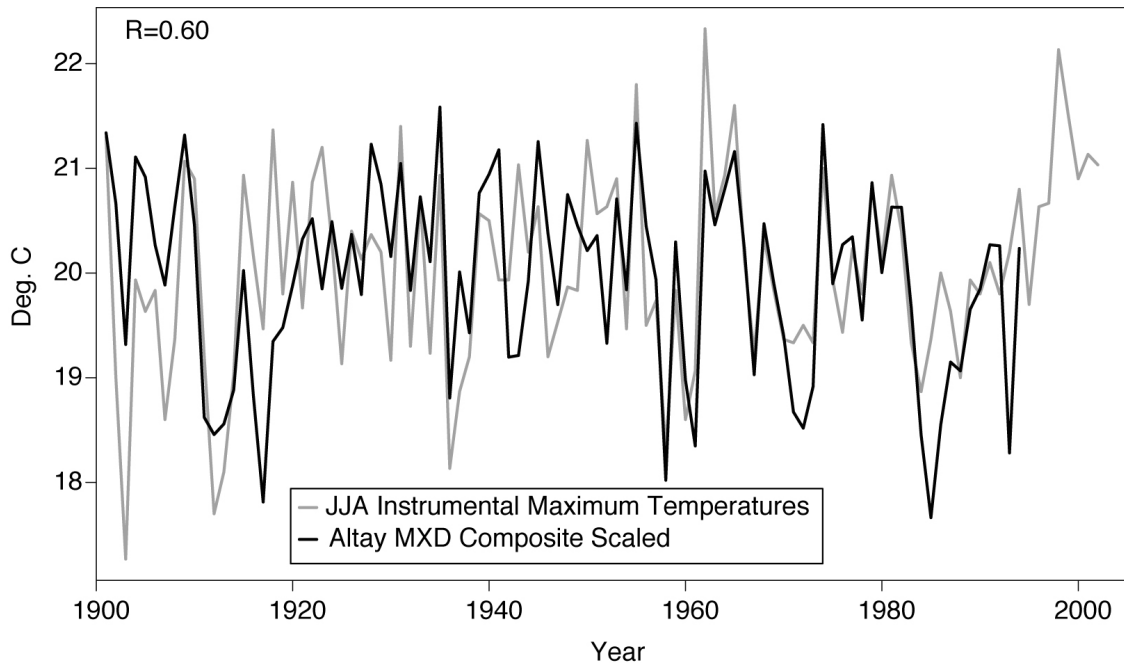
Figure 7: Altay regional composite chronology after scaling to average June-August maximum temperatures.

Discussion

The living and relict material described herein are well positioned to serve as a valuable regional archive of past summer temperature variations. This composite chronology extends prior to AD 1000, and contains more than five samples after 1075 AD making it one of only a handful of records containing MXD data early in the past millennium (Büntgen et al. 2006). From the central Asian region, a RW chronology of Siberian Pine (D'Arrigo et al. 2001) has played a prominent role in large-scale reconstruction efforts (Esper et al. 2002, D'Arrigo et al. 2006, Jones and Mann, 2004). The Russian Altay data are located approximately 800 km west thus widening the "covered" region. Perhaps more importantly, the climate signal which we have demonstrated in the MXD data suggests the potential for a very large contribution capturing central Asian interannual temperature variability more skillfully than existing millennial-length RW records.

The strongest response to maximum summer temperatures represents one of a few recent studies (e.g., Wilson and Luckman 2003, Büntgen et al. 2006) that show this pattern. Maximum temperatures are most clearly related to daytime conditions, and potentially also reflect the positive association between temperatures and solar radiation. For many parts of the world, modelled results indicate a slight to significant radiation limitation on plant growth (Nemani et al. 2003). It is plausible that these increased correlations seen in the MXD parameter, are a reflection of the synergistically increased photosynthetic activity during warmest and also sunniest months.

Climate correlations performed on both 15-year high and low-pass filtered tree-ring and instrumental data (not shown) show the dominant response for the RW and MXD data in the higher frequency domain. It is unclear how much of this relates to the poorer suitability of the high resolution gridded dataset for understanding longer- term behavior, the actual tree response, or other factors. This topic requires further investigation.

For the success and accurate preservation of low-frequency climatic information in a composite reconstruction using detrending methods such as Regional Curve Standardization (RCS, Briffa et al. 1992), living and relict material fused together should come from the same location and site-ecologies, and thereby hopefully contain the same environmental response. Visual comparison of a chronology composed of the living material from the eight most suited sites and with one composed of only relict material demonstrate the common signal for both RW and MXD data in both interannual to multidecadal fluctuations (not shown). These similarities are statistically demonstrated with correlations of 0.51 and 0.58 over the 1581-1812 maximum period of overlap for the RW and MXD data, respectively. Initial tests (not shown) suggest that the form and relative levels of the mean age-aligned data from the living and relict material are reasonably similar. Plots of the mean level of growth vs. the segment length (not shown) also do not immediately reveal exceptional differences. One consideration which we have currently identified, is that the mean segment length (as well as maximum number of rings per sample) is substantially higher for the relict material.

Future field campaigns in this region to locate and sample relict material will hopefully be conducted to further increase the amount of early relict data, as well as to update the material from living trees to include rings from the most recent decade.

References

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

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Shiyatov, S.G. and Vaganov, E.A. (1996): Development of a north Eurasian chronology network: Rationale and preliminary results of comparative ring-width and densitometric analyses in northern Russia. In Tree Rings, Environment and Humanity (Eds. J.S. Dean, D.M. Meko and T.W. Swetnam), Radiocarbon :25-41.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E.A., (2002): Tree-ring width and density data around the Northern Hemisphere: Part 1, local and regional climate signals. The Holocene 12: 737-757.

Büntgen, U., Frank, D.C., Grudd, H., Esper, J. (2006): Eight centuries of Pyrenees summer temperatures from tree-ring density. Climate Dynamics, in review.

Cook, E.R. (1985): A time series analysis approach to tree-ring standardization. PhD dissertation, University of Arizona, Tucson, AZ.

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

D'Arrigo, R., Jacoby, G., Frank, D., Pederson, N., Cook, E., Buckley, B., Nachin, B., Mijiddorj, R., Dugarjav, C. (2001): 1738 years of Mongolian temperature variability inferred from a tree-ring width chronology of Siberian pine. Geophysical Research Letters 28: 543-546.

D'Arrigo, R., Mashig, E., Frank, D., Jacoby, G., Wilson, R.J.S. (2004): Reconstructed Warm Season Temperatures For Nome, Seward Peninsula, Alaska. Geophysical Research Letters. 31, (9): doi:10.1029/2004GL019756.

D'Arrigo, R., Wilson, R. and Jacoby, G. (2006): On the long-term context for late 20th century warming. Journal of Geophysical Research, Vol. 111, D03103, doi:10.1029/2005JD006352

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

Frank, D.C., Esper, J. (2005): Characterization and climate response patterns of a high-elevation, multi-species tree-ring network for the European Alps. Dendrochronologia 22, 107-121.

Frank, D.C., Esper, J., Cook, E.R. (2006): On variance adjustments in tree-ring chronology development. In: Heinrich I et al. (Eds.) Tree rings in archaeology, climatology and ecology, TRACE, Vol. 4, 56-66.

Frank, D.C., Esper, J., Cook, E.R. (2007): Correction for proxy number and coherence in a large-scale temperature reconstruction. Geophysical Research Letters, in review.

Grudd, H. (2006): Torneträsk tree-ring width and density AD 500-2004: A test of climatic sensitivity and a new 1500-year reconstruction of northern Fennoscandian summers. Climate Dynamics (in review).

Jacoby, G.C., Lovelius, N.V, Shumilov, O.I., Raspopov, O.M. Karbainov, J.M., Frank, D.C. (2000): Long-term temperature trends and tree growth in the Taymir Region of Northern Siberia, Quaternary Research 53: 312-318.

Jones, P.D., Mann, M.E. (2004): Climate over past millennia, Reviews of Geophysics 42: doi:10.1029/2003RG000143.

Kirdyanov, A.V., Vaganov, E.A., Hughes, M.K. (2006): Seperating the climatic signal from tree-ring width and maximum latewood density records. Trees. doi: 10.1007/s00468-006-0094-y.

Mann, M.E., Bradley, R.S., Hughes, M.K. (1999): Northern Hemisphere temperatures during the past millennium: Inferences, Uncertainties and Limitations. Geophysical Research Letters 26: 759-762.

Meko, D.M., Baisan, C.H. (2001): Pilot study of latewood-width of confers as an indicator of variability of summer rainfall in the north American Monsoon region: International Journal of Climatology 21: 697-708.

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

Naurzbaev, M.M., Vaganov, E.A., Sidorova, O.V., Schweingruber, F.H. (2002): Summer temperatures in eastern Taimyr inferred from a 2427-year Late Holocene tree-ring chronology and earlier floating series. The Holocene 12: 727-736.

Nemani, R.R., Keeling, C.D., Hashimoto, H., Jolly, W.M., Piper, S.C., Tucker, C.J., Myneni, R.B., Running, S.W. (2003): Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 300: 1560-1563.

Schweingruber, F.H., Bräker, O.U., Schär, E. (1979): Dendroclimatic studies on conifers from central Europe and Great Britain. Boreas 8: 427-452.

Wilson, R.J.S., Luckman, B.H. (2003): Dendroclimatic reconstruction of maximum summer temperatures from upper treeline sites in Interior British Columbia, Canada. The Holocene 13: 851-861.

Dendroclimatology in the Low Mountain Ranges, Germany

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Introduction

The world-wide precipitation amount increased at about 2% within the 20th century due to a changing atmospheric circulation (IPCC 2001). The spatial and temporal variability of this increase is not completely understood. Hence, for a profound assessment of the impact of global change on the regional scale, further spatial high resolution analyses are indispensable. Although earlier studies indicate that precipitation is a dominant growth-limiting factor at specific sites (Spurk 1997, Schweingruber & Nogler 2003, Neuwirth 2005), only few attempts have been made in Low Mountain Ranges of Central Europe to reconstruct precipitation from tree rings (Wilson et al. 2005).

In this study initial dendroecological investigations in the Rheinische Schiefergebirge confirm the strong influence of precipitation on growing-patterns of oak at several sites. They demonstrate that tree-ring/climate-relationships are not constant over the last century, which complicates a precipitation reconstruction.

Material

The research area consists of three parts, from west to east: the northern Eifel, the area close to Bonn, and the Sieg valley (Fig. 1).
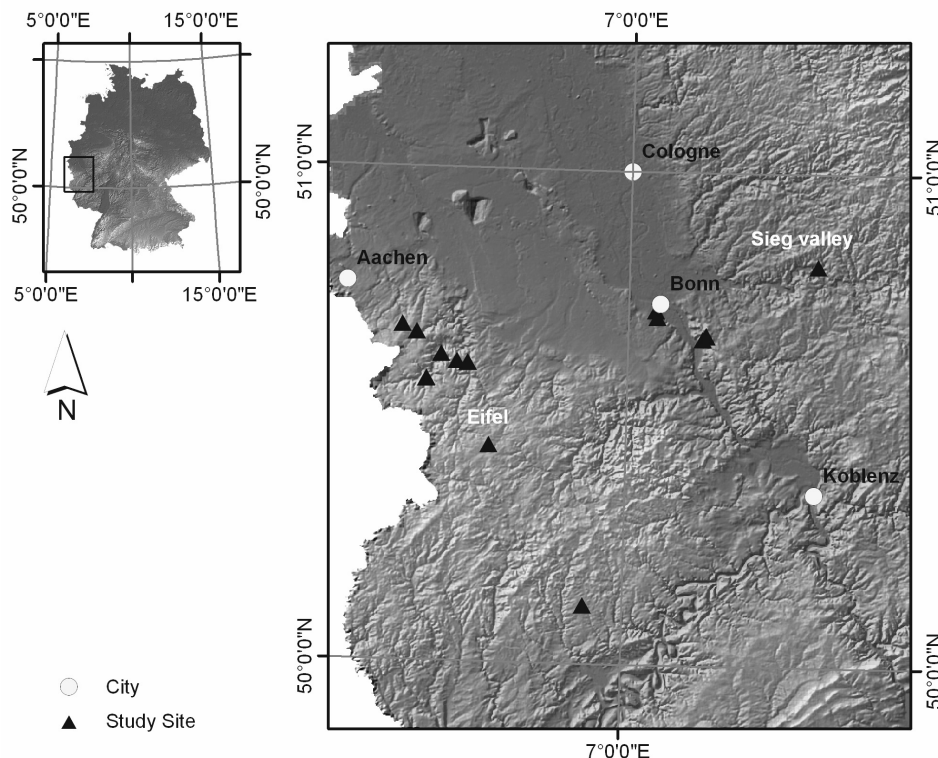
Figure 1: Location map illustrating the study sites.

The sites embrace different ecological conditions, for example the elevation varies from 120m in Bonn up to 570m in sites of the Eifel. Further parameters are the exposition, the inclination as well as the composition of species. For the climate/growth analysis oak cores from 13 sites were taken. Six sites are located in the northern Eifel, five in and close to Bonn and two 40 kilometres east from Bonn in the Sieg valley. The meteorological data is provided from the Tyndall Research Center, UK (Mitchell et al.2004). These data are high resoluted grids (10 minutes resolution) for the time period 1901-2000. Monthly temperature and precipitation values are used for this study.

Methods

Prior to climate/growth analysis the internal site homogeneity of the different tree-ring series was calculated to describe the common signal of trees in the low mountain areas. The chosen statistical parameters were: mean growth, standard deviation, variation coefficient, Gleichläufigkeit (Schweingruber 1983), interseries correlation r_{xy}, autocorrelation (Bahrenberg et al. 1992), and NET (Esper et al. 2001). The parameter NET represents the coefficient of variation and Gegenläufigkeit, the defined threshold is 0.8. The chosen time interval for the investigation comprises the period 1920-2000, in consequence of the correlation coefficient.

By the processing of the climate data, the four closest grid points to a tree site have been selected to get representative climate information for each site. For the monthly values of precipitation and temperature the mean of the four grids was computed.

The raw series of climate and tree growth were both standardized by a 5-year moving average and ratios were calculated to emphasize the interannual signal.

Correlation coefficients between tree-ring width and climate data were calculated for each year with different temporal resolutions (monthly, periods and annual values). Due to the restriction of climate data over time, the research period covers the interval 1903 to 1998. In order to assess the behaviour and stability of the relationship in time, 31-year moving correlations were computed.

Results and Interpretation

The analysis of growth variability, carried out by the internal site comparison, leads to a high level of similarity in tree-ring growth in the research area. The values of all statistical parameters are under/above the defined thresholds and accordingly confirm site homogeneity. The minimum and maximum values are shown in table 1.

Table 1: Internal Site Analysis; minimum and maximum values based on all 13 sites; x = mean growth, s = standard deviation, v = variance, GLK = Gleichläufigkeit, corr = correlation, autocorr = autocorrelation; time period is from 1920 to 2000.

Value	x (mm)	s (mm)	V	GLK (%)	NET	corr	autocorr
Min.	1,09	0,29	0,27	75	0,49	0,49	-0,24
Max.	2,19	0,82	0,48	84	0,71	0,69	-0,38

The significance of the correlation coefficient in each site lies above the 95% level. The mean growth varies from 1,09 mm/y to 2,19 mm/y, which can be explained by the different site conditions. NET, which characterises the signal strength, is adequately below the threshold even in the site of the maximum value. Thus, high signal strength is given in the whole research area. All sites show significant relations to the climate parameters. The trees of some sites respond in different ways to precipitation and temperature. One group of sites including the one in the Sieg valley, shown in figure 2, reacts highly significant in several months and time resolutions; others react significantly only in a few months.

A spatial distribution is given, separating the sites of the northern Eifel from the rest. The Eifel sites react generally weaker to climate parameters compared to sites in Bonn and the Sieg valley. Temperature and precipitation differ in the type of influence, especially in the months of the actual growth year. Correlations between precipitation and growth are most extensively positive, while temperature and tree-ring growth show mainly negative relations.
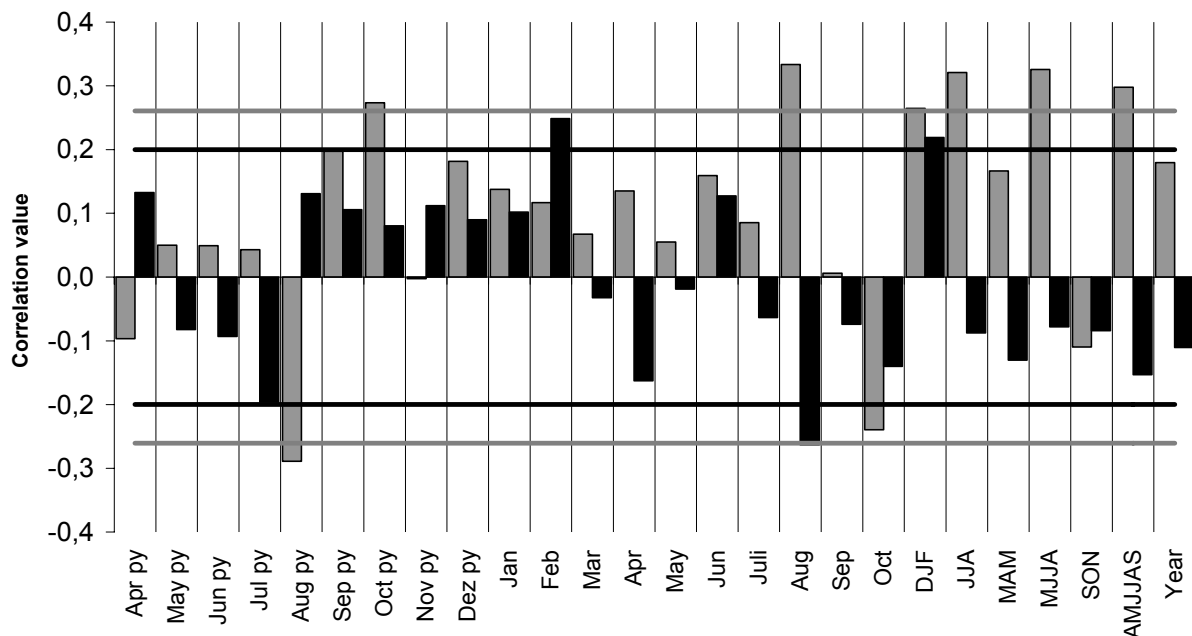
Figure 2: Correlation coefficients between growth and precipitation (light grey), growth and temperature (black). The 95% (black) and 99% (grey) significant levels are indicated by the horizontal lines.

Seven sites show significant positive correlations to precipitation for the time period of April to September, whereas only four of these sites react significantly with temperature. In order to get detailed information about the relationship of growth and the climate parameters in these sites the moving correlations were calculated. Three sites are illustrated in figure 3. The relation between growth and both climate parameters varies over time. Time periods without a significant correlation are found in several sites. Regarding the trend lines, the Sieg valley site (A) represents significant values over the whole time period for both temperature and precipitation. However, going back in time the trend decreases and the precipitation values are no longer on a significant level. The two other sites illustrate a contrary trend in the relationship of precipitation and growth. In both cases no significance in the present can be found and the values increase going back in time.
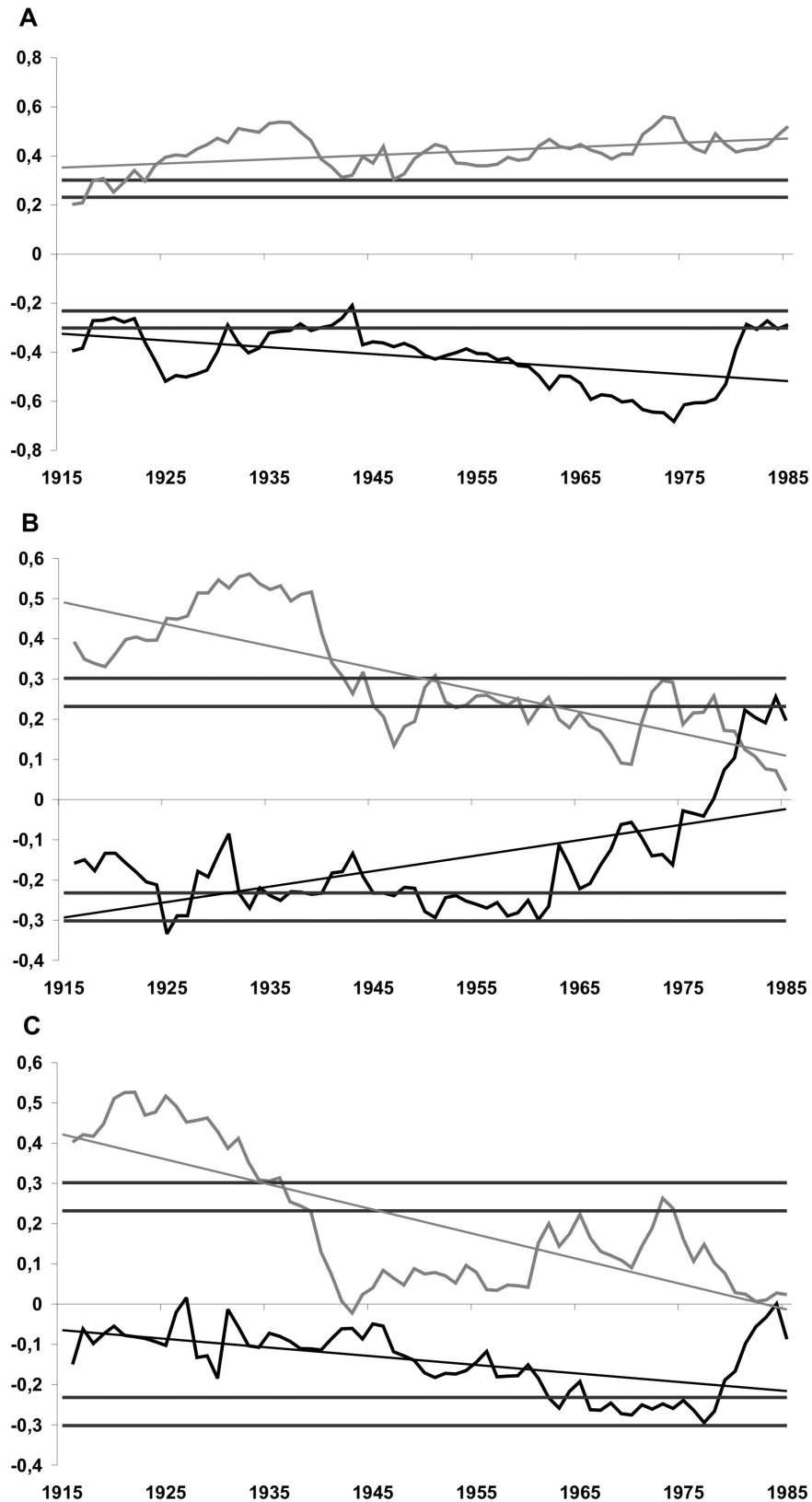
Figure 3: 31-year moving correlation with trend curve between growth and precipitation (grey curve) and temperature (black curve). The 95% (value +/- 0, 2319) and 99% (value +/- 0, 3017) significant levels are indicated by the horizontal lines. A: Sieg valley site, B: Bonn site, C: Eifel site

Thus, the influence of precipitation on ring growth was in the beginning of the century very strong, whereas precipitation in the present loses its importance as influencing factor. Temperature in the Eifel site is not only insignificant; it also has a contrary relation to ring growth than precipitation. Temperature influence decreases while the importance of precipitation rises. Hence, the precipitation represents a self-contained signal.

Conclusions and Outlook

Our first investigations confirm a strong relationship between climate parameters and ring growth in the low mountain ranges in Germany. The subdivision of the research area in regions of diverse climate/growth relations can be explained by the cooler and wetter conditions in the Eifel opposite to the warmer and drier conditions in the rest of the research area. These circumstances can either be caused by the regional climate situation or the ecological factors like elevation etc. Precipitation from the period of April to September is especially an influencing factor on tree-ring width in several sites. The influence of temperature is in most of the sites less important than precipitation. Both climate parameters have no constant influence on growth over time and their trends vary between the different sites.

A stabilisation of the relationship is necessary for reconstructing climate. One approach could be the grouping of several sites to achieve a stronger homogenous climate/growth relationship over time.

References

Bahrenberg, G., Giese, E., Nipper, J. (1990): Statistische Methoden in der Geographie: Univariate und bivariate Statistik. Stuttgart. 233 S.

Esper, J., Neuwirth, B., Treydte, K. (2001): A new parameter to evaluate temporal signal strength of tree ring chronologies. *Dendrochronologia* 19: 93-102.

IPCC (2001a): Climate change 2001: The scientific basis. Contribution of working group I to the third assessment. Report of the Intergovernmental Panel on Climate Change. [Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. & Johnson, C.A. (eds.)].Cambridge University Press, Cambridge, UK und New York, NY, USA, 881 S. (http://www.grida.no/climate/ipcc_tar/wg1/index.htm).

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M., New, M. (2004): A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Tyndell Centre for Climate Change Research, Working Paper 55: 25.

Neuwirth, B. (2005): Klima/Wachstums–Beziehungen zentraleuropäischer Bäume von 1901 bis 1971 - Eine dendroklimatologische Netzwerkanalyse. Dissertation, Geographisches Institut der Universität Bonn, 151 S.

Schweingruber, F.H. (1983): Der Jahrring. Standort, Methodik, Zeit und Klima in der Dendrochronologie. Verlag Paul Haupt, Bern. 234 S.

Schweingruber, F.H., Nogler, P. (2003): Synopsis and climatological interpretation of Central European tree-ring sequences. *Botanica Helvetica* 113 (2): 125-243.

Spurk, M. (1997): Dendroklimatologische Untersuchungen an Kiefern (*Pinus Sylvestris L.*) der planar-kollinen Stufe in Deutschland. *Dendrochronologia* 15: 51-72.

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

Spatial autocorrelation and growth/climate response of a high elevation spruce network along the Carpathian arc

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Introduction

Annually resolved tree-ring width and density measurements are widely used to reconstruct past variations in local- to hemispheric-scale temperatures (e.g., Jones & Mann 2004). Those proxies are generally derived from trees located in the high-northern latitudes or at high elevations (Fritts 1976, Schweingruber 1996). For Europe, multi-centennial to millennial-long tree-ring records (Büntgen et al. 2005, 2006a, b) and network analyses (Frank & Esper 2005) are predominantly derived from the Alps, whereas only few data are available from the Pyrenees (Büntgen et al. 2007a) and the Carpathian arc (Büntgen et al. 2007b). Moreover, only a few dendrochronological studies investigated the effect of anthropogenic airborne pollution on late 20th century forest vigor in the Carpathian arc (Bytnerowicz et al. 2004, Grodzinska et al. 2004). Some other studies have analyzed the growth/climate response at the local-scale (Feliksik 1993, Bednarz et al. 1999, Szychowska-Krapiec 1998). However, studies considering the entire mountain system are broadly missing.

Here we *(i)* developed a tree-ring width (TRW) network of ten high-elevation spruce (*Picea abies* L. Karst) site chronologies along the Carpathian arc, *(ii)* detailed its growth/climate response as a function of *(iii)* geographical settings, and *(iv)* provide first evidence to allow bridging the existing gap between northern and southern European TRW chronologies, which have not been cross-dated in the past.

Geographical setting, data and methods

The Carpathian arc is the second largest mountain system of the European continent (~190,000 km^2 from 45-50°N and 17-27°E) and is characterized by independent sub-regions of elevations >1500 m asl. Peaks >2500 m asl are located in the north-western Tatra Mts. and in the most southern Fogaras Mts. The arc is biogeographically divided into three regions: the Western, the Eastern, and the Southern Carpathians (Warszynska 1995, Voloscuk 1999). Widespread forest stands that reach from the mountain to the sub-alpine zone are typical landscape elements with thermally induced timberlines between 1500-1900 m asl along the north-south gradient. The dominant coniferous species is spruce. In terms of climate, oceanic (NAO in the western part) and continental (EU in the eastern part) influences are evident (Niedzwiedz 1992). The foothills in the Western Carpathians are characterized by mean July temperatures of ~19°C, whereas those in the southern part are ~22°C. While the highest rates of annual precipitation (>2000 mm) are reported from the

summits of the Tatra Mts., the foothills within the south/eastern part of the arc receive <500 mm (Voloscuk 1999).
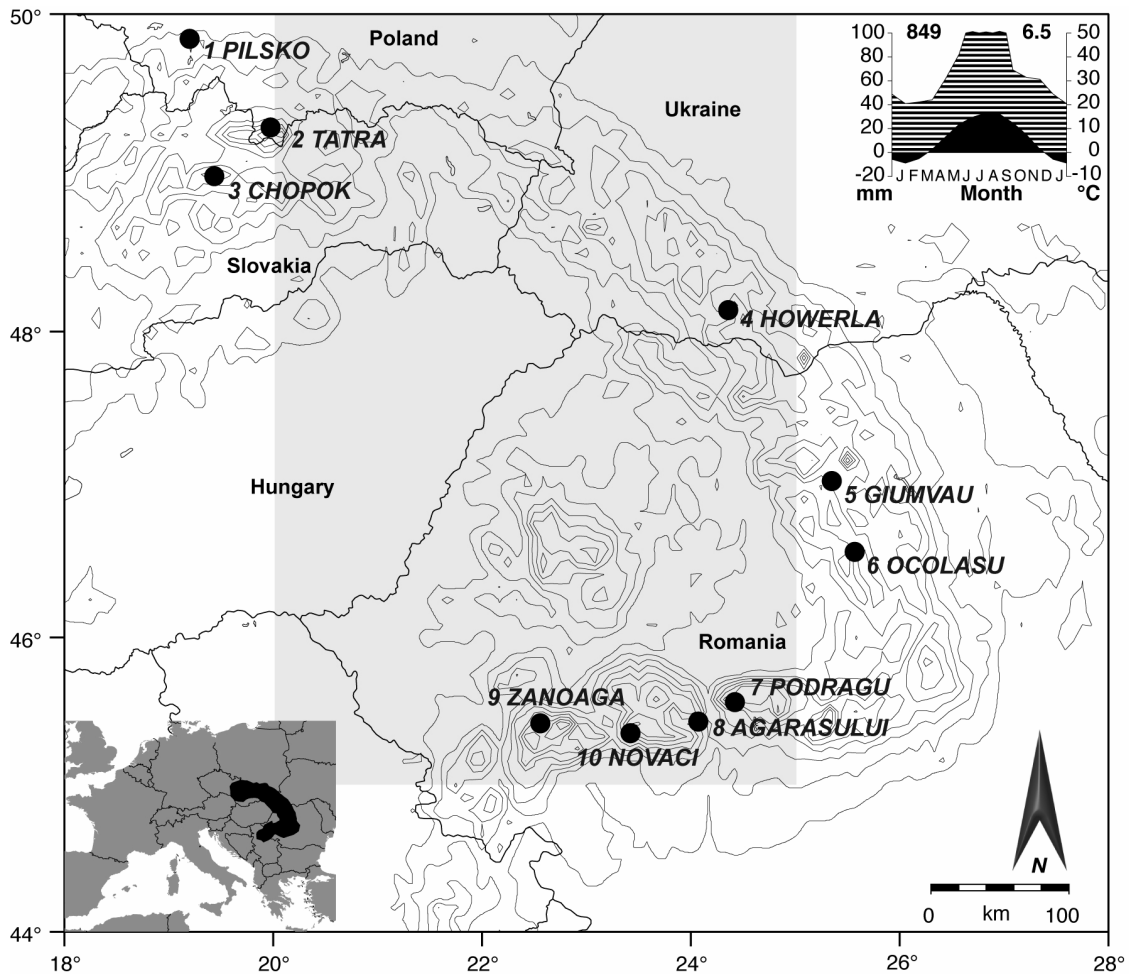
Figure 1: Location of the ten spruce chronologies along the Carpathian arc. Shaded inset denotes the region covered by the 5°x 5° temperature grid-box (HadCruT3v) used for comparison. The climate-histogram shows temperature means and precipitation sums averaged over a period from 1901 to 2002 and 48-50°N to 19-21°E. The lower-left inset denotes the Carpathian arc within Central Europe.

Ten high-elevation (near the local timberline) TRW sites were compiled (Fig. 1). This network spans over a north-south gradient of ~1000 km including the Beskids Mts., Tatra Mts. (both Poland), Chernogora Mts. (Ukraine), Cahlua Mts., Transilvanian Alps and Retezat Mts. (Romania). The number of series collected per site ranges between 20 and 477 (Tab.1). TRW series were checked for missing rings and common signal strength using the program COFECHA (Holmes 1983). To remove non-climatic, age-related growth trends from the raw data (Fritts 1976), individual series standardization and the regional curve standardization were applied (hereafter referred to as spline-detrending and RCS, respectively) using ARSTAN (Cook 1985). Indices were calculated as ratios from 300-year cubic smoothing splines (Cook & Peters 1981). For the relevance, potential and limitation of the differing standardization techniques applied, see Cook et al. (1995) and Esper et al. (2003). Chronologies were developed by, averaging series using their bi-weight robust mean (Cook 1985), and then truncated at a minimum sample size of five series. The variance in the mean

chronology was stabilized using methods described by Osborn et al. (1997). The signal strength of the chronologies was assessed using a 'moving window' approach of the inter-series correlation (*Rbar*), and the expressed population signal (*EPS*; Wigley et al. 1984). A hierarchical clustering of the ten site chronologies based on a multivariate technique and Pearson's correlation coefficients was employed to further detail the network's spatial autocorrelation.

Table 1: Characteristics of the ten spruce TRW chronologies, sorted by altitude (North-South). Statistics refer to chronologies after power transformation, 300-year spline detrending, and truncation <5 series. Elevation= m asl, Period= full length/after truncation, MSL= mean segment length (years), Rbar and EPS= calculated over 30 years lagged by 50% along the full chronology length. Sites: 1 PILSKO (Poland), 2 TATRA (Poland), 3 CHOPOK (Slovakia), 4 HOWERLA (Ukraine), 5 GIUMVAU (Romania), 6 OCOLASU (Romania), 7 PODRAGU (Romania), 8 AGARASULUI (Romania), 9 ZANOAGA (Romania), 10 NOVACI (Romania).

Site	Lat/Long	Elevation	Series	Period	*MSL*	*Rbar*	*EPS*
1	49°31'/19°20'	1300	71	1627/1697-2004	151	0.33	0.89
2	49°00'/20°00'	1450	477	1538/1653-2004	156	0.30	0.94
3	48°56'/19°36'	1450	100	1869/1873-2004	62	0.35	0.96
4	48°09'/24°31'	1430	81	1677/1717-2004	148	0.36	0.90
5	47°27'/25°28'	1480	22	1836/1852-1981	116	0.41	0.93
6	46°57'/25°57'	1790	86	1760/1789-2004	122	0.33	0.92
7	45°37'/24°40'	1500	82	1768/1828-2004	116	0.24	0.87
8	45°33'/24°20'	1600	20	1884/1896-1981	77	0.29	0.88
9	45°21'/22°46'	1640	52	1880/1890-2004	87	0.37	0.91
10	45°18'/23°40'	1650	30	1804/1833-1981	89	0.32	0.85

For growth/climate response analyses, records of monthly resolved gridded (0.5°x0.5°) temperature means (1850-2004) were utilized (CRU; Brohan et al. 2006). This database is optimized for station homogenization, fragmentation, and gridding. Data center 42°5'N and 22°5'E, and are expressed as anomalies of the 1961-90 period.
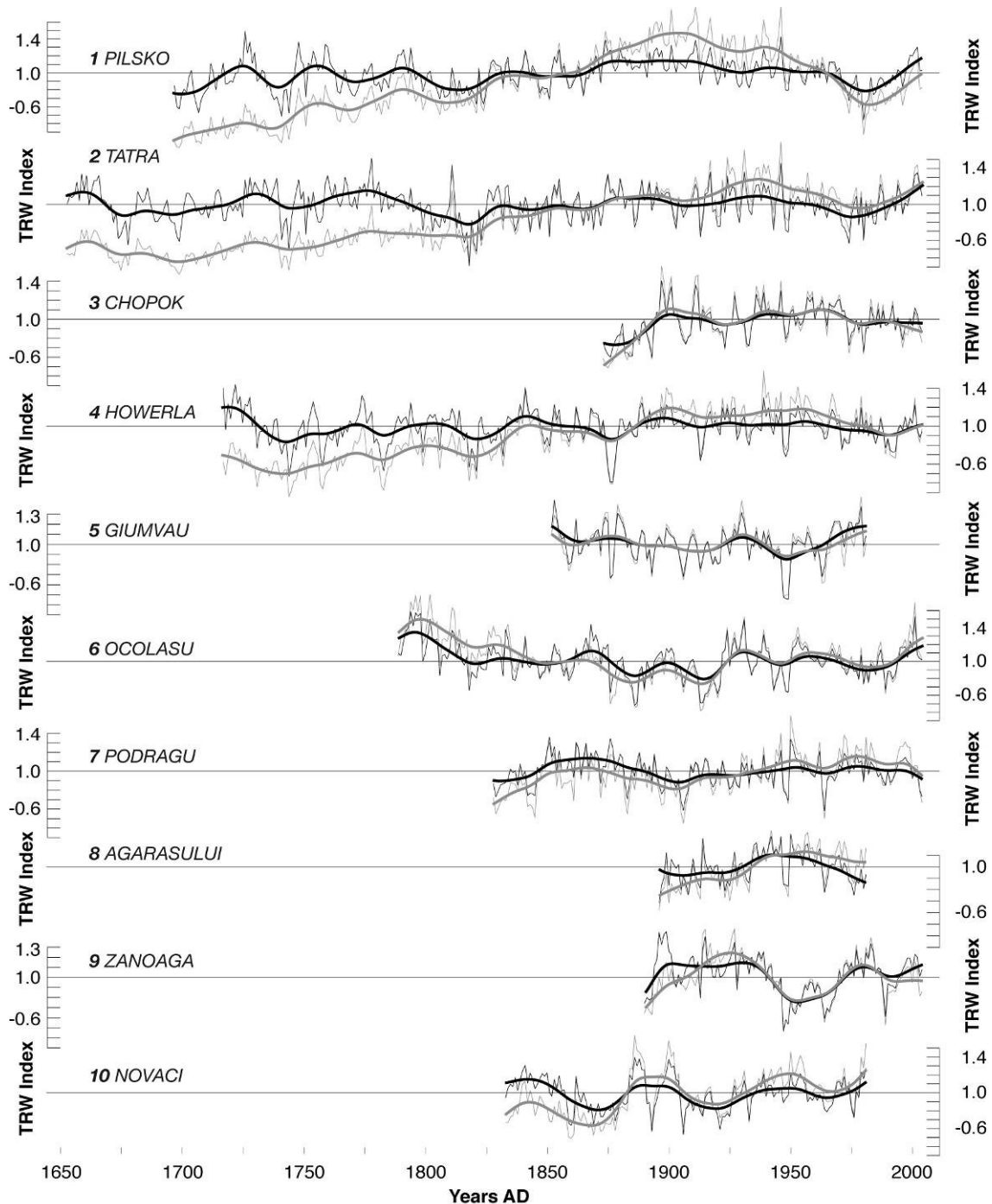
Figure 2: The ten TRW chronologies using individual 300-year spline (black) and composite RCS (grey) detrending. Chronologies were treated using a 30-year low-pass filter.

Results and discussion

Network characteristics

After truncation of >5 series, the chronologies common period was 1884-1981 (Tab. 1). Since most of the records from this study extend into the 21st century, a significant update of a few chronologies developed in the 1980s is provided. The maximum period covered is AD 1653-2004. *Rbar* and *EPS* values of 0.24-0.41 and 0.85-0.96, respectively, indicate internal

consistency in the chronologies common variance. *Lag-1* autocorrelation of the chronologies ranges from 0.43-0.71.
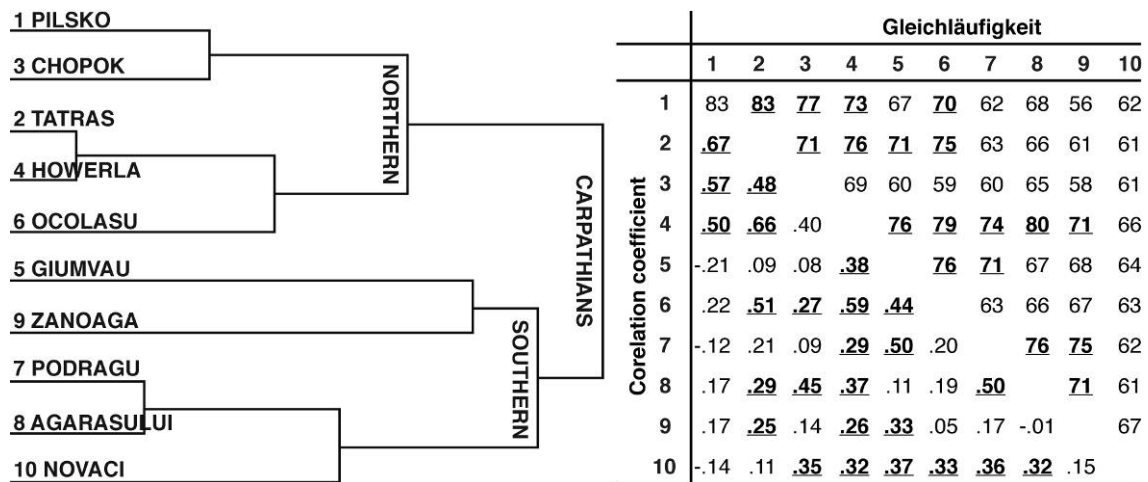
Figure 3: Hierarchical cluster analysis of the ten TRW chronologies using the 1884-1981 common period, and their Gleichlaeufigkeit as well as Pearson's correlation coefficients (bold-underlined values project 70% of GLK and the 95% significance level).

Comparison of the chronologies using the spline-detrending or RCS shows a clear limitation of the spline-detrended chronologies to reflect lower-frequency information, whereas the RCS chronologies generally preserve long-term trends (Fig. 2). Inter-annual variability of the two differently treated chronologies is similar and allows the identification of network pointer years, such as 1816 and 1912/13. Those pointer years are most likely caused by summer cooling effects due to radiative forcing of volcanic eruptions. Long-term variations in ring width, as illustrated by applying the 30-year low-pass filters, mimic the transition from the end of the Little Ice Age towards the 20th century warming. Lowest growth rates are observed during the Dalton solar minimum and coincide with an increased volcanic activity in the early 19th century, followed by an increase with slight depressions in the 1910-20s, and 70-80s. Interestingly, not all chronologies indicated the highest productivity within the last decades. The presence of a recent growth/climate response shift or reduced sensitivity, as reported from a long sub-alpine spruce chronology from the European Alps (Büntgen et al. 2006a), needs to be further investigated when additional tree-ring data and instrumental data from stations becomes available. See also Büntgen et al. (2006b, 2007a, b) for a more detailed analysis of long-term European temperature reconstructions from high-elevation tree-ring width and density measurements.
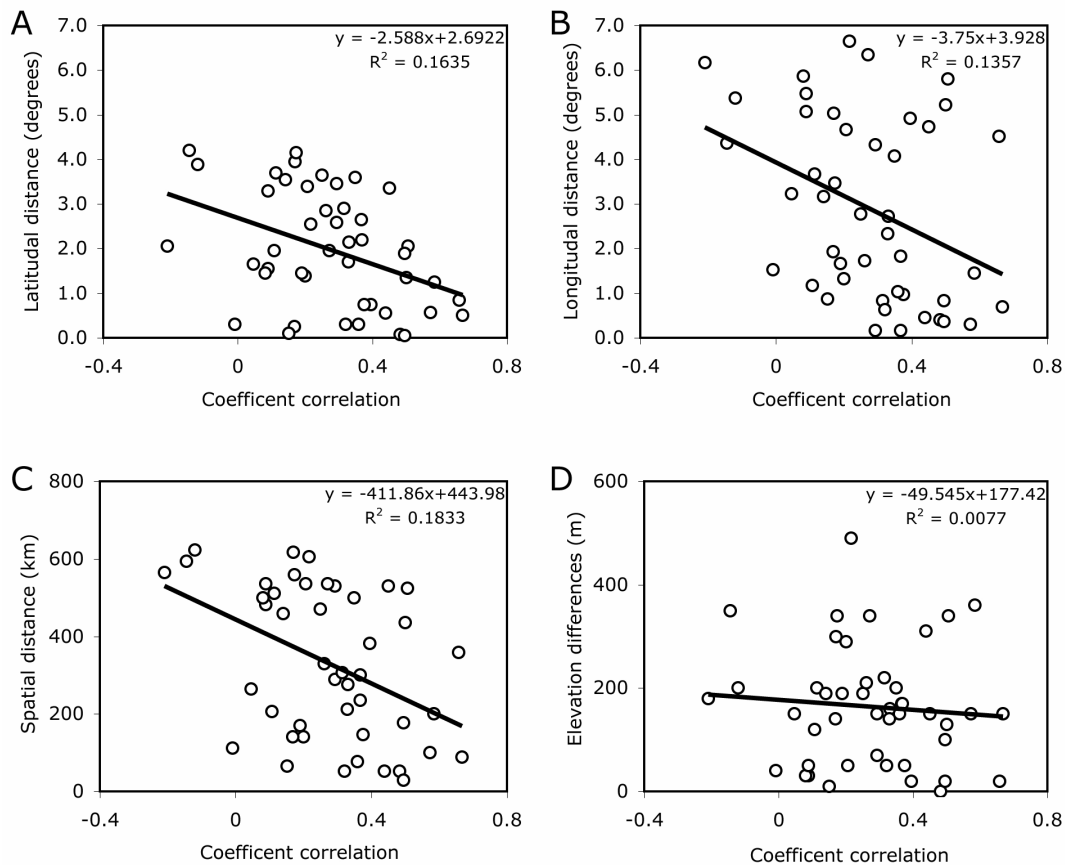
Figure 4: Spatial correlation characteristics of the ten TRW chronologies as a function of (A) latitude, (B) longitude, (C) distance and (D) elevation.

The network's spatial autocorrelation was analyzed using cross-correlation and the Gleichlaeufigkeit (*GLK*) parameter, both applied over the 1884-1981 common period (Fig. 3). The correlation matrix describes distinct signal strengths (0.48-0.67) between the northern site chronologies (Pilsko, Tatra, Chopok, Howerla and partly Ocolasu), whereas the common signal between the more southern sites is lower. Significant correlations of 0.50 exist for the Giumavau and Podragu sites. According to the *GLK*, the common year-to-year TRW signal allows to cross-date almost each pair of chronologies. Significant results are, however, only revealed for 40% of all possible pairings. A similar north-south deviation is evident after performing the hierarchical cluster analysis (Fig. 3). The three northern chronologies (Pilsko, Tatra, Chopok) create a robust cluster. Even though, the two chronologies from Howerla and Ocolosu belong to the northern sites, they still share some common variability with the remaining southern sites, and therefore, reveal a link between the north-south dipole. Spatial correlation characteristics of the ten chronologies as a function of distance, latitude, longitude, and elevation revealed that none of the parameters alone is able to reasonably explain the observed cluster (Fig. 4). The inclusion of the Howerla and Ocalasu chronologies in the northern cluster is somewhat contrary to the correlation results obtained as a function of distance, latitude, longitude, and elevation.
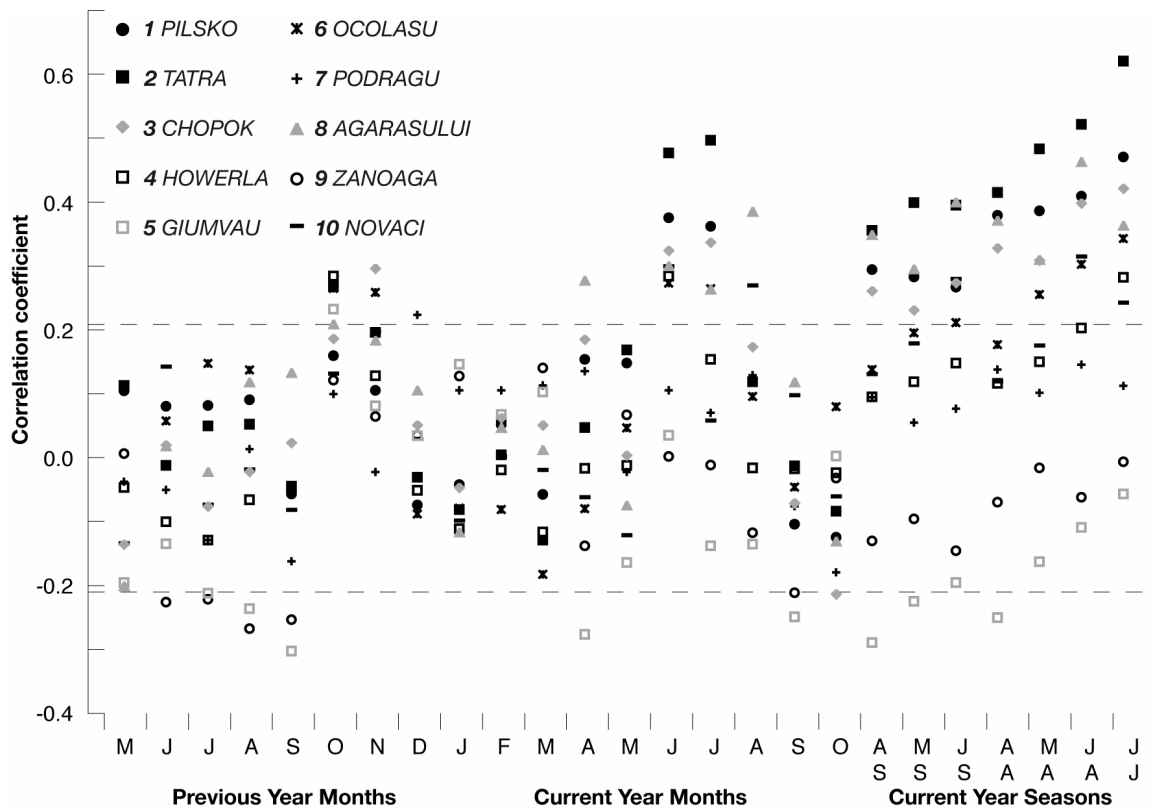
Figure 5: Monthly and seasonal growth response of the ten spruce chronologies (using 300-year spline-detrending) to temperature. Correlations were computed over the 1850-2004, or maximum period of overlap, using monthly means from previous year May to current year November, and seven warm seasons. Horizontal dashed lines denote the 95% significance levels, corrected for lag-1 autocorrelation. The vertical line indicates the beginning of the current growth year.

Growth/climate response

Growth/temperature response analyses using an 18-month window from May of the year prior to tree growth up to October of the growing season, and various seasonal means (April-September =A-S, May-September =M-S, June-September =J-S, April-August =A-A, May-August =M-A, June-August =J-A, June-July =J-J) emphasized the dendroclimatic 'response function' (Fritts 1976) of each chronology (Fig. 5). Highest correlations between TRW and temperatures were found with the October and November temperatures of the previous year. However, correlations generally remained below the 95% significance level. The correlations were stronger for chronologies from the northern part of the Carpathian arc. Similar results were reported from the European Alps (Oberhuber 2004, Frank & Esper 2005). Such positive correlations between TRW and previous year autumn temperatures suggest that warm conditions likely support carbon storage and other physiological processes related to post-xylogenesis activity. Only Chronologies from the southern Carpathian arc tend to correlate negatively at the 95% significance level with May, July, August and September temperatures of the previous year. The two most northern chronologies from Pilsko and Tatra reveal strongest correlations with current year June and July temperatures. For a more detailed view on the growth/climate response within the greater Tatra region, see Büntgen et al. (2005a). Correlations of the two chronologies from Podragu and Zanoaga show non-significant correlations with temperature. Although chronologies from Chopok, Howerla and

Ocolasu do not show any significant response to the monthly temperatures, they reveal significant correlations to the seasonal means of J-A and J-J. To summarize, we show that high-elevation spruce sites in the northern Carpathian arc are generally more sensitive to variations in growing season temperature, particularly of June and July, whereas those sites located in the southern part of the arc are less sensitive to temperature. Growth/precipitation response analyses using the same method as described for temperature revealed generally non-significant correlations for all possible pairings.

Even tough, a clear north-south distinction in the network's growth/climate response was found, a major uncertainty is related to the application of only one general grid-box as 'target' data for the entire Carpathian arc. Such meteorological generalization does not take into account the presence of climatic sub-regions. Additional uncertainty most likely derives from changes in the growing season length (Vaganov et al. 1999, Frank & Esper 2005), modification of the annual meteorological cycle (Jones et al. 2003), and some temporal instability in the growth/climate relationship (Briffa et al. 1998, Büntgen et al. 2006a).

Conclusions

The study revealed significant differences in the annual growth response to temperature between the most northern and southern sites. Accordingly, the network can be split into three sub-groups: *i)* the Northern Carpathians, characterized by a high internal signal strength and a high response to summer temperatures, *ii)* the Eastern Carpathians (in this study only represented by the chronology from Howerla) which shows relatively high correlations with both other sub-groups and a high response to summer temperatures, and *iii)* the Southern Carpathians, which is the most heterogeneous group and shows a reduced internal signal strength and a reduced response to summer temperatures. To improve our knowledge on regional-scale shifts in the trees growth/climate response along the Carpathian arc, and at the same time allow for drawing continental-scale conclusions, future investigations will need to consider *(i)* the update of existing and *(ii)* development of new TRW chronologies and *(iii)* construct density chronologies covering the entire mountain system from the Polish sites, north of the Tarta Mts., to the Romanian sites, south of the Fogaras Mts. Those new data should preliminary be derived from *(iv)* high-elevation (near the timberline) sites, and if possible include *(v)* dead and sub-fossil wood for the network's extension back in time.

Acknowledgement

References
Bednarz, Z., Jaroszewicz, B., Ptak, J. and Szwagrzyk, J. (1999): Dendrochronology of Norway spruce (*Picea abies* (L.) Karst.) in the Babia Gora National Park, Poland. *Dendrochronologia 16*: 45-55.

Briffa, K.R., F.H. Schweingruber, P.D. Jones, T.J. Osborn, Shiyatov and E.A. Vaganov. (1998): Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature 391*: 678-681.

Brohan, P., Kennedy, J.J., Haris, I., Tett, S.F.B. and Jones, P.D., (2006): Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. *Geophysical Research 111,* doi: 10.1029/2005JD006548.

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

Büntgen, U., Frank, D.C., Schmidhalter, M., Neuwirth, B., Seifert, M. and Esper, J. (2006a). Growth/climate response shift in a long subalpine spruce chronology. *Trees 20*: 99-110.

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

Büntgen, U., Frank, D.C., Grudd, H., Verstege, A., Nievergelt, D., Esper, J. (2007a): Eight centuries of Pyrenees summer temperatures from tree-ring density. *Climate Dynamics* (in review).

Büntgen, U., David, F.C., Kaczka, R.J. Verstege, A., Zwijacz-Kozica, T. & Esper, J. (2007b): Growth/climate response of a multi-species tree-ring network in the Western Carpathian Tatra Mountains, Poland and Slovakia. *Tree Physiology* (in press).

Bytnerowicz, A., Badea, O., Fleischer, P., Godzik, B., Grodzinska, K. (2004): Science, land management and policy in international studies on the effects of air pollution on Carpathian forest ecosystems. *Scand. J. For. Res. 19*: 129-137.

Cook, E.R. 1985. A time series analysis approach to tree-ring standardization. Ph.D. Thesis, University of Arizona: 183.

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

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

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

Feliksik, E. (1993): Teleconnection of the radial growth of fir (*Abies alba* Mill.) within central Europe. *Dendrochronologia 11*: 171-175.

Frank, D.C. and Esper, J. (2005): Characterization and climate response patterns of a high elevation, multi species tree-ring network for the European Alps. *Dendrochronologia 22*: 107-121.

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

Grodzinska, K., Godzika, B., Fraczek, W., Badea, O., Oszlanyi, J., Postelnicue, D., Shparykf, Y. (2004): Vegetation of the selected forest stands and land use in the Carpathian Mountains. *Environmental Pollution 130*: 17–32.

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

Jones, P.D., Briffa, K.R. and Osborn, T.J. (2003): Changes in the Northern Hemisphere annual cycle: Implications for paleoclimatology? *Journal of Geophysical Research 108,* doi: 10.1029/2003JD003695.

Jones, P.D. & M. Mann (2004): Climate over the past millennia. Reviews of Geophysics *42,* doi: 10.1029/2003RG000143.

Niedzwiedz, T. (1992): Climate of the Tatra Mountains. *Mountain Research and Development 12*: 131-146.

Oberhuber, W. (2004): Influence of climate on radial growth of *Pinus cembra* within the alpine timberline ecotone. *Tree Physiology 24*: 291-301.

Osborn, T.J., Briffa, K.R., Jones, P.D. (1997): Adjusting variance for sample-size in tree-ring chronologies and other regional-mean time-series. *Dendrochronologia 15:* 89-99.

Schweingruber, F.H. (1996): Tree rings and environment—dendrochronology. Haupt, Bern: 609.

Szychowska-Krapiec, E. (1998): Spruce chronology from Mt. Pilsko area (Zywiec Beskid Range) 1641-1995 AD. *Bulletin of the Polish Academy of Sciences, Earth Sciences 46*: 75-86.

Vaganov, E. A., Hughes, M.K., Kirdyanov, A.V., Schweingruber, F.H. and Silkin, P.P. (1999): Influence of snowfall and melt timing on tree growth in subarctic Eurasia. *Nature 400*: 149-151.

Voloscuk, I. (1999): The National and Biosphere Reserves in Carpathians—The Last Nature Paradises. ACANAP, Tatranska Lomnica, Slovak Republic: 240.

Warszynska, J. (1995): Karpaty polskie. Przyroda, czlowiek i jego dzialalnosc . Uniwersytet Jagiellonski, Krakow: 420.

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

2003 – where is the negative pointer year?
A case study for the NW-German low mountain ranges

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Introduction

From a climatological point of view, 2003 was one of the extremest years since the beginning of meteorological measurements. A long period of dryness and high temperatures led to extreme deficiencies in water availability in larger parts of Central Europe (Anders et al. 2004). In general, such weather conditions cause negative effects on tree growth, expressed in altered plant physiological responses (Herbst & Hormann 1998, Elling & Dittmar 2004), and consequently in narrow tree rings (Lebourgeois et al. 2005). But in respect to the record year 2003, drought resistance and resilience of European leafwood trees has been discussed controversially (Rennenberg et al. 2004, Kölling et al. 2005), especially in view of the anticipated climatic changes (Beniston & Innes 1998, Gerstengarbe & Werner 2005). As reported by Kahle (2006) radial growth of beech trees at high elevations in the Black Forest was only slightly affected by the exceptional weather conditions in the year 2003.

This recent study investigates the effects of the record year 2003 on tree-ring widths of beechs (*Fagus sylvatica*) and oaks (*Quercus petraea* and *Q. robur;* both are combined to one species) in southern regions of Nordrhein-Westfalen in West Germany. The growth responses to the weather conditions in 2003 will be compared with the responses of beeches and oaks in other extreme years of the last century by using a pointer year analysis.

Figure 1: Map of NW-Germany with locations of dendrochronological sites. The triangles represent stands for oak and beech chronologies.

Data and methods

Dendrochronological data

The research area (Fig. 1) of the present study is located in north-western Germany between 50° to 51° N and 6° to 8° E, representing the Eifel, the so called "Köln-Bonner Bucht" with the Siebengebirge and the valley of the river Sieg in the east of Cologne. Twelve oak and 10 beech stands were selected representing the whole ecological spectrum of closed forest in the research area. The sites are located in a N-S and W-E transect covering altitudes from 100 to nearly 600 m a.s.l.. All sites consist of mature, mixed-species stands and all sampled trees belong to the crown classes 'co-dominant' and 'dominant'. Table1 illustrates site topographic and dendrochronological characteristics of the 22 sampling sites.

Table 1: Characterisation of the dendrochronological sampling sites

subregion	location	latitude / longitude	altitude/ exposition/ inclination	code	species	length of chrono
Vulkaneifel	Holzmaar	50°07'10" / 6°52'30"	430 / S / 10-20	dpe01	QUPE	1821-2004
				dpe02	FASY	1822-2004
Bonn	Kottenforst	50°42'19" / 7°05'21"	170 / WSW / 8	drb01	QURO	1852-2004
	Melbtal	50°42'22" / 7°05'04"	140 / W / 35-40	drb02	QURO	1802-2004
Siebengebirge	Fritschesberg	50°39'45" / 7°14'10"	250 / W / 10	drb04	QURO	1860-2004
	Lohrberg S	50°40'10" / 7°14'58"	375 / N / 40	drb05	FASY	1851-2004
				drb06	QURO	1847-2004
	Lohrberg N	50°40'12" / 7°14'46"	340 / S / 45	drb07	QURO	1868-2004
				drb08	FASY	1850-2004
Nordeifel	Hürtgenwald	50°46'13" / 6°21'58"	290 / NNW / 15	dre01	QUPE	1828-2004
				dre02	FASY	1822-2004
Rureifel	Schäferheld	50°36'35" / 6°27'25"	520 / NW / 20	dre03	FASY	1823-2004
	Wiegelkammer	50°36'26" / 6°29'25"	450 / E / 15	dre05	FASY	1858-2004
	Weidenauer B.	50°37'25 / 6°23'30"	370 / NW / 40	dre09	QUPE	1808-2004
	Im Brand	50°34'14" / 6°21'37"	500 / SE / 20	dre10	FASY	1817-2004
				dre11	QUPE	1834-2004
		50°34'15" / 6°21'49"	470 / SSE / 30	dre12	FASY	1818-2004
Kalkeifel	Hütterbusch	50°26'27" / 6°33'56"	575 / E / 5-10	dre06	QUPE	1848-2004
Hohes Venn	Kreitzberg	50°40'52" / 6°16'38"	440 / NE / 0-5	dre07	QUPE	1806-2004
				dre08	FASY	1858-2004
Siegtal	Wasserfall	50°48'19" / 7°35'25"	140 / SW / 40	drs02	FASY	1872-2005
	Bodenberg	50°48'49" / 7°35'57"	200 / W / 35	drs03	QURO	1867-2005

For every tree, two increment cores from opposite directions were sampled at breast height. Using Lintab V measurement tables and the software package TSAPWin-Scientific version 0.53 (Rinn 2005) series of tree-ring widths with a 1/100 mm resolution were measured and averaged to tree-mean-curves. All trees are older than 130 years (last column of Tab. 1).

As Meyer (1998-1999) documented for spatial comparisons, indexation techniques which are based on a smoothing average are useful. Hence, in this study z-transformed pointer values C_z were calculated for all trees (Neuwirth 2005). This value leads to time series highlighting the anomalies against the mean radial growth for every site. Due to the high similarity of the resulting master plots between all beech sites and between all oak sites, respectively (not shown), the C_z-values were averaged for every species. In addition to the intensity of growth anomalies, only years with $C_z < -1.645$ were classified as negative pointer years. With respect to the probability density function of the standardized normal distribution, the probability for such years is lower than 5% (Neuwirth et al. 2007).

Climatological data

Temperature and precipitation values are obtained from gridded data in a spatial resolution of 10 minutes, over the time period 1901 to 2004, which were provided by the Climate Research Unit in Norwich/UK (Mitchell et al. 2004) by averaging all gridpoints of the research area. From these monthly mean curves temperature and precipitation anomalies were calculated as z-transformed residuals from the monthly mean values of the period 1961 to 1990. Thus, the resulting values are interpretable as standard deviations from the monthly mean values of the climate standard period.

Strategy

Because time series will be shortened at the beginning and at the end by the half of the filter-bandwidth using the Cropper-method, it is not possible to analyse the growth anomalies for the years 2003 and 2004. In case of a 5-year long bandwidth the last year for all series is 2002. Due to the advantages of a two side filter with respect to the detection and separation of different long-run behaviour (Riemer 1994), it is not reasonable, to evaluate climate forcings in pointer years by using a left-side moving average. Therefore, this study will be realized in two steps. At first, the z-transformed Cropper-values C_z for all sites is calculated for the 20th century as described above. This is followed by a pointer-year analysis where selected negative pointer years were compared with the climatic anomalies. After this, the crucial climatic events, related to the narrow tree rings, will be pointed out and classified into types of growth/climate responses for the 20th century. In a second step, the climatological situation of the year 2003 will be analysed and confronted with indexed growth chronologies for beechs and oaks for the time period from 2000 to 2004. For this, residuals against a left-side 3-year weighted moving average will be calculated. The comparision of the situation in 2003 with the types of growth/climate responses for the 20th century will give an explanation for the missing negative tree ring in 2003 especially in the beechs.

Results

Growth/climate responses in the 20th century

The calculations of pointer values as described before showed nearly the same site-related masterplots for beeches on the one hand and for oaks on the other hand. Thus, species specific masterplots were created by averageing the C_z-values of all beechs and the C_z-values of all oaks. The negative half of the combined materplot for beech and oak in the NW-German low mountain ranges is presented in figure 2a, where the ordinate represents the time scale beginning at the top with ad 1900 and ending at the bottom with ad 2000. The x-axis describes the C_z-values and ranges from 0 on the left hand to -3 on the right hand. In the 20th century beeches reacted in 9 years (1912, 1922, 1948, 1960, 1976, 1983, 1990, 1996, and 2000) with extreme negative pointer years (grey beams), while for oaks (black beams) only 8 negative pointer years (1909, 1921, 1942, 1947, 1959, 1968, 1976, and 1996) are signed (Fig. 2a). Only in the two years 1976 and 1996 (grey beams with black vertical stripes) both species show synchronous reactions.

For the interpretation of these negative pointer years comparisions with climatological anomalies in the year of tree reaction and the year before were made. Therefore, temperature (grey surfaces) and precipitation (black bars) against the monthly means of the period 1961 to 1990 are shown in figure 2b. On the right hand of the climate diagrams special anomalies, which are crucial for the narrow tree rings, are listed (Fig. 2c).

Regarding the listed interpretations for each species, three types of growth/climate responses can be classified.

Beeches have negative pointer years, if

− the growing season of the current year is cold and dry like in 1996;

− the growing season of the current year is hot and dry like in 1976 or 1983;

− the autumn of the year before was warm and dry and the end of the growing season of the current year is cold like in 1912, 1922, 1948, 1960, or 2000.

Oaks have negative pointer years, if:

− the growing season of the current year is cold and dry like in 1996;

− the autumn of the year before was cold and dry like in 1909 or 1942;

− the growing season of the current year is hot and dry like in 1921, 1947, or 1976.

Comparing the tree responses concerning only warm and dry weather conditions, beeches and oaks produce narrow rings after the same dryness periods. However, in the northwest German low mountain ranges beeches mostly react one year later than oaks like in 1921/22, 1947/48, or 1959/60. Only in 1976, both species react after a strong dryness period within the same year.

The start of the dryness period seems to be the crucial fact to explain the time-shift in growth response. In some years, the dryness period starts in February like in 1976, where for other years the dryness period starts in July or August like in 1921, 1947, or 1959. In the second case, tree-ring widths of beeches decrease not until the following growing season.
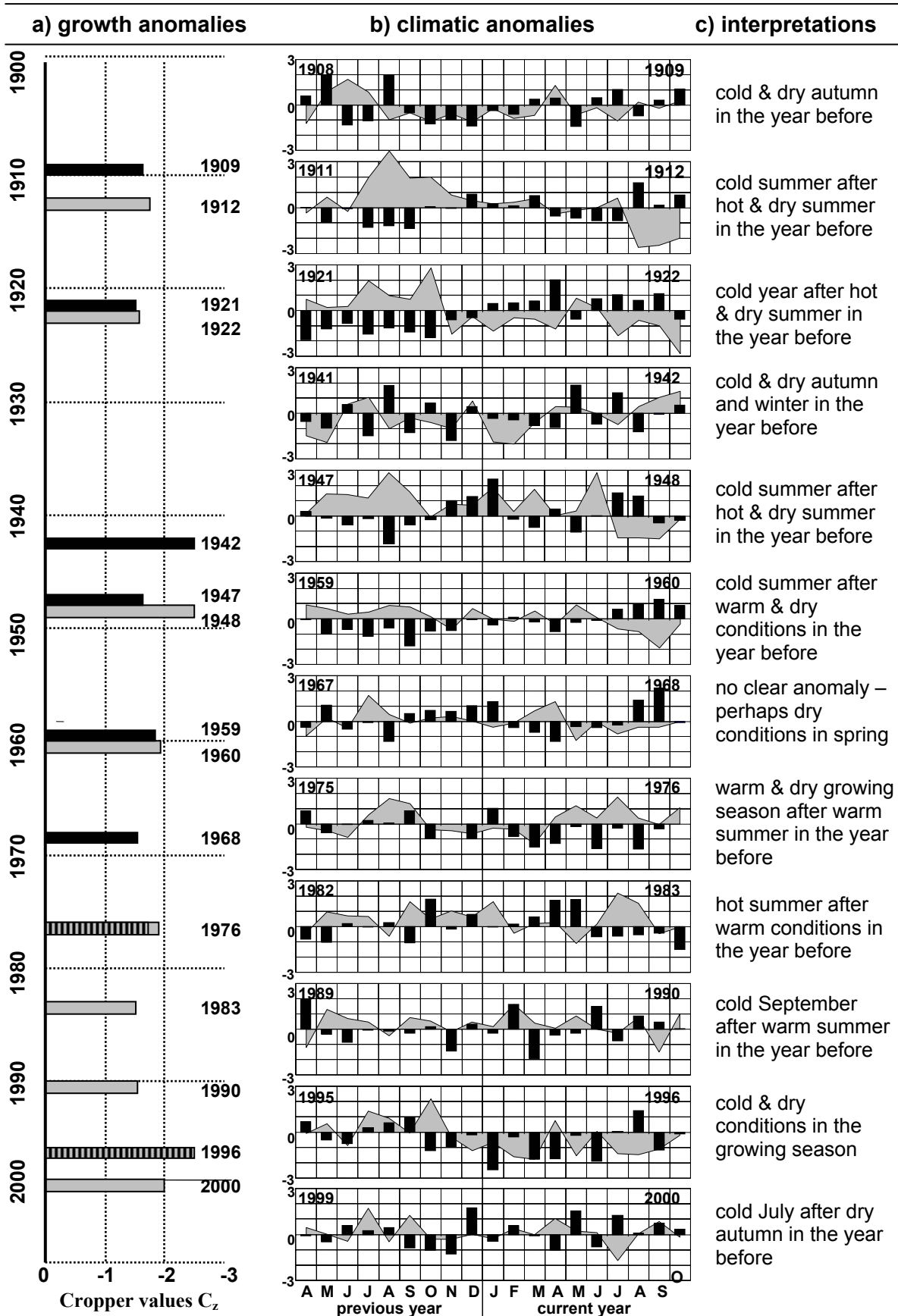
Figure 2: (a) Negative growth anomalies for beech (grey) and oak (black) from 1901 to 2000, (b) corresponding temperature (grey) and precipitation (black) anomalies shown as z-transformed deviations from the monthly long-term means, and (c) interpretations.

Climate and growth conditions in 2003/04

Climatic anomalies in the research area from April 2003 to October 2004 are shown in figure 3a. From June to September 2003 the monthly temperature means were approximately 1σ higher than the corresponding means of the reference period 1961 to 1990.
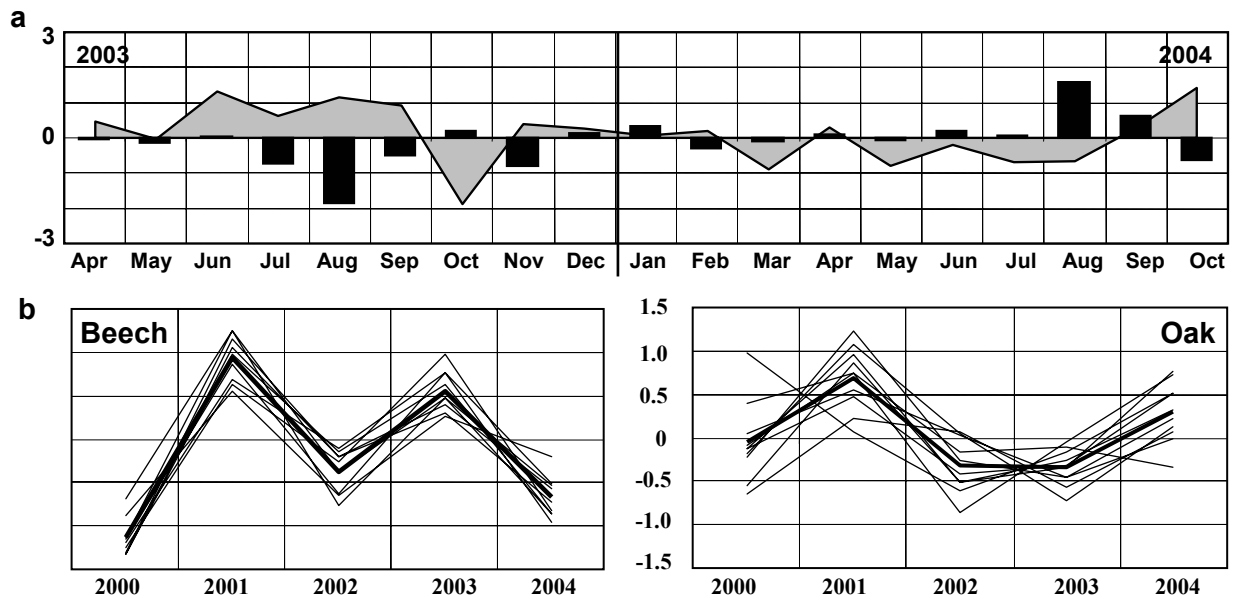
Figure 3: The a) temperature (grey) and precipitation (black) anomalies 2003/04 and b) the growth anomalies from 2000 to 2004 illustrated as residuals against a 3-year left-side weighted moving average for beechs (left) and oaks (right) in the NW-German low mountain ranges.

However, during the spring and June of 2003, the precipitation sums nearly reached the values of the reference period. First, in July (-0.8σ) and especially in August (-1.9σ) they stayed clearly behind the reference values. Therefore, the strong dryness period in 2003 began not before July and persisted until September, followed by a cold October. In 2004, the whole growing season was characterized by temperatures slightly below the reference values and precipitation sums near by the values from the reference period 1961 to 1990.

The indexed growth chronologies, illustrated as residuals against a 3-year left-side weighted moving average, for beeches and oaks from 2000 to 2004 are shown in figure 3b. For the years 2000 until 2002 both species have synchronous radial increments. After a wide tree ring in 2001, beeches and oaks show a weak growth depression in 2002 with tree-ring widths slighly below the moving average. In the following years both species reacted with contrary growth behaviour. While oak tree rings in 2003 remained on the level of 2002 or became slightly smaller, beeches produced wide tree rings in 2003. In contrast to the oaks, which showed increasing tree-ring widths in 2004, beeches had narrow tree rings at all locations. But the growth depression was not strong enough to reach a negative pointer year (z-values from -0.5 to 1.0).

Weather conditions in 2003/04 are characterized by a strong dryness in the late summer, and therefore they are comparable to 1921/22, 1947/48, and with limitations to 1959/60 (Fig. 2b).

Conclusions

Beeches and oaks in the NW-German low mountain ranges have similar numbers of negative pointer years in the 20th century. But only in two years (1976 and 1996) both species show synchronal reactions. Whereas in 1996 a cold and dry growing season was responsible for narrow tree rings, in 1976 from April to August temperatures above average and precipitation below average caused the growth depressions.

In respect to dryness conditions, growth/climate responses of beeches and oaks in NW-German low mountain ranges can be devided into three types:

- narrow tree-ring widths as a response to dryness at the end of the growing season in the year before (valid for beech only);
- narrow tree-ring widths as response to dryness during the whole growing season (valid for beechs and oaks);
- narrow tree-ring widths as a response to dryness in the summer of the current year (valid for oaks only).

In the research area the dryness period of 2003 persisted especially from July to September, which is comparable to periods in 1921/22, 1947/48, and 1959/60. The response of the oaks to these weather conditions was a weak growth depression in 2003. Beeches reacted with a unique but weak negative growth depression in 2004. In fact, in NW-German low-mountain ranges 2003 is no negative pointer year.

References

Anders, S., Beck, W., Lux, W., Müller, J., Fischer, R., König, A., Küppers, J.G., Thoroe, C., Kätzel, R., Löffler, S., Heydeck, P., Möller, K. (2004): Auswirkung der Trockenheit 2003 auf Waldzustand und Waldbau. Eberswalde, BMVEL 533-7120/1, BFH Hamburg: 109.

Beniston, M., Innes, J.L. (1998): The impacts of climate variability on forests. Springer, Berlin. 329.

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

Elling, W., Dittmar, C. (2003): Neuartige Zuwachsdepressionen bei Buchen. AFZ/Der Wald 58: 42-45.

Gerstengarbe, F.W., Werner, P.C. (2005): Das NRW-Klima im Jahr 2055. Abschätzung der Klimaentwicklung in NRW zwischen 1951 und 2055. LÖBF-Mitteilungen 2/05: 15-18.

Herbst, M., Hormann, G. (1998): Predicting effects of temperature increase on the water balance of beech forests: An application of the "Kausha" model. Climatic Change 40: 683-698.

Kahle, H.P. (2006): Impact of the drought in 2003 on intra- and inter-annual stem radial growth of beech and spruce along an altitudinal gradient in the Black Forest, Germany. In: Heinrich, I., Gärtner, H., Monbarron, M., Schleser, G.H. (Eds.):Tree rings in Archaeology, climatology and ecology, TRACE 4: 151-163.

Kölling, C., Walentowski, H., Borchert, H. (2005): Die Buche in Mitteleuropa: Eine Wald-baumart mit grandioser Vergangenheit und sicherer Zukunft. AFZ/Der Wald 60: 696-701.

Lebourgeois, F., Bréda, N., Ulrich, E., Granier, A. (2005): Climate-tree-growth relationships of European beech (Fagus sylvatica L.) in the French permanent plot network (RENECOFOR). Trees 19: 385-401.

Meyer, F.D. (1998-1999): Pointer year analysis in dendroecology: a comparision of methods. Dendrochronologia 16-17: 193-204.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M., New, M. (2004): A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Tyndell Centre for Climate Change Research, Working Paper 55: 25.

Neuwirth, B. (2005): Interannuelle Klima/Wachstums-Beziehungen zentraleuropäischer Bäume von ad1901 bis 1971 – eine dendroklimatologische Netzwerkanalyse. Dissertation University of Bonn: 162.

Neuwirth, B., Schweingruber, F.H., Winiger, M. (2007): Spatial patterns of Central European pointer years. Dendrochronologia 24: 79-89.

Rennenberg, H., Seiler, W., Matyssek, R., Geßler, A., Kreuzwieser, J. (2004): Die Buche (Fagus sylvatica) – ein Waldbaum ohne Zukunft im südlichen Mitteleuropa? Allgemeine Forst- und Jagdzeitung 175: 210-224.

Riemer, T. (1994): Über die Varianz von Jahrringbreiten – Statistische Methedon für die Auswertung der jährlichen Dickenzuwächse von Bäumen unter sich ändernden Lebensbedingungen. Berichte des Forschungszentrums Waldökologie, Reihe A, Bd. 121, Göttingen: 373.

Rinn, F. (2005): TSAPWin^{TM} – Time Series Analysis and Presentation for Dendrochronology and Related Applications, Version 0.53, User Reference. Heidelberg: 91.

GWL-Fingerprints in Central European Tree-Rings

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Introduction

Dendroclimatological research often deals with the reconstruction of past climate conditions. Up to now all tree-ring based reconstructions try to extract the signal of one climatic parameter or a combination of different climatic parameters from tree-ring series (Fritts 1976). One important step to be able to use tree-ring series as proxies for climate-reconstruction is the elimination of the non-climatic environmental signals. Further, it is necessary to take into consideration that tree growth can even differ at the same site due to the different demands and sensitivity of the various tree species towards environmental and climate conditions (Schweingruber 1996).

Moreover, in temperate climates it is quite difficult to separate the different climatic parameters, because the correlation between tree-ring growth and these parameters is weak (Glaser 2001). Nevertheless, it is possible to investigate the relation between climatic parameters and radial tree-ring growth in temperate climates if certain conditions, like biogeographical stratification, similar editing and statistical preparation of all datasets, are fulfilled (Schweingruber & Nogler 2003).

This paper presents a conceptual approach for a new dendroclimatological project. The target of the project is to estimate the influence of synoptic circulation conditions on high resolution spatial patterns of variations of radial-growth anomalies for Central European trees at annual resolution from 1901 to 2000. The synoptic conditions will be parameterized by a daily resolved dataset of 29 so called Großwetterlagen (GWL). These GWLs were often called 'extended-range weather situations' or 'weather regime types' and were introduced first by Baur 1943 and extended by Hess & Brezowsky 1952 (Gerstengarbe 2005, Hess & Brezowsky 1952, Baur 1944). The spatial patterns of radial-growth anomalies will be derived from pointer years, which were expressed by z-transformed Cropper-values (Neuwirth et al. 2006a, b).

Is there a linkage between GWL and spatial patterns of tree-ring growth?

Climate is an important forcing factor for tree-ring growth. Regarding the growth responses to variations in temperature and precipitation, the annual patterns of tree-ring growth in Central Europe could not be explained comprehensively for the time between 1901 to 1971 (Neuwirth et al. 2006b). This is caused by the fact, that, on the one hand, other climatic factors like air moisture or irradiance also can influence tree-ring growth and, on the other hand, the data from meteorological stations do not reflect the real climatic situations in the respective forests.

But, all climatic factors all over Central Europe are caused by the large scale circulation condition over the North Atlantic, which are determined by the situation of the atmospheric control centres Icelandic Low and Azores High, and the topography of the local sites. The situation of the atmospheric control centres determines the basic flow direction towards Europe, which can be classified into three general circulation types: zonal, mixed, and meridional.

Table 1: Classification of the circulation types into 10 synoptic types and 29 GWLs. (Gerstengarbe 2005)

CirculationType	Synoptic Type	GWL Großwetterlagen
zonal	West	West Anticyclonic (WA), West Cyclonic (WZ), Southern West (WS), Angleformed West (WW)
mixed	South-West	South-West Anticyclonic (SWA), South-West Cyclonic (SWZ)
	North-West	North-West Anticyclonic (NWA), North-West Cyclonic (NWZ)
	Central European High	Central European High (HM), Central European Ridge (BM)
	Central European Low	Central European Low (TM)
meridional	North	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	North-East Anticyclonic (NEA), North-East Cyclonicl (NEZ)
	East	Fennoscandian High Anticyclonic (HFA), Fennoscandian High Cyclonic (HFZ), Norwegian Sea - Fennoscandian High Anticyclonic (HNFA), Norwegian Sea - Fennoscandian High Cyclonic (HNFZ)
	South-East	South-East Anticyclonic (SEA), South-East Cyclonic (SEZ)
	South	South Anticyclonic (SA), South Cyclonic (SZ), British Isles Low (TB), Western European Trough (TRW)

According to the flow direction, the circulation types can be classified into 10 synoptic types and furthermore into 29 GWLs (Tab. 1). The GWLs are accompanied by different air masses which are characterized by distinctive combination of properties in terms of temperature, moisture etc. For example, the GWL WZ (Tab.1) normally comes along with very wet conditions in the north of the study area and drier conditions in the south of the study area. The weather conditions at specific locations are modified by the topographic situation. In the luff of a mountain range, rainfall is stronger than in the lee side, for example. Therefore, it is useful to investigate the growth responses related to the frequency distribution of the GWLs. If it is possible to extract the GWL signal from tree-ring chronologies nearly the complete climatic signal is explainable.

Study area

The research area is located in Central Europe and defined as the area between 5°-15°E / 42.5°-52.5°N (Fig. 1). The triangles in the map show the spatial distribution of dendro-chronological sites representing more than 8,000 trees from all the important Central European tree species (*Abies alba, Fagus sylvatica, Larix decidua, Quercus robur, Quercus petraea, Picea abies, Pinus cembra, Pinus sylvestris, and Pinus uncinata*). The circles in figure 1 mark regions without or only a few sites. These gaps should be closed to get a network with a homogeneous density. A homogeneous density is needed to exclude results

and interpretations for the GWL-growth responses, which were affected by inhomogeneties in the site network.
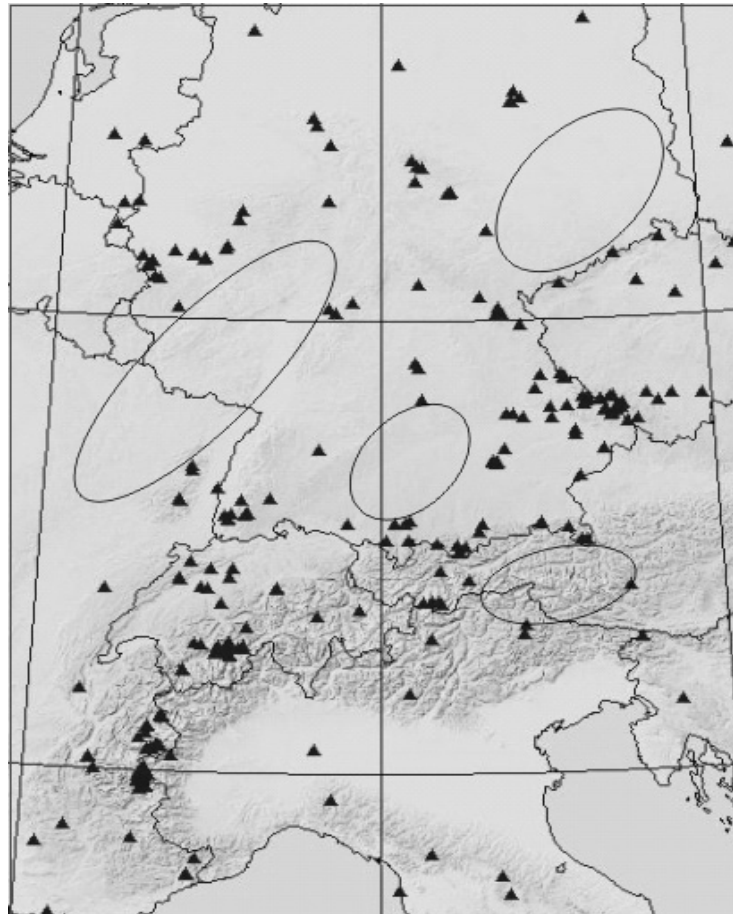
Figure 1: Spatial distribution of dendrochronological sites in Central Europe (modified after Neuwirth, 2005, p. 57). Circles indicate regions without or only few sites.

Procedure

The relations between spatial patterns of tree-ring growth and GWL will be analysed by a dendroclimatological network covering the period from 1901 to 2000. This network is based on a multidimensional data base structure which combines annually resolved dendrochronological time series and their corresponding meta data (site related information) with daily resolved GWL-data. The data bank will be developed by using the object-oriented software package ORACLE 10g.

The dendrochronological part of the network includes ring-width data from more than 500 Central European sites (Fig. 1) and their topographic and site-ecological data. The primary steps for the preparation of the dendrochronological data are:

- data collection,
- editing (quality check, data inputting, encoding, data formatting (Neuwirth 2005)),
- processing (indexation and, if necessary, elimination of the age trend by Regional Curve Standardization RCS (Esper et al. 2003; Cook & Peters 1997)).

The indexed time series will be grouped by using techniques like Principal Component Analyses (PCA) and Cluster Analyses (CA) to gather all sites with similar growth anomalies

into one group. Then, the characteristics of the resulting groups will be defined by interpreting those meta data which are common for the group. Finally, for every group the GWL signal on different time scales (extreme years, interannual, decadal, long-time trend) will be evaluated by using pointer-year analyses, time-series analyses, and GIS-analyses (GIS: Geographical Information Systems).

GIS-analysis for the investigation of the growth / GWL- response
Due to the fact that pointer-year analyses (e.g. Neuwirth et al. 2005; Neuwirth et al. 2006b) and time-series analyses (e.g. Frank & Esper 2005; Neuwirth 2005) are quite common, only the GIS-analyses will be presented. During the GIS-analysis GWL-charts and growth maps are analysed and combined. In the left part of figure 2 the pressure chart shows the typical circulation and pressure situation for the most frequent GWL, the so-called 'West Cyclonic' (WZ) (Tab.1). The northern part of Central Europe is influenced by low-pressure, the south is influenced by high-pressure. This synoptic situation is linked to wet conditions, especially in the north of the study area and more or less dry conditions in the southern part of the study area.
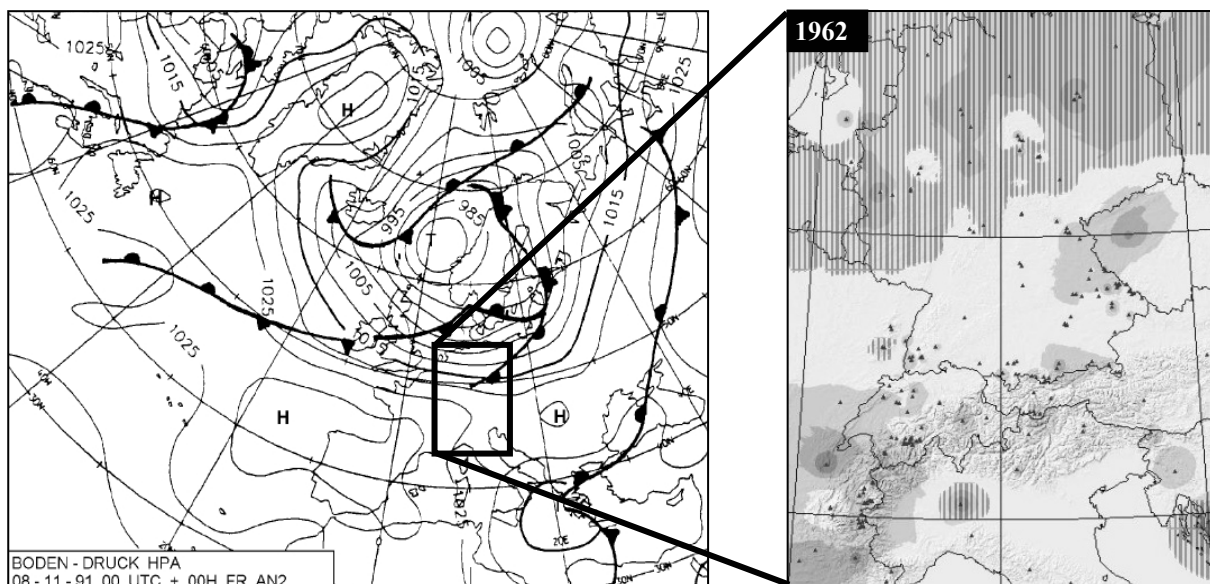
Figure 2: Example for the GIS-analyses. Comparison between the growth map for the year 1962 (source: Neuwirth 2005) and the typical synoptic situation for the GWL WZ which is presented in the pressure chart (source: Gerstengarbe 2005).

On the right side of figure 2, the growth map for the year 1962 is presented. This map reflects the negative (grey colour) and positive (grey vertical lines) growth anomalies derived from z-transformed Cropper-values (Neuwirth et al. 2006b). The vertical grey lines dominate the northern parts of the map, whereas in southern parts negative growth anomalies are dominant.

Within the framework of the GIS analysis it will be endeavoured to link the circulation and pressure situation as represented by a GWL or a combination of different GWLs for a period (month, year, decade) to the spatial distribution of tree-ring growth. Thus, in the pressure chart and in the growth map similar spatial divisions can be observed. Normally, wet

conditions lead to positive growth anomalies and dry conditions to negative growth anomalies. Therefore, the chosen synoptic situation fits very well the growth map for the year 1962. To exclude random and to discover systematic relations between GWL and growth reactions, several questions have to be answered.

Questions and aims of the project

The main target of the project is to explain the spatial pattern of tree-ring growth anomalies in Central Europe with the frequency distribution of the GWLs. For the investigation of the linkage between tree ring growth anomalies and GWL it is necessary to answer the following questions using time series-, pointer year- and GIS-analysis.

- Is it possible to establish a link between tree-ring growth and GWL?
- Is it possible to trace back extreme growth responses to a special frequency distribution of the GWLs?
- Are there seasonal differences regarding the influence of the various GWLs on tree-ring growth?
- What is the most important factor for tree-ring growth: circulation type, synoptic type, a combination of different GWLs or even one GWL?
- Is it possible to detect the circulation changes above Central Europe in tree-ring series?

The expected results of this project can be used to reconstruct past climate conditions for Central Europe on a high spatial resolution. The first step for a reconstruction is to understand the link between the spatial pattern of tree-ring growth and the frequency distribution of GWLs in the present. Afterwards it will be possible to reconstruct the frequency distribution of the GWLs of the past. The advantage of a tree ring-based GWL reconstruction is the stability of the climate signal derived from GWL towards topographic and spatial modifications, because all climate elements like precipitation or temperature are modified by the topography but the overall trigger is the GWL.

References

Baur, F., Hess, P., Nagel H. (1944): Kalender der Großwetterlagen Europas 1881-1939. Bad Homburg v. d. H.

Cook, E.R., Peters, K. (1997): Calculating unbiased tree-ring indices for the study of climatic and environmental change. *The Holocene* 7(3): 359-368.

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

Frank, D., Esper, J. (2005): Characterization and climate responses of a high-elevation, multi-species tree-ring network in the European Alps. *Dendrochronologia* 22 (2): 107-122.

Fritts, H. C. (1976): Tree-rings and climate. Academic Press, London: 567.

Gerstengarbe, F.-W., Werner P.C. (2005): Katalog der Großwetterlagen (1881-2004) nach Paul Hess und Helmut Brezowsky. 6th edition, *PIK Report* 100, Potsdam: 153.

Glaser, R. (2001): Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen. Wiss. Buchgesellschaft, Darmstadt: 227.

Hess, P., Brezowsky, H. (1952): Katalog der Großwetterlagen Europas. Berichte des Deutschen Wetterdienst in der US-Zone 33.

Neuwirth, B. (2005): Interannuelle Klima/Wachstums-Beziehungen zentraleuropäischer Bäume von AD1901 bis 1971. Dissertation, University of Bonn (http:///hss.ulb.uni-bonn.de/diss_online/math_nat_fak/2005/neuwirth_burkhard/index.htm) 165 + appendix.

Neuwirth, B., Schweingruber, F.H., Winiger, M. (2006a): Interannual climate/growth-relations of Central European tree rings – A dendroecological network analysis. In: Heinrich, I., Gärtner, H., Monbarron, M., Schleser, G.H.: *TRACE* 4, Fribourg, Jülich: 67-76.

Neuwirth, B., Schweingruber, F.H., Winiger, M. (2006b): Spatial patterns of Central European pointer years. *Dendrochronologia* (in press).

Schweingruber, F.H., (1996): Tree rings and environment - Dendroecology. Paul Haupt, Bern, Stuttgart, Wien: 609.

Schweingruber, Nogler, P. (2003): Synopsis and climatological interpretation of Central European tree-ring sequences. *Botanica Helvetica* 113(2): 125-143.

Fire-climate interactions in northern California

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Introduction

Twentieth century fire exclusion in western U.S. forest ecosystems has dramatically disrupted existing fire regimes and has had an impact on forest structure and dynamics (Taylor 2000). Ecosystem management and ecological restoration increasingly include fire reintroduction through prescribed burning (Fulé et al. 1997) and depend on information on pre-fire exclusion fire regimes to serve as a reference for management guidelines. Pre-Euroamerican settlement fire regimes have been studied extensively for this end in ponderosa pine (*Pinus ponderosa* Laws) and mixed conifer forests of the western U.S. (*e.g.* Heyerdahl et al. 2002, Swetnam & Baisan 2003, Swetnam & Betancourt 1990, Taylor & Beaty 2005, Veblen et al. 2000).

Fire environments are locally controlled by topography and vegetation type, but the synchronicity of specific fire events across a range of spatial scales reflects the influence of regional climatic variation on fire occurrence and extent (Swetnam & Baisan 2003). Precipitation variability is well documented as a driver of fire regimes, with dry conditions conducive to widespread burns and vice versa, but the interaction between fire and climate is often more complex. A lagging pattern of wet conditions preceding large fire years occurs in pine-dominated forests due to the promotion of fine fuel production in wet years and the importance of fuel accumulation for fire activity in these dry ecosystems (Swetnam & Betancourt 1998, Swetnam & Baisan 2003). This lag effect is minimal in higher elevation, mixed conifer sites, and at low-elevation ponderosa pine sites in the Pacific Northwest (PNW) that are snow covered in winter, where fuels are generally not a limiting factor (Heyerdahl et al. 2002).

Fire regimes have also been associated with the mechanisms underlying regional patterns of climate variability. Global circulation patterns (El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO)) drive climate regimes in the western U.S. through teleconnections (simultaneous variations in climate observed over distant areas) on different time-scales. Their influence is reflected in pre-settlement fire regimes. In the Southwest, the warm (cool) ENSO phase is associated with anomalously wet (dry) winters and increased (decreased) fire activity (Swetnam & Betancourt 1990). Opposite effects for both phases are generated in the Pacific Northwest (McCabe et al. 2004). The Pacific Decadal Oscillation (PDO) shows a teleconnection pattern similar to ENSO, but tends to be expressed in 20 to 30 year cycles of warm and cool phases (Mantua et al. 1997). Moreover, the PDO cycle interacts with the ENSO cycle, so that El Niño (La Niña) events, their climatic teleconnections and their influence on fire regimes tend to be stronger during positive (negative) PDO phases (Gershunov & Barnett 1998).

This study addresses the following questions for fire-prone forests in the southern Cascade Range of northern California:

(1) Did pre-fire exclusion (1700-1900) fire frequency and fire extent of different sites show temporal synchronicity?
(2) How were fire frequency and extent related to inter-annual regional climate variability?
(3) Did fire frequency and extent vary in response to ENSO and PDO teleconnections?

Pre-settlement records of fire frequency and extent from 7 sites spread throughout the Southern Cascades Range (Taylor 2000, Beaty and Taylor 2001, Bekker and Taylor 2001, Taylor and Solem 2001, Norman and Taylor 2005, Ritchie 2005, Heyerdahl *et al.* 2006) were aggregated for this study, to emphasize the regional scale of the studied influence of climate on fire regimes.

Material and Methods

Study area

Mid-montane forests were studied at seven sites in the southern Cascades in northern California, U.S. (Fig. 1). Detailed descriptions of the individual sites can be found in the appropriate reference papers (Tab. 1). The climate is characterized by warm, dry summers and cold, wet winters.

Fire regimes in the southern Cascades may have been influenced by people. Native Americans are known to have used fire to drive game and to encourage certain plants used for food and fibre, but there is no evidence in our study areas. A policy of fire exclusion was implemented in the area in the early 20th century.

Table 1: Site and sampling characteristics for 7 sites in the southern Cascades used in this study. The time period covered for each site is derived from the inner ring of the oldest sample and the outer ring of the youngest sample.

Site	Elevation (m)	Area (km^2)	Samples	Time	Reference
Caribou	2060-2390	9.5	39	1735-1982	Taylor & Solem 2001
Cub Creek	1136-2044	15.9	56	1616-1926	Beaty & Taylor 2001
Goosenest	1495-1800	2	44	1375-1935	Ritchie 2005
Lassen Meadows	1650-2300	700	152	1520-1944	Norman & Taylor 2003
Lava Beds	1580-1670	13.7	63	1563-1904	Heyerdahl et al. 2006
Prospect Peak	1800-2420	26.3	126	1507-1937	Taylor 2000
Thousand Lakes	1700-2646	20.4	50	1652-1942	Bekker & Taylor 2001
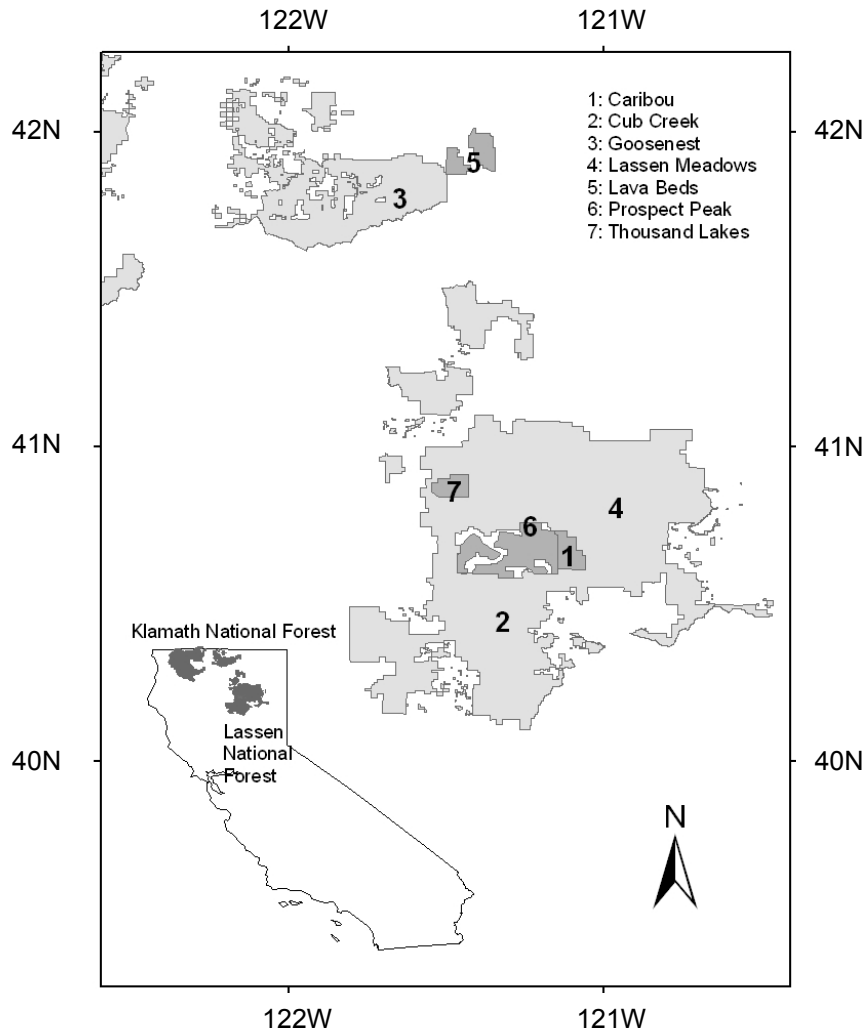
Figure 1: Location of the seven study areas in the southern Cascades in northern California. Klamath and Lassen National Forest (including the Goosenest Adaptive Management Area, the Cub Creek Research Natural Area and the Lassen Meadows site) are marked in light grey, Caribou and Thousand Lakes Wilderness, Lava Beds National Monument and Lassen Volcanic National Park in dark grey.

Fire record

Pre-fire exclusion fire occurrence and extent were quantified based on fire scars in partial wood cross sections removed from 530 fire-scarred trees at the seven study sites. Partial wood cross sections were removed from each scarred tree with a chainsaw (Arno & Sneck 1977). Cross sections were sanded to a high polish to allow cross-dating of the annual rings in each sample with a nearby tree-ring chronology. The calendar year of tree ring with a fire scar was then recorded as the fire date (Stokes & Smiley 1968). Fire history data were analysed using FHX2 software (Grissino-Mayer 1996).

The time during which fires were recorded ranged between 247 (1735-1982) and 560 (1375-1935) years. The proportions of samples burned per year for every site were summed to construct a composite record of region-wide annual fire extent (Fig. 2). To avoid problems caused by low sample depth, the fire-climate analysis was limited to the period 1700-1900, during which a minimum of a hundred samples were recording fires (Fig.2).
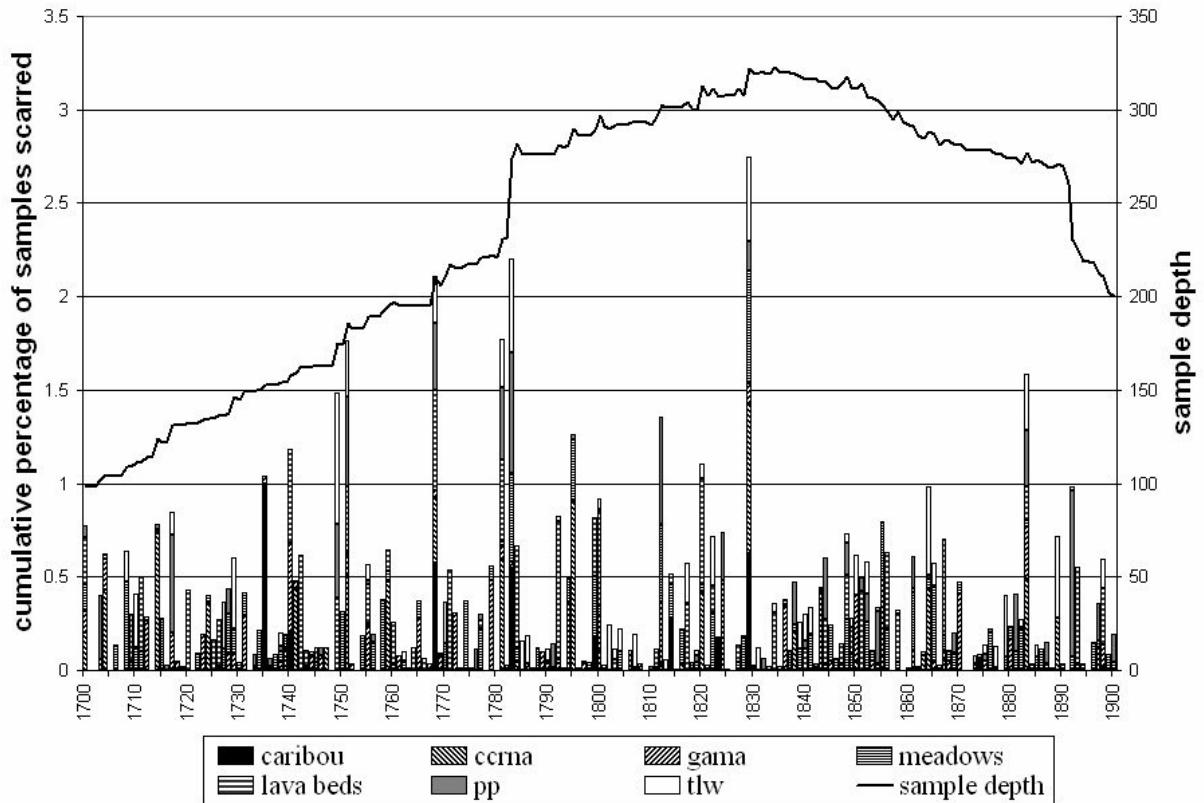
Figure 2: Composite time series of annual percentage of samples scarred and cumulative total sample depth based on 7 sites in the southern Cascades Range

Climate data

Cook and Krusic (2004) developed a gridded (2.5°x2.5°) network of tree-ring based reconstructions of summer Palmer Drought Severity Index (PDSI; Palmer 1965) for North America. We used the PDSI reconstruction for gridpoint 35 (northern California). A time series of summer temperature anomalies (relative to a 1951-1970 base period) for northern California was derived from the western North America gridpoint and regional summer temperature reconstruction (Briffa et al. 1992; gridpoint 16).

The influence of teleconnections on fire occurrence and extent was analyzed by comparing the fire record with a tree-ring and coral derived reconstruction of PDO (Gedalof et al. 2002), and a tree-ring based Niño3 reconstruction (Cook 2000) for the period 1700-1900.

Fire-climate analysis

A contingency analysis was used to test the statistical significance of the synchrony of multiple site fire events (Swetnam 1993). Observed numbers of fires co-occurring in different combinations of sites (0 to 7 sites) were compared to expected numbers based on a χ^2 test. Pearson product moment correlation coefficients were calculated between climate (PDSI, temperature, ENSO, PDO) and composite fire extent time series to study interannual relationships. Interannual variations in all time series are emphasized by computing first differences (value (year t) – value (year t-1)).

Results

The observed co-occurrence of fire dates in multiple sites was much higher than would be expected based on chance (χ^2 = 69.2, p<0.001 for 1700-1800; χ^2 = 46.5, p<0.001 for 1800-1900). Whereas less than 7 fire dates are expected to co-occur over the 200 year period in 3 or more sites, we found 29 fire dates for which this was the case. This strong synchronicity among spatially disperse sites indicates a regional climatic influence on fire occurrence. Climate is the only known environmental driver operating at these spatial and temporal scales (Swetnam & Baisan 2003).

*Table 2: Pearson correlation coefficients for the relationship between time series of fire extent (for 7 sites in the southern Cascade Range, California and the composite time series including all sites) and time series of PDSI values, summer temperature anomalies and Niño3 values of the fire year Statistically significant correlations are marked by * (p<.05) or ** (p<.01)*

site	PDSI	Temp	ENSO
Caribou	-.185**	.07	-.049
CCRNA	-.2**	.222**	.04
GAMA	-.208**	.163*	-.05
Lassen Meadows	-.206**	.145*	.153*
Lava Beds	-.06	-.023	.057
Prospect Peak	-.228**	.192**	.155*
TLW	-.251**	.171*	.157*
Composite	-.356**	.252**	.129

Fire extent at all individual sites except for the Lava Beds site, is strongly associated with dry, hot conditions in the concurrent summer (Table 2). The correlation with current year PDSI and temperature (R=-0.356 and R=0.252, p<.01) is stronger for the composite time series than for individual time series (Fig. 3), indicating the regional character of the climatic association. Fire extent was not associated with climatic conditions in (up to four) previous years. Fire extent at some sites is positively correlated with the concurrent Niño3 index (Table 2), which reflects drier and warmer than normal conditions during El Niño years in northern California. This pattern is also found in the relation between the composite fire time series and ENSO, but is not statistically significant. No significant correlations were found with the PDO index on an inter-annual time-scale for the period 1700-1900.
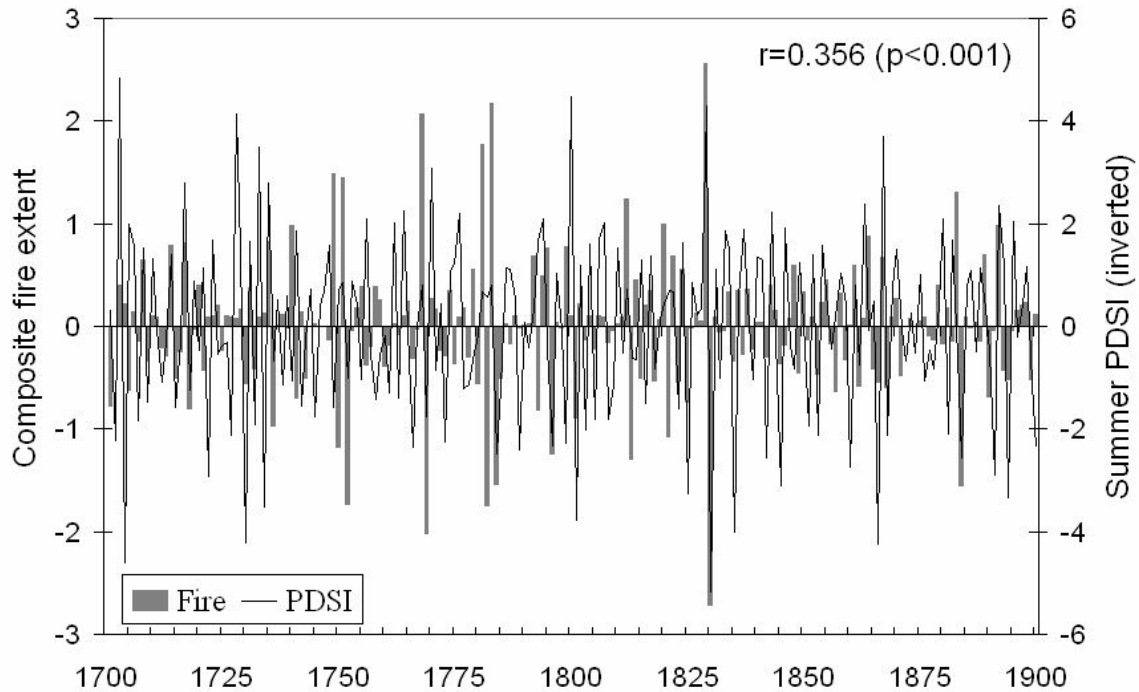
Figure 3: Time series of correlations between a composite time series of fire extent for 7 sites in the southern Cascade Range, California and reconstructed summer PDSI for northern California. PDSI values and corresponding correlation coefficients are inverted to visually enhance the relationship.

Discussion

We developed an extensive regional network of fire extent time series for the southern Cascades in northern California. This network allowed us to investigate broad-scale fire patterns, by separating them from local patterns characterizing individual sites. Wildfires in the region showed a strong synchroneity, reflected by the co-occurrence of fire dates in spatially dispersed sites. The expected frequency of a fire date co-occurring in six out of seven study sites strictly by chance, is once in over 13000 years. We found five years (1751, 1781, 1800, 1829 and 1883) in our 200-year study period, however, during which this was the case. This high level of synchroneity does not imply a continuously burned area between sample sites, but reflects the influence of climate in creating regionally synchronized conditions conducive to burning (Swetnam & Betancourt 1998).

We built a time series of regional fire spread by combining the proportion of trees recording fire per site with the number of sites burnt by fire in any given fire year. This approach allowed us to emphasize the ability of fire to spread within and between sites in our study area (Grissino-Mayer & Swetnam 2000). Interannual variability in fire spread is climate-driven, which is reflected by the strong correlations we found between regional fire extent and PDSI and temperature. Widespread fires coincided with dry and warm conditions in the fire year (Fig.3a), but were not associated with preceding climatic conditions. Wet and cool years promote fine fuel accumulation in low-elevation, pine-dominated sites, which are generally relatively dry (Norman & Taylor 2003), but are unlikely to cause significant variation

in fine fuel production at higher-elevation sites and at low-elevation sites that are snow covered in winter (Swetnam & Baisan 2003). Snowmelt in spring increases soil and fuel moistures at the beginning of each fire season and fuels are generally not a limiting factor for fire occurrence at these sites (Heyerdahl et al. 2002).

The fire extent time series showed some interdecadal variation, but no long-term trends could be distinguished, apart from the abrupt decline of fire frequency after 1900. Hardly any fire scars could be found after 1900, reflecting successful fire exclusion.

The importance of winter snow cover in the modulation of pre-fire exclusion fire regimes in the southern Cascades, is expressed in the regional fire response to the ENSO circulation pattern. We found a weak positive relation between ENSO and fire extent, reflecting the coincidence of El Niño events with dry conditions and large fire years found in the PNW (Heyerdahl et al. 2002, Hessl et al. 2004). In this region, the ENSO teleconnection is most strongly expressed in winter snowfall, rather than in summer PDSI (Cayan et al. 1999). Fire extent in this region is thus indirectly influenced by ENSO, through the timing of snowmelt and the linked length of the fire season (Heyerdahl et al. 2002), rather than directly through its influence on fuel moisture conditions. Fire extent in the southern Cascades is therefore less explicitly driven by interannual ENSO variations than is the case for the southern Rocky Mountains and the Southwest, where ENSO is more closely linked to fine fuel production and fuel moisture content (Swetnam & Betancourt 1998, Veblen et al. 2000).

Although the PDO shows a teleconnection pattern similar to ENSO in northern California, no correlations between fire spread and the PDO cycle were found for the period 1700-1900. Large fire years tended to coincide with positive PDO phases in the PNW (Hessl et al. 2004), where PDO is a driver of multidecadal winter precipitation (Mantua et al. 1997). The PDO teleconnection pattern shows a dipole in the Western U.S., however, the pivot point of which is located in northern California. PDO teleconnections show a strong spatial and temporal variability in northern California, leading to a mixed PDO signal in pre-settlement fire regimes (Norman & Taylor 2003, Taylor & Beaty 2005).

Considering the climatic influence on pre-settlement fire regimes in the southern Cascade range, particularly the association of fire with temperature variations, future climatic change is likely to affect fire regimes in the region. Despite the influence of fire exclusion and other forest management activities on 20th century fire regimes (Skinner & Chang 1996), fire extent appears still to be linked to climatic conditions (Westerling et al. 2003, Trouet et al. 2006). However, because of anthropogenic interference on the one hand and the complex character of fire-climate interactions on the other, predicting the response of local forest fire activity to future climatic change remains a major challenge.

References

Arno, S. F., Sneck, K. M. (1977): A method for determining fire history in coniferous forest of the mountain west. USDA Forest General Technical Report INT-GTR-42.

Beaty, R.M., Taylor, A.H. (2001): Spatial and temporal variation of fire regimes in a mixed conifer forest landscape, Southern Cascades, California, USA. *Journal of Biogeography* 28:955-966.

Bekker, M.F., Taylor, A.H. (2001). Gradient Analysis of fire regimes in montane forests of the Southern Cascade Range, Thousand Lakes Wilderness, California, USA. *Plant Ecology* 155:15-28.

Briffa, K.R., Jones, P.D., Schweingruber, F.H. (1992): Tree-Ring Density Reconstructions of Summer Temperature Patterns across Western North America since 1600. *Journal of Climate* 5: 735-754.

Cayan, D.R., Redmond, K.T., Riddle, L.G. (1999): ENSO and hydrologic extremes in the western United States. *Journal of Climate* 12: 2881-2893.

Cook, E.R. (2000): Nino 3 Index Reconstruction. International Tree-Ring Data Bank. IGBP PAGES/World Data Center-A for Paleoclimatology. Data Contribution Series #2000-052. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Cook, E.R., Krusic, P.J. (2004): The North American Drought Atlas. Lamont-Doherty Earth Observatory and the National Science Foundation.

Fulé, P.Z., Covington, W.W., Moore, M.M. (1997): Determining reference conditions for ecosystem management of southwestern ponderosa pine ecosystems. *Ecological Applications* 7:895-908.

Gedalof, Z., N.J. Mantua, D.L. Peterson (2002): A multi-century perspective of variability in the Pacific Decadal Oscillation: new insights from tree rings and coral. *Geophysical Research Letters* 29: 2204.

Gershunov, A., Barnett, T. (1998): Interdecadal modulation of ENSO teleconnections. Bulletin of the American Meteorological Society 79:2715-2725.

Grissino-Mayer, H. D. (1996): FHX2 User's Manual: Software for the Analysis of Fire History from Tree Rings.

Grissino-Mayer, H. D., Swetnam, T.W. (2000): Century-scale climate forcing of fire regimes in the American Southwest. *The Holocene* 10: 213-220.

Hessl, A.E., McKenzie, D., Schellhaas, R. (2004): Drought and Pacific Decadal Oscillation linked to fire occurrence in the inland Pacific Northwest. *Ecological Applications* 14(2): 425-442.

Heyerdahl, E.K., Brubaker, L.B., Agee, J.K. (2002): Annual and decadal climate forcing of historical fire regimes in the interior Pacific Northwest, USA. *The Holocene* 12: 597-604.

Heyerdahl, E.K., Miller, R.F., Hopkins, K. (2006): Fire-scar chronologies from Lava Beds National Monument. [online] IGBP PAGES/World Data Center for Paleoclimatology Data Contribution. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M, Francis, R.C. (1997): A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society4* 78: 1069-1079.

McCabe, G.J., Palecki, M., Betancourt, J. (2004): Pacific and Atlantic ocean influences on multidecadal drought frequency in the United States. *PNAS* 101:4136-4141.

Norman, S.P., Taylor, A.H. (2003): Tropical and north Pacific teleconnections influence fire regimes in pine-dominated forests of north-eastern California. *Journal of Biogeography 30*: 1081-1092.

Palmer, W.C. (1965): Meteorological drought, *Res. Paper No. 45*, U.S. Dep. Comm. Wea. Bur., Washington, D.C.

Ritchie, M.W. (2005): Ecological research at the Goosenest Adaptive Management Area in northeastern California. Gen. Tech. Rept. PSW-GTR-192. USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

Skinner, C.N., Chang, C.R. (1996): Fire regimes, past and present. Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

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

Swetnam, T.W., Baisan, C.H. (2003): Tree ring reconstructions of fire and climate history in the Sierra Nevada and southwestern United States. In: Fire and climatic change in temperate ecosystems of the western Americas (ed. by Veblen, T.T., Baker, W.L., Montenegro, B. Swetnam, T.W.), pp. 158-195. Springer Verlag, New York.

Swetnam, T.W., Betancourt, J.L. (1990): Fire-Southern Oscillation relations in the southwestern United States. *Science* 249:1017-1020.

Swetnam, T.W., Betancourt, J.L. (1998): Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate* 11:3128-3147.

Taylor, A.H. (2000): Fire regimes and forest changes in mid and upper montane forests of the southern Cascades, Lassen Volcanic National Park, California, USA. *Journal of Biogeography* 27:87-104.

Taylor, A.H., Beaty, R.M. (2005): Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA. *Journal of Biogeography* 32:425-438.

Taylor, A.H., Solem, M.N. (2001): Fire regimes and stand dynamics in an upper montane forest landscape in hte southern Cascades, Caribou Wilderness, California. *Journal of the Torry Botanical Society* 128: 350-361.

Trouet, V., Taylor, A.H., Carleton, A.M., Skinner, C.N. (2006): Fire-Climate Interactions in forests of the American Pacific Coast, *Geophysical Research Letters 33* (18): DOI L18704.

Veblen, T.T., Kitzberger, T., Donnegan, J. (2000): Climate and human influences on fire regi;es in ponderosa pine forests in the Colorado Front Range. *Ecological Applications* 10: 1178-1195.

Westerling, A., Swetnam, T.W. (2003): Interannual to decadal drought and wildfire in the western United States. *EOS* 84: 545-560.

SECTION 3

ISOTOPES

Climate signals in the European isotope network ISONET

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Introduction

Over the last three years, 16 European isotope labs collaborated in the EU project ISONET (co-ordinator: G. Schleser, http//www.isonet-online.de) on developing the first large-scale network of $\delta^{13}C$, $\delta^{18}O$ and δ^2H in from oak, pine and cedar tree-rings, covering sites from Fennoscandia to the Mediterranean region. The sampling design considered not only ecologically "extreme" sites, with a single climate factor predominantly determining tree growth, as required for ring width and wood density analyses (Bräuning & Mantwill 2005, Briffa et al. 2001, 2002, Frank & Esper 2005a, b), but also temperate regions with diffuse climate signals recorded in the 'traditional' tree ring parameters. This strategy, however, may enable expanding climatic reconstructions into regions not yet well covered. As reported earlier (Treydte et al. 2005), the aim is to estimate temperature, humidity and precipitation variations with annual resolution, to reconstruct local to European scale climate variability over the last 400 years. Climate variability is addressed on intra-annual to century timescales. This strategy should allow understanding both, high frequency variations including the exploration of seasonality signals and extreme events, and longer-term trends including source water/air mass changes and baseline variability across Europe.

Here we present first climate calibration results for the 20th century, using $\delta^{13}C$ and $\delta^{18}O$ data from up to 25 sites currently available in the network. We discuss (i) relationships of each

parameter to summer conditions expressed by maximum temperatures, precipitation and drought, (ii) strength of the climate signal within the networks and (iii) similarities/differences of climate response between the networks. Finally we provide some ideas for further investigations of this unique dataset to fully exploit its potential for detailed European climate reconstruction beyond the information commonly achieved from ring width and density analyses.

Material and Methods

At every site ring widths were measured using a semi-automated RinnTech system with 0.01 mm resolution and cross dated following standard procedures (Fritts 1976). Four trees per site (two cores per tree) were selected for isotope analysis. Criteria for sample selection were low numbers of missing rings and regular ring boundaries. Tree rings were then separated year-by-year using sharp knifes or scalpels (for oak only late-wood was considered). For the majority of sites tree-rings grown in the same year were pooled prior to cellulose extraction to facilitate the development of this large network (Borella et al. 1998, Leavitt & Long 1984, Treydte et al. 2001). Cellulose was extracted following standard procedures and burned to CO_2 or pyrolised to CO, respectively, before mass spectrometer analysis (McCarroll & Loader 2004). $\delta^{18}O$ values are expressed as deviations from the VSMOW and $\delta^{13}C$ values as deviations from the VPDB standard (Craig 1957). For determination of deuterium/hydrogen (D/H) ratios of nonexchangeable hydrogen in cellulose an improved on-line method has been developed (Filot et al. 2006) based on the equilibration reaction of hydroxyl hydrogen of cellulose and water vapour of known isotopic composition (Feng et al. 1993, Schimmelmann 1991, Wassenaar et al. 2000). The equilibrated cellulose is pyrolysed and the total D/H ratio determined by subsequent online IRMS. With a mass balance system the D/H ratio of nonexchangeable hydrogen is recalculated and expressed as deviation from the VSMOW standard after an empirical calibration has been performed (Filot et al. 2006). Climate calibration of the δ^2H network will be published separately.

25 sites of the network - ranging from northern Sweden to Marocco (Fig. 1) - have been considered in this study, with 24 containing C and O isotope data, and two sites only either C or O isotope data respectively (Tab. 1).
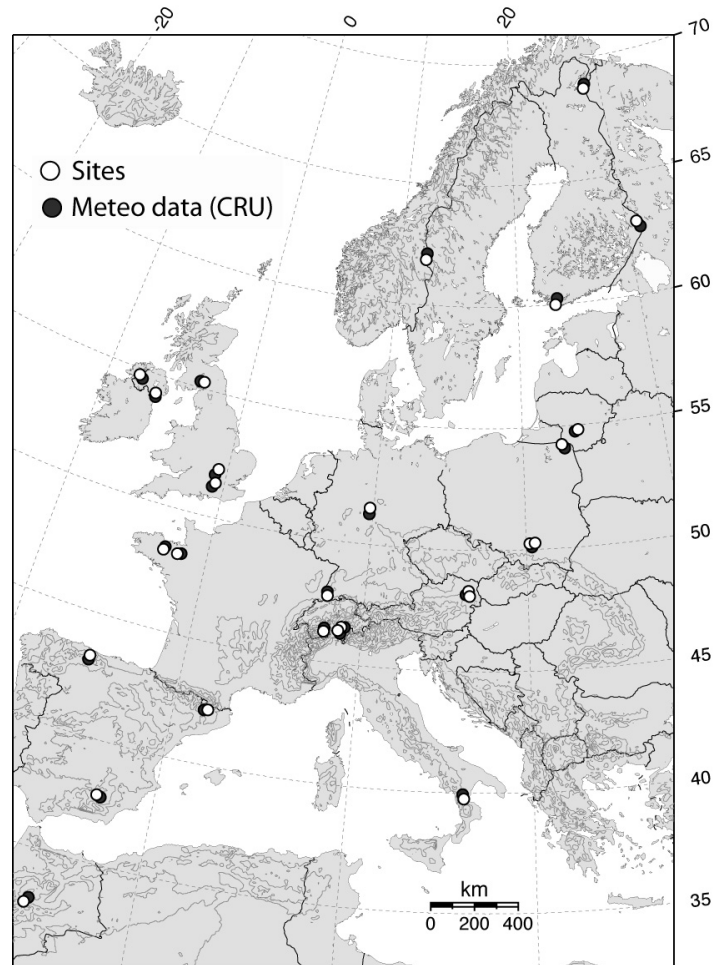
Figure 1: Tree sites and corresponding grid cells with meteorological data (0.5° x 0.5° CRU grids; Mitchell and Jones 2005; van der Schrier et al. 2006) considered in this study

Table 1: Sites, species and isotope data used in this study

Country	Site	Code	Coordinates	Altitude (m asl)	Species	$\delta^{13}C$	$\delta^{18}O$
Austria	Lainzer Tiergarten	**Lai**	16.20, 48.18	300	*Quercus petrea*	x	x
Austria	Poellau	**Poe**	16.06, 47.95	500	*Pinus nigra*	x	x
Finland	Bromarv	**Bro**	23.08, 60.00	5	*Quercus robur*	x	x
Finland	Sivakkovaara, Ilomantsi	**Ilo**	30.98, 62.98	200	*Pinus sylvestris*	x	x
Finland	Kessi, Inari	**Ina**	28.42, 68.93	150	*Pinus sylvestris*	x	x
France	Fontainebleau	**Fon**	-2.67, 48.38	100	*Quercus petrea*	x	x
France	Rennes	**Ren**	-1.70, 48.25	100	*Quercus robur*	x	x
Germany	Dransfeld	**Dra**	9.78, 51.50	320	*Quercus petrea*	x	x
Germany	Hardwald	**Har**	7.33, 47.78	240	*Quercus petrea*	x	
Italy	Monte Polino	**Mon**	16.20, 39.93	1900	*Pinus leucodermis*	x	x
Lithuiana	Panemunes Silas	**Pan**	23.97, 54.88	45	*Pinus sylvestris*	x	x
Marocco	Col Du Zad	**Col**	-5.07, 32.97	2200	*Cedrus atlantica*	x	x
Norway	Gutuli	**Gut**	12.18, 62.00	800	*Pinus sylvestris*	x	x
Poland	Niepolomice, Gibiel	**Nie1**	20.38, 50.12	190	*Quercus robur*	x	x
Poland	Niepolomice, Gibiel	**Nie2**	20.38, 50.12	190	*Pinus sylvestris*	x	x
Poland	Suwalki	**Suw**	22.93, 54.10	160	*Pinus sylvestris*	x	x
Scotland	Lochwood	**Lch**	-3.43, 55.27	175	*Quercus robur*		x
Spain	Sierra de Cazorla	**Caz**	-2.96, 37.81	1820	*Pinus nigra*	x	x
Spain	Pinar de Lillo	**Lil**	-5.25, 43.07	1600	*Pinus sylvestris*	x	x
Spain	Massis del Pedraforca	**Ped**	1.70, 42.24	2120	*Pinus uncinata*	x	x
Switzerland	Cavergno	**Cav**	8.60, 46.35	900	*Quercus petrea*	x	x
Switzerland	Lötschental	**Löt**	7.78, 46.40	1900	*Pinus sylvestris*	x	x
Switzerland	Vigera	**Vig**	8.77, 46.50	1400	*Pinus sylvestris*	x	x
United Kingdom	Windsor	**Win**	-0.59, 51.41	10	*Pinus sylvestris*	x	x
United Kingdom	Woburn	**Wob**	-0.59, 51.98	50	*Quercus robur*	x	x

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Common period of overlap is a 98-year time window ranging from 1901 to 1998, except the Lötschental site (Swiss Alps) covering only 50 years (AD 1946-1995). Nevertheless we included it in the analyses, since it is one of only few sites that represents alpine tree line conditions (Treydte et al. 2001, Neuwirth et al. 2004).

Pearson's correlation coefficients between isotope ratios and climate variables were calculated using an updated version of the 0.5° x 0.5° gridded meteorological data set TS 2.1 of the *Climate Research Unit* (CRU, Norwich/UK), providing homogenized monthly data for the full 20th century (1901-2002) (Mitchell & Jones 2005). For this study we considered mean, minimum and maximum temperatures, precipitation, wet day frequencies and vapour pressure, but present only results from the two variables leading to highest correlations, namely maximum temperatures and precipitation. Moreover we used a newly developed European 0.5° x 0.5° grid of monthly resolved Palmer Drought Severity Index data (PDSI) which is available for the same period (van der Schrier et al. 2006, Wells et al. 2004). At every site, the closest grid cell was chosen and in cases of similar distance to the site, all relevant grid cells were tested and finally the one providing best results was used. It should be noted that in some cases correlations using single meteo station records reveal higher correlation values, as it is for example the case at the Spanish site Pedraforca (Planells et al. 2005), since artificial grid cells might sometimes not ideally represent local site conditions. To achieve, however, best homogeneity in terms of data use and treatment when running analyses over the whole network, we accept single cases of lower correlation as long as they do not contradict site internal results.

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). Assuming that similar, non-climatic biases are absent in oxygen and hydrogen isotope records at least during the 20th century calibration period, we here present correlation results based on raw data only, without any correction or detrending.

Results

Correlation calculations based on monthly data from March of the previous to October of the current year revealed no systematic and significant impact of previous year climate conditions on the fixation of either carbon or oxygen isotopes in tree-rings (without figure). This finding was somewhat expected for oak species, where isotope ratios were measured from late wood cellulose only. However, the observation also holds for pine species and therefore contradicts hypotheses on memory effects in conifers, where cellulose of whole tree rings was measured, with the early wood potentially containing remobilized reserves built up under previous year late summer conditions (Helle et al. 2004).

Generally, strongest response of all isotope parameters was found to current year summer conditions, with highest correlations from June or July to August. Figure 2 shows the strength of the relationships on a site basis for combined July/August mean maximum temperatures, precipitation sums and PDSI indices. Despite the broad range of ecological conditions in the network, nearly all sites respond in a similar way, with positive relationships to temperature and negative relationships to precipitation and PDSI, respectively. Signals are not only robust

between sites (although in some cases not reaching significance) but also between isotope parameters, with only one exception: $\delta^{18}O$-temperature Caz. Both networks show strong similarities in their correlation coefficients' signs as well as in the strength of the relationships, suggesting common forcing of isotope fixation. This is confirmed through mean and maximum correlation values given in the table of figure 2.

	Tmax	P	PDSI
13C-mean	0.36	-0.29	-0.29
13C-max	0.66	-0.52	-0.59
18O-mean	0.32	-0.28	-0.33
18O-max	0.57	-0.53	-0.55
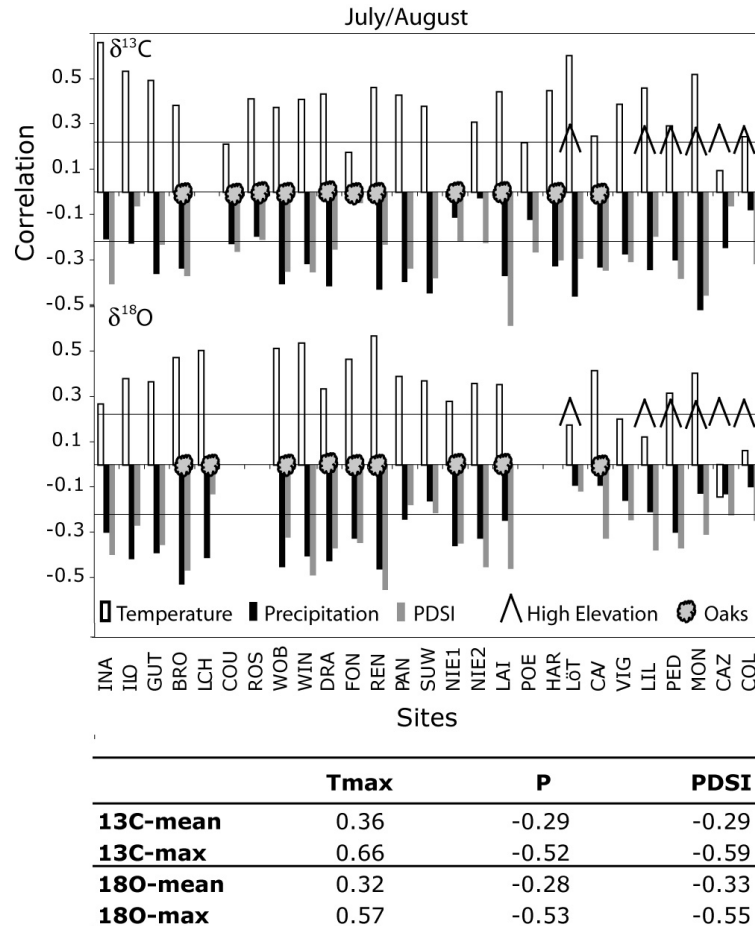
Figure 2: Correlation between carbon and oxygen isotope ratios and climate variables, using CRU 0.5° x 0.5° gridded data, namely mean maximum temperatures, precipitation sums and PDSI indices for combined July/August conditions, with lines representing 99% signifcance levels. Mean (averaged over all sites) and highest (max) correlation values per network are given in the table.

Overall correlation to temperatures is slightly higher for $\delta^{13}C$ than for $\delta^{18}O$ (0.36 versus 0.32), whereas the latter shows slightly higher absolute values concerning drought (-0.29 versus -0.33). Correlations with precipitation sums are a similar (-0.29 versus -0.28). Although these averaged correlation values are not extraordinarily high (but nevertheless strongly significant), they highlight the potential of increasing the strength of the climatic signals when averaging several site datasets to regional records. This was demonstrated earlier with a rather coarse data treatment for the oxygen isotope network: Averaging all site records and correlating them with similarly averaged meteorological data, increased strength of the correlations for June-August precipitation to -0.52 and April-September temperature to 0.41, indicating the potential for regionalized European climate reconstructions (Treydte et al. 2005).

More detailed site-by-site analyses did not reveal systematic differences between signal strength of C and O isotope ratios, neither on latitudinal nor on altitudinal or species-specific scales. Therefore, closer correlations of one or another isotope parameter seem to largely depend on local site ecological conditions.

Discussion

Despite the fact of different fractionation processes driving the fixation of C and O isotopes in tree rings, since carbon and water uptake rely on independent sources (atmospheric CO_2 versus soil water), strong similarities in the response of $\delta^{13}C$ and $\delta^{18}O$ networks to summer climate conditions are found. Carbon isotope ratios depend on diffusion and biochemical processes during photosynthetic CO_2 assimilation, with fractionation effects occurring on the way of carbon dioxide diffusion into the stomata and during carbon fixation processes at the enzyme Rubisco. High $\delta^{13}C$ values therefore reflect low CO_2 concentration in the leaf intercellulars (depending on low stomatal conductance e.g. related to drought stress) and/or high photosynthetic rates (related to temperature and photon flux), or some combination of both (McCarroll & Pawellek 2001).

In contrast, $\delta^{18}O$ (and also δ^2H) values largely depend on the isotope ratio of soil water, which itself is related to the isotope composition of rain water, residence time in the soil, evaporation effects and of leaf water enrichment due to evapo-transpiration through the stomata (Yakir & Sternberg 2000), strongly biasing the original source water signal. On the way down from the leaves, 40-50% of sugar bound oxygen atoms transported in the phloem undergo isotope exchange with xylem water ascending from the roots, which carries the original source water signal (Hill et al. 1995).

Earlier network analyses based on a rather coarse data treatment by averaging site C and O isotope chronologies over the whole network already indicated significant correlation between both parameters of 0.53 for the 20th century (Treydte et al. 2005). Correlations between the first principal components of both data sets even increased this relationship to 0.58, confirming single site investigations, which report significant d13C-d18O relationships as well (Planells et al. 2005; 2006, Rafalli-Delerce et al. 2004, Saurer et al. 1997). Results presented here allow a view beyond these relationships, by shedding light on the common site response to climate. Processes described above allow for the statement, that both isotope parameters are linked through the explained effects on the leaf level, namely variation in stomatal conductance due to the combined effect of varying temperature and precipitation conditions, which themselves are inter-correlated. Low stomatal conductance during dry/warm weather conditions causes high $\delta^{13}C$ values through weak discrimination against [13]C. Nevertheless transpiration increases compared to cool/wet conditions, resulting in higher leaf water enrichment and thus in higher $\delta^{18}O$ values (Anderson et al. 1998, 2002, Farquhar & Lloyd 1993, Leuenberger et al. 1998, Masson-Delmotte et al. 2005, Rafalli-Delerce et al. 2004, Roden et al. 2000, Treydte 2003, Treydte et al. 2004). Hence, particularly under temperate conditions both parameters are mainly driven by summer moisture conditions, in this study expressed through strong positive correlations to temperature and negative correlations to precipitation, which in most cases are in a similar

range. Although not at all sites leading to the highest absolute correlation values, we believe the ecologically integrating PDSI expressing drought to represent best the general climatic-ecological control on the networks – at least in the higher frequencies. It has to be noted that calculations of this study were based on raw values only. Taking into account the possibility of long-term effects of an atmospheric CO_2 increase as well as biological trends (Treydte et al. 2001, 2006), these results could still change if potential age-related biases, variable physiological response (e.g. reduction of stomatal conductance) to increasing CO_2 depending on differing site conditions, or currently unexplainable noise are removed from the records (Treydte 2003, Treydte et al. 2005). Therefore further tests on the networks' climate sensitivity need to be based on high and low pass filtered data respectively, which also should enable a regionalization of climate response patterns.

Conclusion and Outlook

First climate correlation results of the European isotope network ISONET, calculated on a site-by-site basis, indicate that trees not growing at their ecological distribution boundaries, record significant climate information and hence enable to spatially extend climate reconstruction from tree rings in temperate regions. These findings confirm an earlier hypothesis that isotope parameters of the European network ISONET are mainly driven through summer moisture availability. This is crucial for future reconstruction efforts, since currently detailed tree-ring reconstructions of precipitation or drought are lacking for temperate regions. Moreover, there is still no clear evidence for species-specific climate response in the network, what proves the potential of combining all species for a well-replicated and robust regional to European scale climate reconstruction. Further calibration tests will include combined $\delta^{13}C$ and $\delta^{18}O$ series with the aim to reduce the non-climatic noise contained in these records, possibly favouring the common climatic variability. This was recently shown by Planells et al. (2006), who found that a combination of both reveals the best proxy record to reconstruct summer climate, namely aridity, at an alpine *Pinus uncinata* site in the Spanish Pyrenees. Band-pass filtering based on complete and extended isotope datasets from all sites, covering the full period of 400 years where possible will be employed by separating the datasets into different timescales (high frequency, decadal, secular). This will enable better understanding particularly of centennial scale variations, which currently seem to be heterogenous over the networks. Possible reasons include the incompleteness of the current datasets, regionally differing synoptic conditions, age-related biases, and varying plant physiological reactions on changing atmospheric CO_2 concentrations.

Comparisons with European datasets of the IAEA Global Network of Isotopes in Precipitation (GNIP) (Jouzel et al. 2000, Rozanski et al. 1993), large-scale surface pressure data sets such as NAO, and with new European temperature reconstructions (e.g., Luterbacher et al. 2004) should provide detailed knowledge about European climate variation over the past few centuries.

Acknowledgements

References

Anderson, W.T., Bernasconi, S.M., McKenzie, J.A. (1998): Oxygen and carbon isotopic record of climate variability in tree-ring cellulose (*Picea abies*): an example from central Switzerland. *Journal of Geophysical Research 103*: 31625-31636.

Anderson, W.T., Bernasconi, S.M., McKenzie, J.A., Saurer, M. & Schweingruber, F.H. (2002): Model evaluation for reconstructing the oxygen isotopic composition in precipitation from tree ring cellulose over the last century. *Chemical Geology 182*: 121-137.

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

Bräuning, A., Mantwill, B. (2005): Summer temperature and summer monsoon history on the Tibetan Plateau during the last 400 years recorded by tree-rings. *Geophysical Research Letters 32*, doi:10.1029/2004GL020793.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Harris, I.C,. Jones, P.D., Shiyatov, S.G., Vaganov, E.A. (2001): Low-frequency temperature variations from a northern tree ring density network. *Journal of Geophysical Research 106*: 2929-2941.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E.A. (2002): Tree-ring width and density data around the Northern Hemisphere – part 2, spatio-temporal variability and associated climate patterns. *The Holocene 12*: 759-789.

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

Farquhar, G.D. & Lloyd, J. (1993): Carbon and oxygen isotope effects in the exchange of carbon dioxide between terrestrial plants and the atmosphere. In: Ehleringer, J.R., Hall, A.E. & Farquhar, G.D. (Eds.): Stable Isotopes and Plant Carbon Water Relations. Academic, San Diego, California: 47-70.

Feng. X., Krishnamurty, R.V., Epstein, S. (1993): Determination of D/H ratios of nonexchangeable hydrogen in cellulose: A method based on the cellulose-water exchange reaction. *Geochimica et Cosmochimica Acta 57*, DOI:10.1016/0016-7037(93)90320-V.

Filot, M., Leuenberger, M., Pazdur, A., Boettger, T. (2006): Rapid online equilibration method to determine the D/H ratios of nonexchangeable hydrogen in cellulose. *Rapid Communications in Mass Spectrometry,* in press.

Francey, R.J., Allison, C.E., Etheridge, D.M., Trudinger, C.M., Enting, I.G., Leuenberger, M.C., Langenfelds, R.L., Michel, E., Steele, L.P. (1999): A 1000-year high precision record of δ^{13}C in atmospheric CO_2. *Tellus 51B*: 170-193.

Friedli, H., Lötscher, H., Siegenthaler, U., Stauffer, B. (1986): Ice core record of the ^{13}C/^{12}C ratio of atmospheric CO_2 in the past two centuries. *Nature 324*: 237-238.

Frank, D., Esper, J. (2005a): Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps. *Dendrochronologia 22:* 107-121.

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

Fritts, H.C. (1976): Tree rings and climate. New York: Academic Press, 567 S.

Helle, G., Schleser, G.H. (2004): Beyond CO_2-fixation by Rubisco – an interpretation of $^{13}C/^{12}C$ variations in tree rings from novel intra-seasonal studies on broad-leaf trees. *Plant, Cell and Environment 27*: 367–380.

Hill S.A., Waterhouse J.S., Field E.M. & Ap Rees T. (1995): Rapid recycling of triose phosphates in oak stem tissue. *Plant, Cell and Environment 18*: 931–936.

IAEA/WMO (2004). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://isohis.iaea.org.

Jouzel, J., Hoffmann, G., Koster, R.D., Masson, V. (2000): Water isotopes in precipitation: data/model comparison for present-day and past climates. *Quaternary Science Reviews 19*: 363-379.

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

Leuenberger, M, Borella, S., Stocker, T., Saurer, M., Siegwolf, R., Schweingruber, F.H., Matyssek, R. (1998): Stable isotopes in tree rings as stress indicators. vdf Hochschulverlag Zürich. 200 S.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H. (2004): European seasonal and annual temperature variability, trends, and extremes since 1500. *Science 303*: 1499-1503.

Masson-Delmotte, V., Raffalli-Delerce, G., Danis, P. A., Yiou, P., Stievenard, M., Guibal, F., Mestre, O., Bernard, V., Goose, H., Hoffmann, G., Jouzel, J. (2005): Changes in European precipitation seasonality and in drought frequencies revealed by a four-century-long tree-ring isotopic record from Brittany, France. *Climate Dynamics 24*: 57-69.

McCarroll, D., Pawellek, F. (2001): Stable carbon isotope ratios of *Pinus sylvestris* from northern Finland and the potential for extracting a climate signal from long Fennoscandian chronologies. *The Holocene 11*: 517-526.

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

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

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

Planells, O., Andreu, L., Bosch, O., Gutiérrez, E., Filot, M., Leuenberger, M., Helle, G., Schleser, G.H. (2005): The potential of stable isotopes to record aridity conditions in a forest with low-sensitive rings widths from the eastern Pre-Pyrenees. *TRACE 4*: 266-272.

Planells, O., Gutiérrez, E., Helle, G., Schleser, G.H. (2006): Assessment of 20th century ring width, $\delta^{13}C$ and $\delta^{18}O$ of two pine species from the Iberian System (Spain) as climate proxy series. Submitted to *Climate Research*.

Rafalli-Delerce, G., Masson-Delmotte, V., Dupouey, J. L., Stievenard, M., Breda, M., Moisselin, M. (2004): Reconstruction of summer droughts using tree-ring cellulose isotopes: a calibration study with living oaks from Brittany (western France). *Tellus 56B*: 160-174.

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

Rozanski, K., Araguas-Araguas, L. & Gonfiantini, R. (1993): Isotopic patterns in modern global precipitation. In: Swart KLLPK, McKenzie, J., Savin, S. (eds.): Climate change in continental isotopic records. AGU *Geophysical Monograph*: 1-37.

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

Schimmelmann, A. (1991): Determination of the concentration and stable isotopic composition of nonexchangeable hydrogen in organic mater. *Anal. Chem. 63*, 2456. DOI:10.1021/ac00021a013.

Treydte, K., Schleser, G.H., Helle, G., Frank, D., Winiger, M., Haug, G., Esper, J. (2006): The 20th century was the wettest period in northern Pakistan over the past millennium. *Nature 440*: 1179-1182.

Treydte, K. and 33 co-authors (2005): The European isotope network ISONET: First results. *TRACE 4*: 273-280.

Treydte, K., Welscher, C., Schleser, G.H., Helle, G., Esper, J., Frank, D., Büntgen, U. (2004): The climatic signal in oxygen isotopes of junipers at the lower timberline in the Karakorum, Pakistan. *TRACE 2*: 100-106.

Treydte, K. (2003): Dendro-Isotope und Jahrringbreiten als Klimaproxis der letzten 1200 Jahre im Karakorumgebirge/Pakistan. Schriften des Forschungszentrums Jülich, Reihe Umwelt/Environment 38, 190 S.

Treydte, K., Schleser, G.H., Schweingruber, F.H., Winiger, M. (2001): The climatic significance of $\delta^{13}C$ in subalpine spruce (Lötschental, Swiss Alps) – a case study with respect to altitude, exposure and soil moisture. *Tellus 53*: 593-611.

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

Wells, N., Goddard, S. and Hayes, M. J. (2004): A Self-Calibrating Palmer Drought Severity Index, *Journal of Climate 17*:2335-2351.

Wassenaar, L.I., Hobson, K.A. (2000). Improved Method for Determining the Stable-Hydrogen Isotopic Composition (dD) of Complex Organic Materials of Environmental Interest. *Environ. Sci. Technol. 34*, DOI:10.1021/es990804i.

Yakir, D., Sternberg, L.S.L. (2000): The use of stable isotopes to study ecosystem gas exchange. *Oecologia 123*: 297-311.

Stable isotope and tree-ring width variations of larch affected by larch budmoth outbreaks

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Introduction

European Larch (*Larix decidua* Mill.) possesses a high potential for dendroclimatic analyses due to its frequent occurrence at the timberline of the European Alps, due to its longevity of up to 1000 years and due to its growth sensitivity to temperature (Neuwirth, 2004). So far, European Larch is solely used for low-frequency temperature reconstructions (e.g. Büntgen et al., 2005) as medium-term variations occur in tree-ring growth curves which presently cannot be traced back to climatic factors. These variations are caused by larch budmoth (LBM; *Zeiraphera diniana* Gn) outbreaks. Normally, the population of this insect strongly multiplies at intervals of 8-9 years. Its larvae gnaw at the needles, gradually damaging them (Baltensweiler/Rubli, 1999). As a result, assimilation and tree-ring growth decrease accordingly. This causes a typical pattern in ring width which is characterised by an abrupt growth reduction in the year of the outbreak and the following year, with a slow increase of ring width afterwards. The way trees recover depends on the intensity of the previous outbreak. Obviously a number of plant physiological processes are affected such that only after several years the trees regain their normal ring growth activity. Stable isotopes usually provide better insight into plant physiological processes underlying tree growth than ring widths (Schleser, personal communication). Therefore the aim of this study was to investigate to what extent LBM outbreaks modify the signature of the stable carbon and oxygen isotopes of the corresponding tree-rings. The study area chosen is located in the Lötschental, an inner-alpine dry valley in Valais, Switzerland.

Material and Methods

For inter-annual $\delta^{13}C$ and $\delta^{18}O$ analysis we sampled 5 trees located at 2000m a.s.l. on a south exposed slope. After measuring the ring widths of the cores with a resolution of 0.01 mm, the cores were dated by synchronizing the ring widths with the corrected master-chronology of the Lötschental (Büntgen et al., 2004). The years of LBM outbreaks were identified by comparison of the tree-ring pattern with historical documentation which exists back to AD1850 (Baltensweiler and Rubli, 1999). Based on ring width data, LBM outbreaks were identified quantitatively as well as qualitatively. For each tree ring the relative width change was calculated by comparing with the mean value of the 4 previous years. The threshold for potential LBM outbreaks was fixed at 40% of growth reduction (Rolland et al., 2001). The qualitative way of detecting LBM outbreaks consisted in the visual detection of the typical pattern described above. The historical documentation confirmed these methods

of identification of LBM outbreaks from ring width analyses. For stable isotope analyses each tree-ring of the time span AD1900-2004 was separated from 5mm cores.

It is usual to extract cellulose to concentrate on one chemical compound because the different components of the wood have different isotopic signatures. Nevertheless, we analysed cellulose and wood of one tree for the time span AD1950-1982, with the idea that similar results for cellulose and total wood could ease the workload considerably by concentrating on wood. The investigations resulted in a correlation coefficient between wood and cellulose of r = 0.84 for carbon and r = 0.91 for oxygen stable isotope ratios. Due to the high similarity we decided to use only wood for this study. The samples were measured by using an elemental analyser interfaced to a continuous flow isotope ratio mass spectrometer (Micromass Optima). The resulting δ-values are defined as the isotope ratio R of an element relative to the ratio of an internationally accepted reference material of this element. Thus, e.g.: $\delta^{13}C = [R_{sample}/R_{reference}-1]*1000$. Since the values are multiplied by 1000, δ-values are given as per mill (‰) deviation from the reference. The analytical error was < ±0.1‰ for carbon and < ±0.35‰ for oxygen isotope ratios.

Precipitation data covers the time span 1900-1995 and originate from the meteorological stations of Kippel (1370 m) and Ried (1480 m) in the Lötschental (Neuwirth, 1998, Neuwirth et al., 2004). The temperature data were taken from the ALPCLIM-Dataset (version 2004) (Böhm et al., 2001). The nearest climate stations to the site are Sion (482m a.s.l.) and Jungfraujoch (3572m a.s.l.). We calculated the mean adiabatic gradient from these two stations and used it to calculate the temperature at 2000m a.s.l. from the data of Sion for the time span 1900-2002.

Results and discussion

Potential outbreaks of LBM were identified for the years 1908, 1915, 1923, 1937, 1945, 1954, 1963, 1972 and 1981 on the basis of ring width. Tree-ring widths, $\delta^{13}C$ and $\delta^{18}O$ records are shown in figure 1, 2, and 3.

Tree-ring width records (Fig. 1) show decreasing values in the years of LBM outbreaks and still lower values in the following year except for 1923 and 1981. The $\delta^{18}O$-values (Fig. 2) are characterised by a strong decrease in the years of LBM outbreaks except for 1923, i.e. both, ring width and $\delta^{18}O$ respond to LBM outbreaks with strongly decreasing values. In contrast to ring width, $\delta^{18}O$-values solely decrease in the year of an outbreak. The following year seems to be not affected. In general, carbon isotopes also show a decrease in the year of LBM outbreak as compared to $\delta^{18}O$, but it is less pronounced. In the year after an outbreak, $\delta^{13}C$ shows both, increasing and decreasing values. A detailed analysis of the isotope changes will be given elsewhere (Weidner et al. in prep.). Unlike ring width, carbon and oxygen isotopes show increasing values in 1923. Although historical documentations and the qualitative and quantitative methods identify an outbreak in 1923, the isotope signature may indicate that probably no outbreak took place.
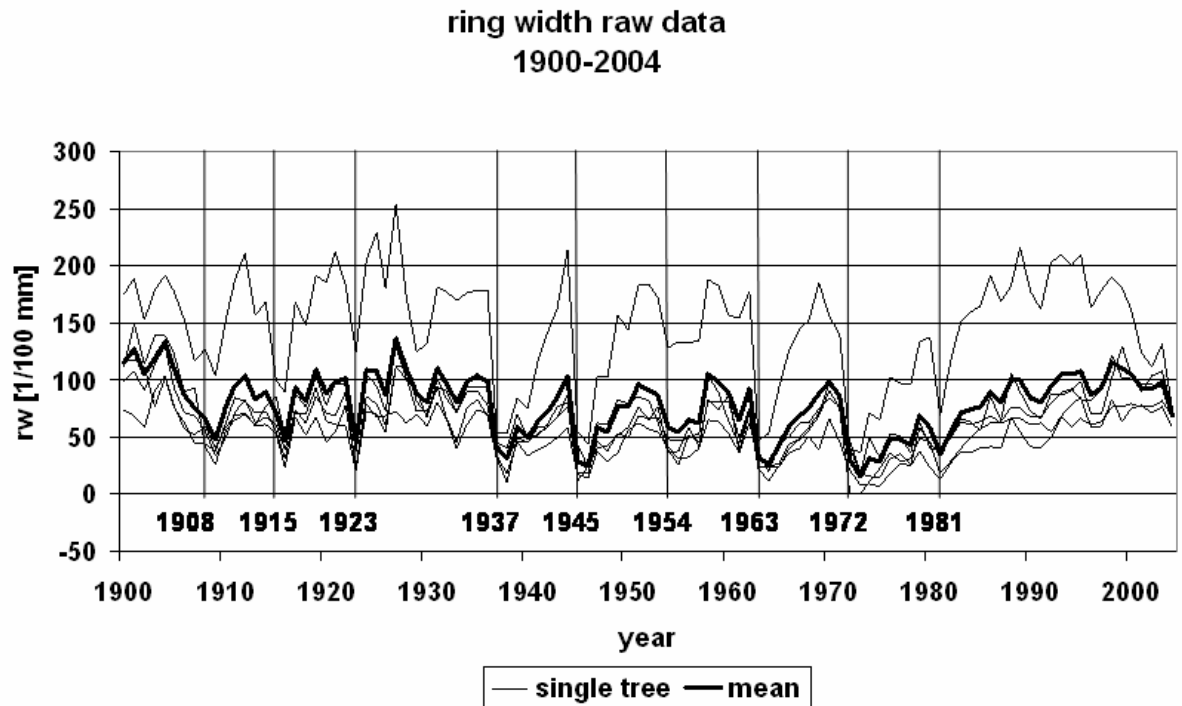
**ring width raw data
1900-2004**

Figure 1: Records of ring widths and mean curve for the time period 1900-2004.

**$\delta^{18}O$ raw data
1900-2004**
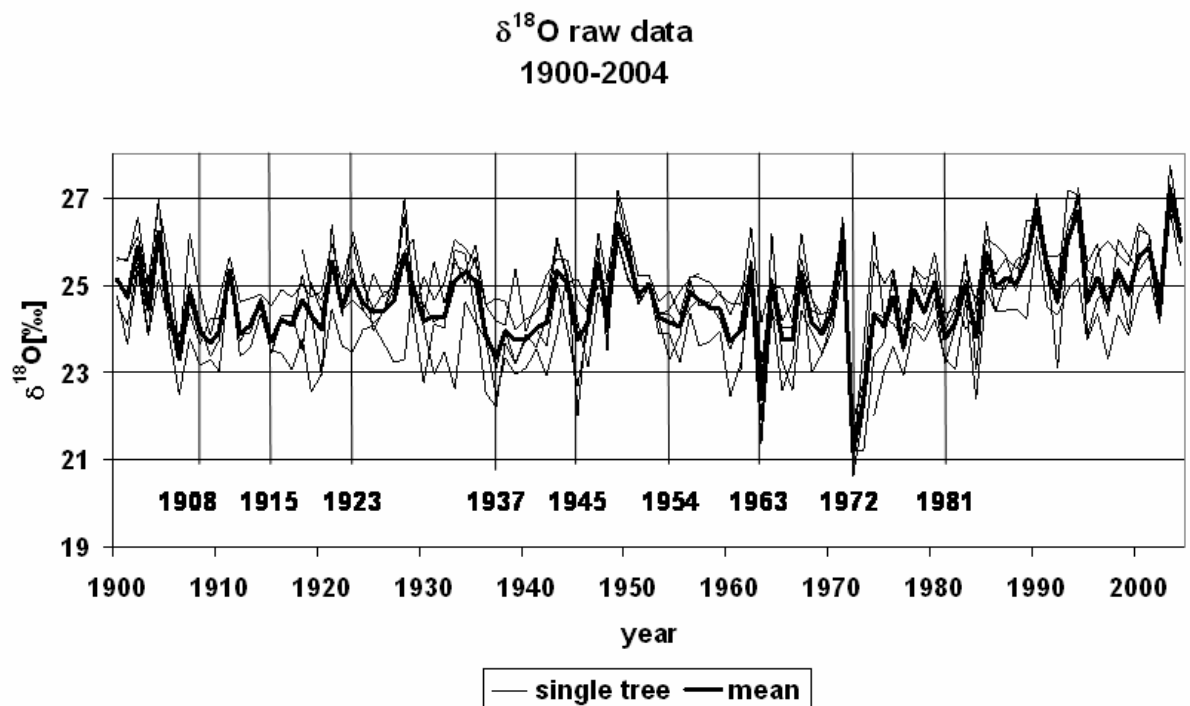
Figure 2: Records of $\delta^{18}O$ and mean curve for the time period 1900-2004.
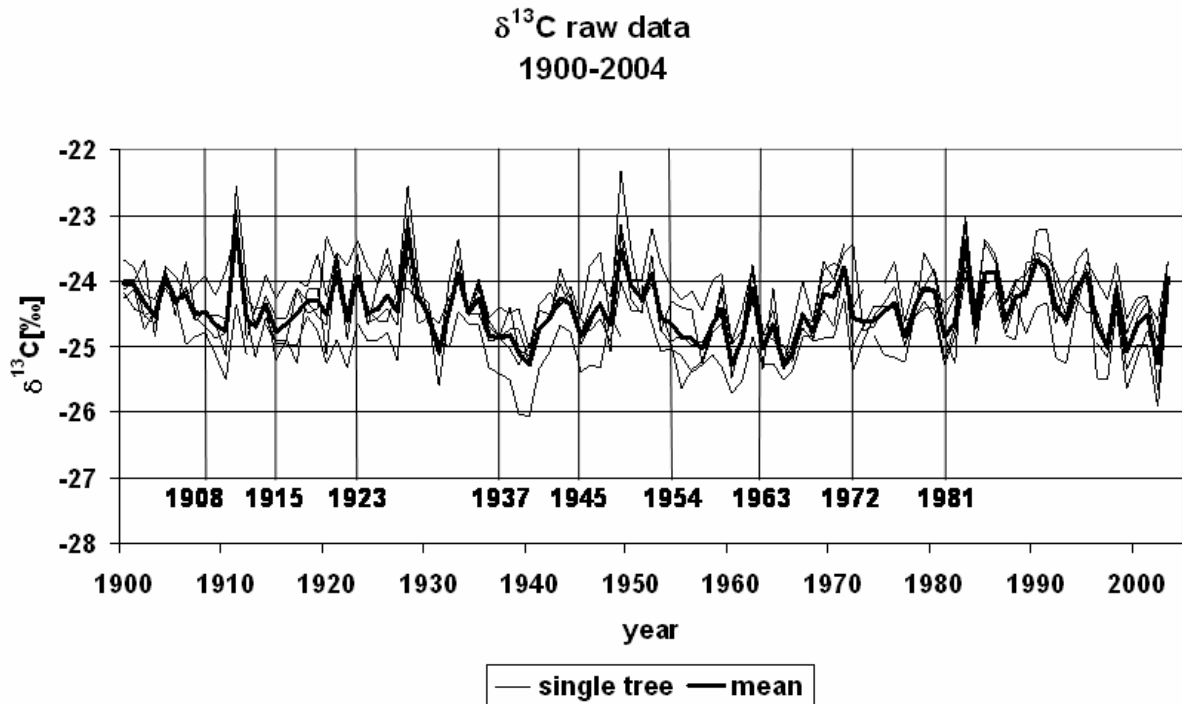
Figure 3: Records of $\delta^{13}C$ and mean curve for the time period 1900-2004.

Correlations between ring width, $\delta^{13}C$ and $\delta^{18}O$ and temperature are shown in Figure 4. Correlation between ring width and temperature is low. Just one tree exceeds the 99,9% significance level. On the contrary, correlations between oxygen and most notably between carbon isotopes and temperature are significantly positive in July and August.
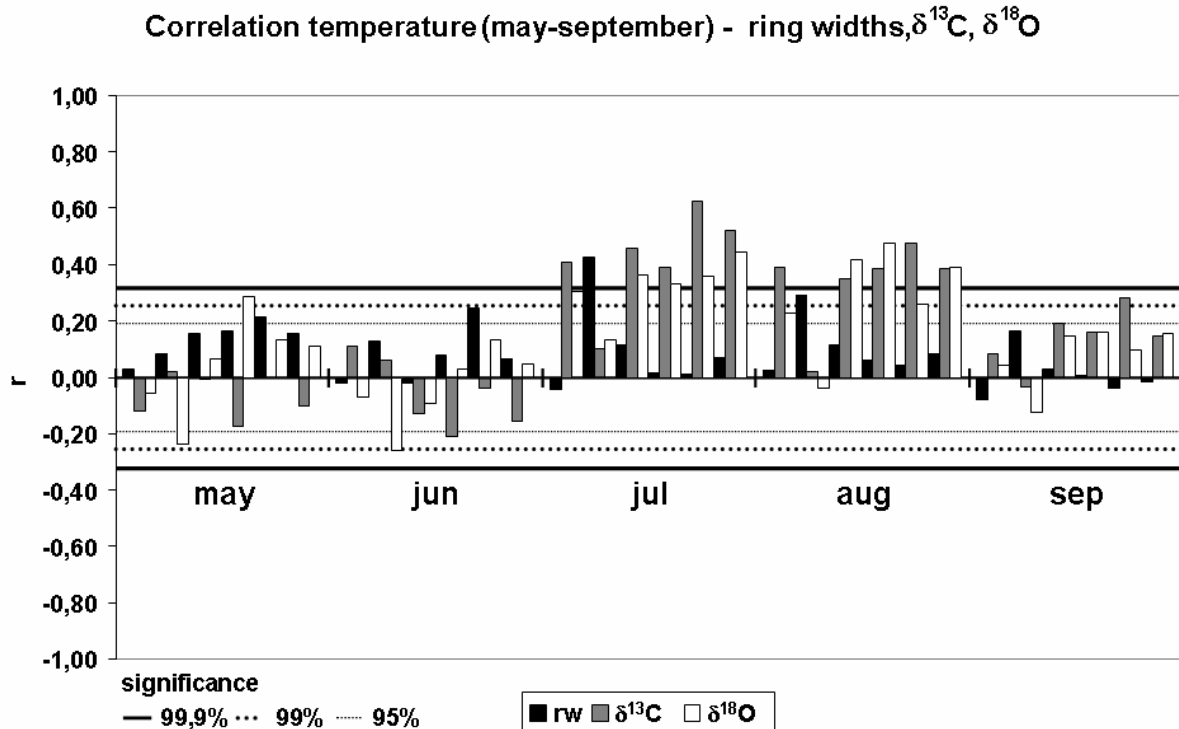
Figure 4: Correlation between ring width, $\delta^{13}C$ and $\delta^{18}O$ and temperature during the growth period.

Figure 5: Correlation between ring width, δ¹³C and δ¹⁸O and precipitation during the growth period.

Correlations between ring width, $\delta^{13}C$ and $\delta^{18}O$ and precipitation (Fig. 5) are not significant in case of ring width but in case of $\delta^{13}C$ and $\delta^{18}O$ significantly negative. Effects of LBM outbreaks on ring width seem to override effects of climatic factors. The significant correlations be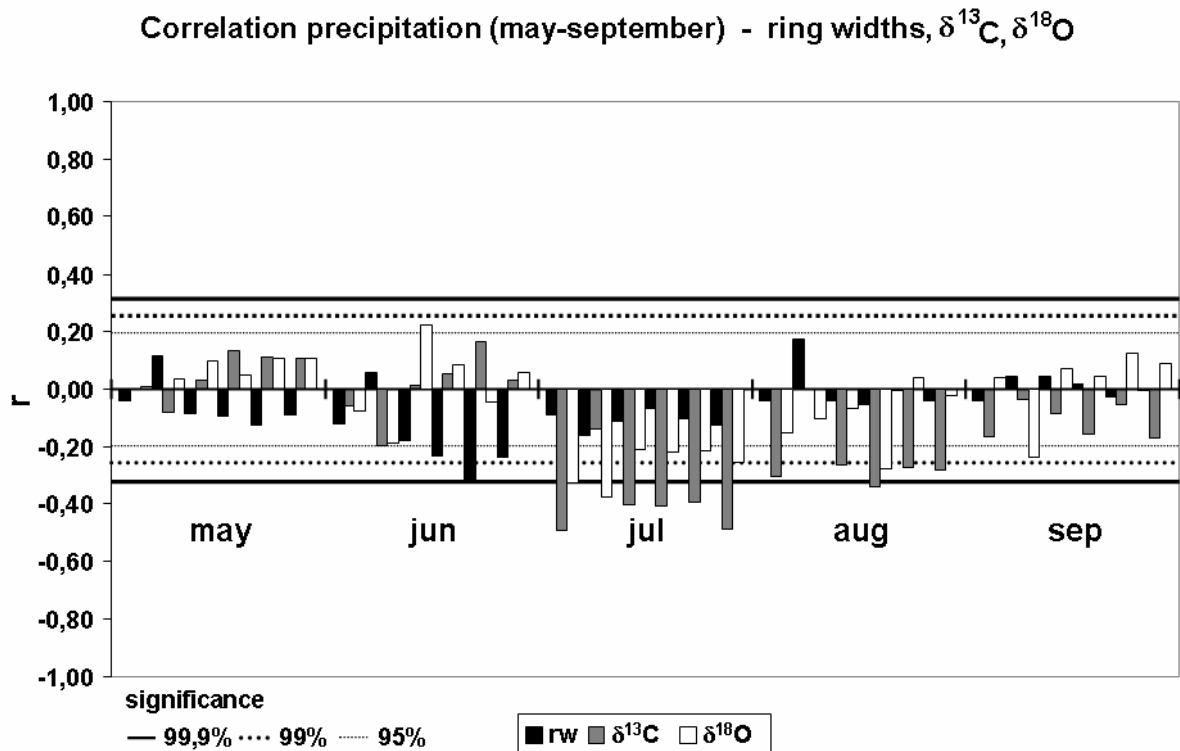tween carbon and oxygen isotopes and climatic factors confirm the assumption that $\delta^{13}C$ and $\delta^{18}O$ are less affected by LBM outbreaks than ring width. The carbon isotope ratio is more strongly correlated to climate than the oxygen isotope ratio. Whether or not the weaker correlation of $\delta^{18}O$ is caused by a stronger influence of LBM outbreaks on $\delta^{18}O$ is currently under examination. The isotopic mechanisms underlying the tree ring $\delta^{13}C$- and $\delta^{18}O$-signatures observed during LBM outbreaks and the following years will be discussed elsewhere (Weidner et al. in prep.).

Conclusions

The results of this inter-annual analysis revealed an influence of LBM outbreaks on ring widths over several years. Oxygen isotopes seem to be influenced for only one year. Carbon isotope signatures seemed to be influenced in the year of LBM outbreak. The reaction in the following year is inconsistent. Comparisons with climate data revealed highly significant correlations between carbon and oxygen isotopes and temperature as well as precipitation. This indicates that climate signals are still to be traced during LBM outbreaks. However, it is currently not clear to what extent the signal is possibly dampened.

Further investigations, particularly on seasonal basis e.g. during the growth period during the growth period are necessary to understand the plant physiological processes. Various cores

are currently prepared for intra-annual carbon and oxygen isotope analyses to investigate the seasonal behaviour. However, this study shows that multi-parameter investigations bear a great potential for studying the influence of LBM outbreaks on trees.

Acknowledgement

References

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

Böhm, R., Auer, I., Brunetti, M., Maugeri, M., Nanni, T. u. W. Schoner (2001): Regional temperature variability in the european alps: 1760-1998 from homogenized instrumental time series. International Journal of Climatology 21. S. 1779-1801.

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

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

Neuwirth, B. (1998): Dendroklimatologische Untersuchungen im Lötschental, Schweiz. Visuelle Jahrringparameter subalpiner Fichten in Abhängigkeit von Höhenlage, Exposition und Standortverhältnissen. Diploma Thesis. Geographical Institute, University of Bonn. Germany. 97pp.

Neuwirth, B., Esper, J., Schweingruber, F. H. & M. Winiger (2004): Site ecological differences to the climatic forcing of spruce pointer years from the Lötschental, Switzerland. Dendrochronologia 21 (2): 69-78.

Rolland, C., Baltensweiler, W. and V. Petitcolas (2001): The potential for using Larix decidua ring widths in reconstruction of larch budmoth (Zeiraphera diniana) outbreak history: dendrochronological estimates compared with insect survey. Trees 15: 414-424.

Weidner, K., Helle, G., Löffler, J., Neuwirth, B. u. G. H. Schleser: Effects of larch budmoth outbreaks on intra-annual δ^{13}C- and δ^{18}O variations. (in prep.)

SECTION 4

ECOLOGY

Climate-growth relationships of the dwarf shrub species *Empetrum hermaphroditum* in the Norwegian Scandes

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Introduction

Dwarf shrubs present a good, but until now relatively unstudied, resource to research high alpine climate fluctuations, both between different microsites and in the greater geographic area where climate information is rare. The circumpolar abundance of the dwarf shrub *Empetrum hermaphroditum* along with the relative clarity of its rings, compared to other species, make it an ideal specimen for this study and others that may follow. By analyzing the tree-ring structure of *E. hermaphroditum* at different microsites, this study tries to determine micro-climatic differences between the sites and the factors that most significantly control the growth of the dwarf shrub. Many problems in the tree-ring record make dating synchronization difficult, however. This includes the presence of wedging rings, missing rings, frost rings, and asymmetric growth common to dwarf shrubs, largely as the result of the extreme environment which they inhabit (Kolishchuk 1990, Woodcook & Bradley 1994, Schweingruber 2001, Schweingruber & Poschlod 2005, Bär et al. 2006).

Material and Methods

Study Area

Samples were taken from the middle alpine belt in the Vågå/Oppland region (61° 53´ N; 9° 15´ E) of the Central Norwegian Scandes, which experience one of the most continental climates of Scandinavia and receive precipitation of 300 – 400 mm/yr (Moen 1999). The middle alpine belt ranges from about 1,350 m to 1,500 m a.s.l. and vegetation in the zone is scarce and scattered. The upper tree line is located at about 1,000 m a.s.l. *E. hermaphroditum* is close to its altitudinal limit at the study sites. Samples were taken from two microsite types, at ridges and north-facing slopes. Shrubs at north-facing slopes are protected by snow cover throughout winter until mid June, while at ridge positions they lack snow cover due to the presence of high winds and are therefore exposed nearly year-round.

Sampling Preparation and Analysis

Complete individuals of *E. hermaphroditum* were collected from both sites and photographed. Microtome sections of each individual were taken using a sledge microtome, with some individuals having many cross-sections for the detection of inconsistent rings along the stem applying the "serial sectioning" method (Kolishchuk, 1990; Bär et al. 2006). Ring widths were measured from digital photos of the microtome. This was done in each image along two transects (cores) that had the least complications from irregular growth. All individuals from

each microsite were synchronized using the "serial sectioning" curves and prints of the digital photos as a reference. A ring width chronology from *Betula pubescens* growing at the local tree line was used for a final cross-dating check due to the lack of preexisting dwarf shrub chronologies and experience. Using the program ARSTAN (Cook 1985), the mean curves were detrended using a 32 year smoothing spline to remove age related growth trends, intra-plant variations, and long term growth trends.

Climate Analysis

Data from the closest official climate station was used in growth-climate analysis. Data was taken from the "Fokstua"/Oppland station, approximately 40 km northeast from the sampling sites at 970 m a.s.l. in the Dovre mountain range on a ridge position (Meteorologisk institutt, eklima 2006). This station provides continuous measurements over the whole time period covered by the chronologies and gives data for monthly mean temperatures and precipitation sums. Anomalies of mean monthly temperatures and precipitation sums were calculated for single years which represent wide rings in 1988 and 1997 and narrow rings in 1990 and 1993. Graphs were made for these years, where anomalies are expressed as standard deviations from the means of each single month from 1923-2004, the longest time period for which data is available (figure 1).

Results and Discussion

Chronology Characteristics

The oldest individuals of *E. hermaphroditum* found were between 80 and 85 years (Bär et al. 2006). However, we confined the chronology to only the last 54 years due to decreasing sample depth and uncertainty in dating. These are the first chronologies ever developed using standard methods of ring width analysis for dwarf shrubs, specifically *E. hermaphroditum*. The chronologies show very high inter-annual variations expressed by low and even negative autocorrelation values (table 1). Variations between the two micro-site types were small and highly correlated, with r = 0.81 (p < 0.01), however. The chronologies differ in mean annual growth increments, with the chronology for the ridge site type showing larger rings (figure 1). The ridge chronology shows average growth of 0.09 mm/yr, compared to 0.07 mm/yr at north-facing slopes.

Table 1: Statistical characteristics of the raw-chronologies of E. hermaphroditum at the ridges and north-facing slopes, (N = max. number of radii included in the chronologies; Mean = mean growth increment; SD = standard deviation; AC(1) = first-order autocorrelation; rbar = mean correlation coefficient among all growth curves; EPS = expressed population signal). Bold values are significant at p < 0.01, others at p < 0.05. Mean growth increment was calculated from the measured raw values, all other values were calculated for ARSTAN standard chronologies.

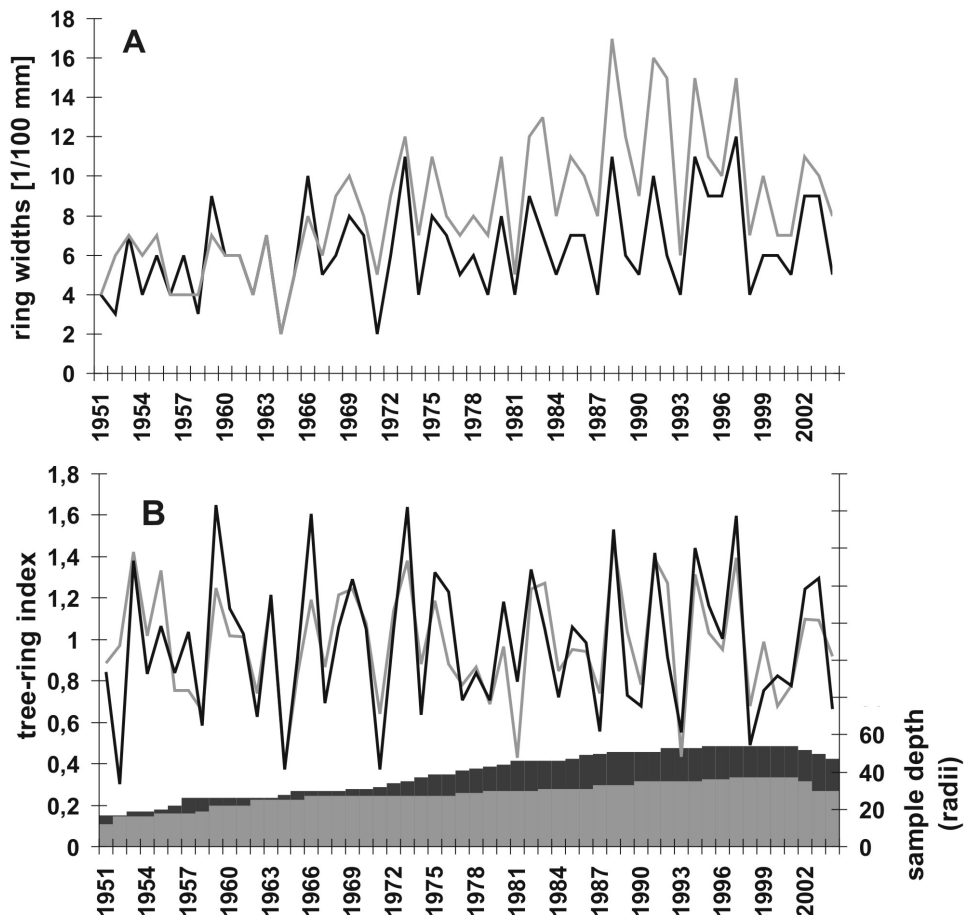| Chronology	N	Mean [mm] ± SD	AC(1)	Mean rbar	Mean EPS
Ridge	54	0.09 ± 0.05	-0.01	**0.38**	0.87
North-facing slope	37	0.07 ± 0.03	-0.04	**0.42**	0.88

Figure 1: Growth-ring chronologies of E. hermaphroditum at the north-facing slopes (black curve) and at the ridges (grey curve). The chronologies in a) are raw values of annual growth increments whereas those in b) were standardized using a 32 year smoothing spline function.

Climate – Growth Relationships

The period from June to August, when average air temperatures exceed 5 °C, is the normal growing season in the sampling region. Temperature during the growing season seems to be the primary factor in determining growth. In 1997 tree ring growth was significantly greater than in 1993, even though the length of the growing season was much shorter due to the late snow melt in 1997 (table 2 and figure 2). Average temperatures were much greater during the growing season in 1997. This suggests that the length of the growing period must only be a secondary factor in the amount of growth occurring in a year, being outweighed by the effects of temperature. The year 1988 showed above average temperatures from June to August and the mean temperature in May exceeded 5 °C, leading to an extended growing season. As expected the growth rate for that year was above average at both sites with rates of 0.17 mm/yr at ridges and 0.11 mm/yr at north-facing slopes. In 1990 temperatures during the growing season were about average, and the growth rate at the ridge position for that year was exactly average. The north-facing slope chronology showed a slightly lower than average growth rate for that year, however. This could possibly be due to the fact that more than average snow felt in that year, which could have limited the amount of time that growth

was possible if the snow lasted into the growing season. This process could explain why the ring is smaller than could be explained by temperature values alone.

High positive correlation with seasonal means of mean temperatures from June to August at ridges were found with r = 0.74 (1951-2004; p<0.01). At north-facing slopes, the correlation coefficient was r = 0.76. No significant correlations could be found between monthly precipitation sums and ring widths. Even in this continental area soil moisture availability is not a limiting growth factor throughout the year (Löffler 2005) and the plants have adequate supply with melt water during the early growing season.

Table 2: Ring width values of E. hermaphroditum at the ridge and north facing slope micro-sites, temperature, and snow characteristics, for selected years. Temperature values are averages for the normal growing period from June to August (JJA).

Year	1988	1990	1993	1997
Ridge ring width [mm]	0.17	0.09	0.06	0.15
Slope ring width [mm]	0.11	0.05	0.04	0.12
Temperature JJA [°C]	10.6	9.5	7.2	11.7
Snow melt date	May 21	Apr 25	May 10	Jun 06
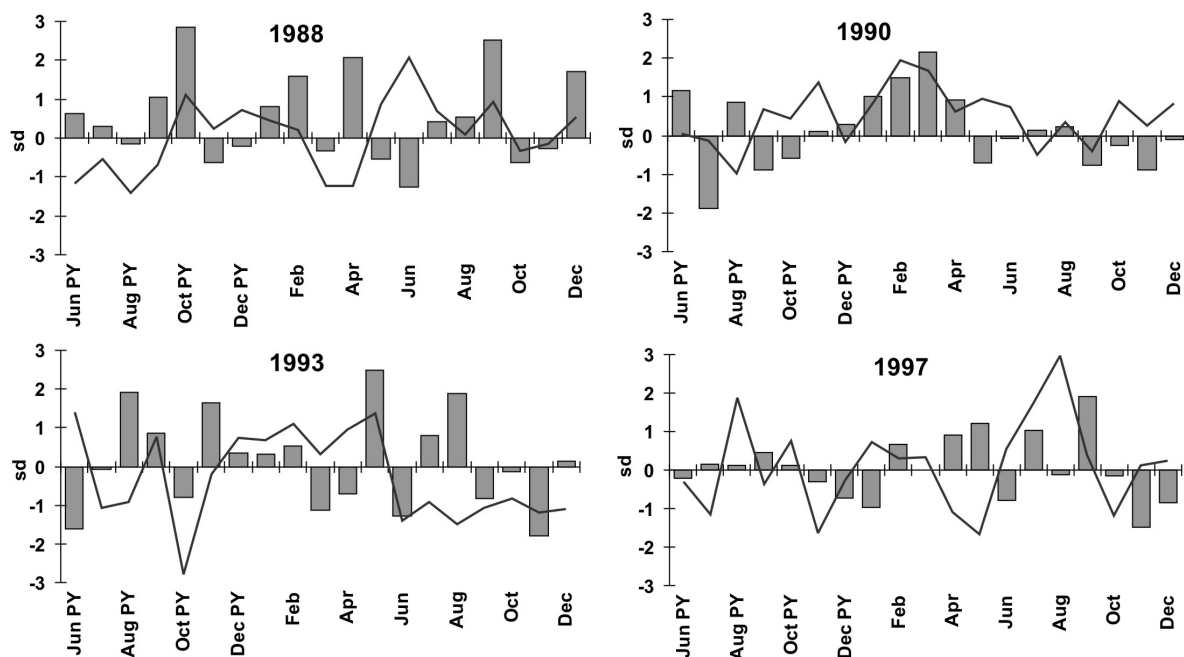
Figure 2: Anomalies of mean monthly temperatures and precipitation sums (grey bars) calculated for single years which represent wide rings in 1988 and 1997 and narrow rings in 1990 and 1993. Anomalies are expressed as standard deviations (sd) from the means of each single month from 1923-2004. Anomalies are given for single months of the previous year (PY) from June – December and January – October of the current year.

Conclusions

This study highlights the possibilities of using the growth rings of dwarf shrubs to analyze changes in the growing conditions of alpine environments. The results implicate that micro-

climatic differences do not cause contrasting annual growth ring variations but lead to differences in the mean annual growth increments between north-facing slopes and ridges. Greater snow cover accumulation and duration might modify the length of the growing period and thus lead to lower annual increments at the north-facing slopes compared with those at the ridges. To determine the impact of temperature and snow cover duration resulting from micro-site differences more precisely, fine-scale analysis of micro-climate measurements within the sampling area will be carried out. Studying *E. hermaphroditum* growth rates at other micro-site types such as depressions, south facing slopes, and at different altitudes along with increasing the number of individuals analyzed will give a more comprehensive picture of how dwarf shrubs respond to different climatic factors due to micro-site differences. In large areas of alpine and arctic regions globally, dwarf shrubs provide the only information about climate and changes in growth over time, giving them a high potential for dendrochronological studies. Studies of this kind might help to expand approved dendroecological techniques into new climatic zones and contribute to a deeper knowledge of how alpine and arctic ecosystems are affected by expected future environmental changes.

References

Bär, A., Bräuning, A., Löffler, J. (2006): Dendroecology of dwarf shrubs in the high mountains of Norway - A methodological approach. *Dendrochronologia* 24:17-27.

Cook, E.R. (1985): A time series analysis approach to tree-ring standardization. PhD. Dissertation. University of Arizona, Tuscon.

Kolishchuk, V.G. (1990): Dendroclimatological study of prostrate woody plants. In: Cook, E.R., Kairiukstis, L.A. (eds.) Methods of Dendrochronology. Applications in the environmental sciences. Kluwer, Dordrecht, Boston, London. p. 51-55.

Löffler, J. (2005): Snow cover, soil moisture, and vegetation ecology in central Norwegian high mountain catchments. *Hydrological Processes* 19: 2385-2405.

Meteorologisk institutt (eklima) (2006): http://shimmer.oslo.dnmi.no/portal/page?_pageid =35,96278,35_96303&_dad=portal&_schema=PORTAL (15.01.2006).

Moen, A. (1999): National atlas of Norway: Vegetation. Norwegian Mapping Authority, Hønefoss. 200 pp.

Schweingruber, F.H. (2001): Dendroökologische Holzanatomie. Anatomische Grundlagen der Dendrochronologie. Paul Haupt Verlag, Bern, Stuttgart, Vienna. 472 pp.

Schweingruber, F.H., Poschlod, P. (2005): Growth rings in herbs and shrubs: life span, age determination and stem anatomy. Forest Snow and Landscape Research 79: 195-415.

Woodcook, H., Bradley, R. (1994): Salix arctica (pall.) Its potential for dendroclimatological studies in the high arctic. *Dendrochronologia* 12: 11-22.

Study of the elemental concentration variation of Mn, Fe, Cu, Zn and Pb in rings of growth of *Abies religiosa* and *Pinus montezumae* from Mexico Basin Surroundings

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Introduction

Dendrochemistry and dendroecological studies of the tree rings agree in the argument that the environmental factors and composition of the soil determine the elemental composition and the properties of the wood (Watmough 1999, Nabais 1999). The soil characteristics also depend on the atmospherical and hydrological conditions (Pernestal et *al.* 1991, Schäffer & Wilpert 2001). Those conditions are related to natural factors, as winds, rain, volcanic eruptions, and by anthropogenic factors due to human activities. Especially, anthropogenic factors have been playing an important role in the modification of the natural patterns of winds and rain as well as in the atmospheric aerosols composition since the last century.

The constituent elements of the wood can be divided in two types: the macroelements are those components of the wood presented in high concentrations (H, C, O, N), while microelements occur in low concentrations (such as Mn, Fe, Cu, Zn) (Lindeberg 2004). The microelements are necessary for physiological processes of the trees, but in high concentrations they become toxic, producing plant illness or dead (Schäffer & Wilpert 2001). For this reason, the study of metallic elements in the trees and their relationship with the environmental conditions is important for forest conservation and for human communities that still survive from the production of wood.

Mexico City is located in the center of the Mexico basin surrounded by mountainous systems in the South-West, South and East regions. The mountains surrounding the basin have forests of pines and firs in the altitudes from 2,800 m to 3200 m asl. The trees of those forests have been exposed to the prevailing atmospheric conditions in the zone which are affected especially by the emission of pollution agents by traffic and industry. Also, the Popocatepetl Volcano located 70 km South-east from the downtown of Mexico City has increased its activity since 1991. Several exhalations of gases and ashes have taken place reaching the Mexico basin. Those events have affected the atmospherical conditions significantly during the last 35 years, producing changes in the composition of aerosols and having an impact on the environment of the whole region. Also, they have affected the ecological conditions of the basin and the chemical conditions in the soils of the forests. It is expected that the effects of the changes mentioned above are recorded in the elemental composition of the growth rings of the trees (Mäkinen & Vannienen 1999).

For the elemental measurements, the PIXE (Particle Induced X-ray Emission) technique was used thanks to its capability for ppm metallic element detection in tree rings (Aoki *et al.* 1998, Vanderlei *et al.* 1999, Liao *et al.* 2000).

The first report on a dendrochemical analysis of the surrounding forest of Mexico City over the past 100 years was carried out on sacred fir (*Abies religiosa* H.B.K. et Cham) (Watmough & Hutchison 1999). The main results indicated an increment in the pollution when the city extended and the number of cars started to escalate 35 years ago. In previous studies by Miranda *et al.* (2003), tree rings series from pine and sacred fir corresponding to 1970 up to 2000 AD from forests in the Mexico basin were analyzed using PIXE in order to obtain a record of contaminants. However, they concluded that more analysis were required to validate the statistical information. Calva *et al.* (2006) continued this research with significant experimental improvements in the PIXE setup and additional measurements of Zn, Fe, Mn and Cu concentrations in tree rings of sacred fir and pine from the same forest. They concluded that the elemental concentrations may not reflect the changes in the environmental conditions due to the human activities in the basin. Moreover, the trends in the elemental concentrations of Fe and Zn can be related to the recent events of the Popocatepetl volcano.

In this work, we present a study of metallic elemental concentrations in growth rings from trees from forests of the Zoquiapan National Park (ZNP), located in the mountains east of the Mexico basin (Fig. 1). The aim of this work is to determine differences in elemental concentration among firs and pines from two different altitudes, considering that there is a different exposure to pollution and environmental conditions, particularly due to the Popocatepetl volcano eruptions.

Area of Study and Sampling

The forest at the Zoquiapan National Park (ZNP) is located in the mountains 55 km east of Mexico City. It consists mainly of pines and firs and extends from 2,450 m to 4000 m asl. The top of the mountains are covered with snow during most time of the year. The Popocatepetl volcano is located 15 km south of the ZNP. It has intensified its activity since the year 1991. There are four kinds of volcano exhalations: Dry fumes (mainly emission of sodium and potassium chlorides, sulfuric and carbon anhydrides), acid fumes (sulfuric and chloride acid), alkaline fumes (ammonia chloride) and rock fragments. The largest exhalations occurred in the periods December 1994 – August 1995 (Volcanic Explosivity Index, VEI 2), March 1996 – November 2003 (VEI 3), May 2004 (VEI 2) and January 2005 – January 2006 (VEI 2), when gases and ashes emitted reached Mexico City (Smithsonian, 2007; CENAPRED Mexico, 2005).
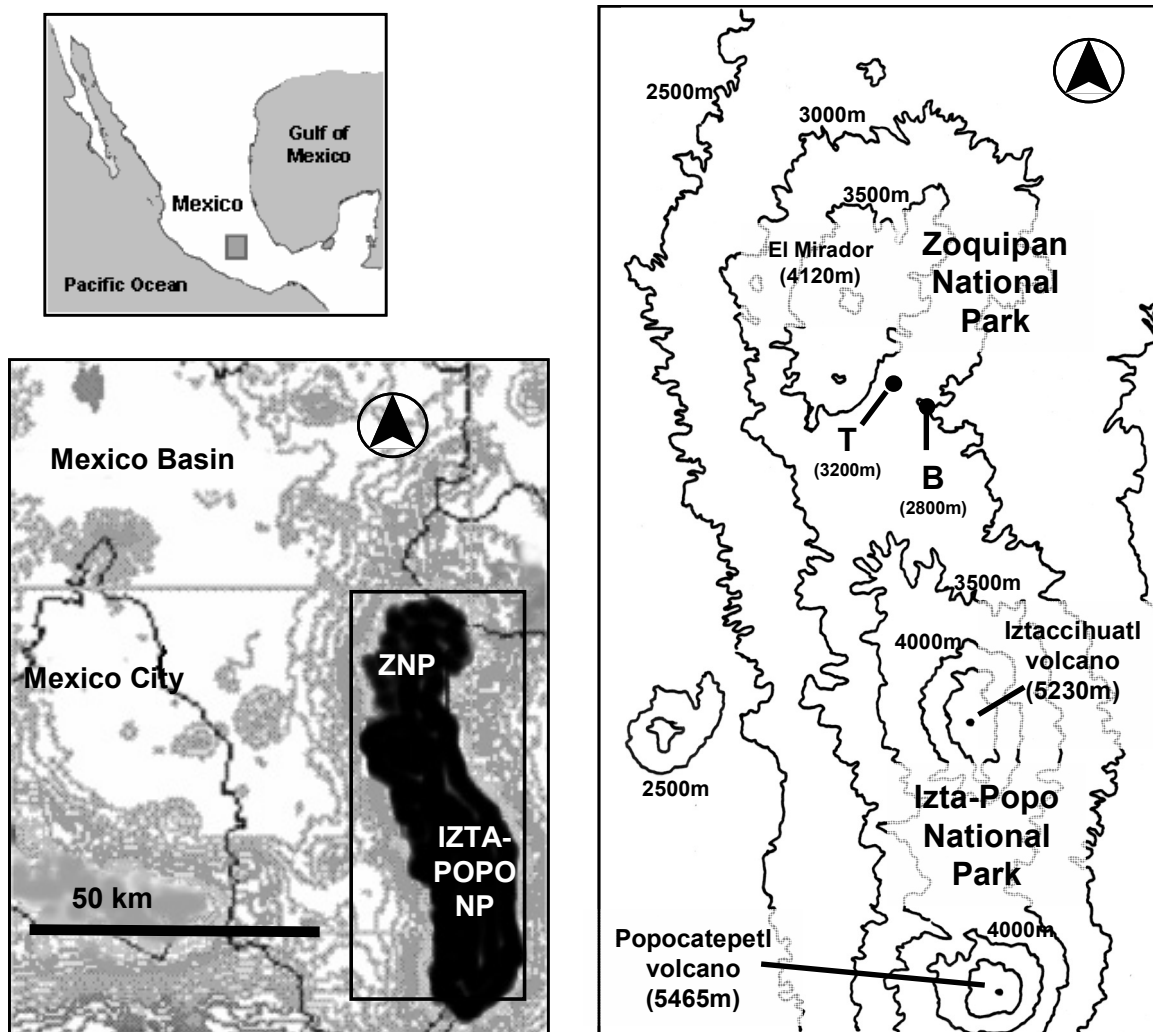
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Figure 1: Map showing the location of the Mexican Basin and the Zoquiapan and Izta-Popocatepetl National Parks. The points T (top) and B (bottom) indicate the respectively sampling regions for this work.

The substances emitted by the volcano fumes are incorporated to the ecosystem, mainly through the melt water from the glaciers on top of Popocatepetl and the adjacent mountains. The water from the slopes of the mountains forms the streams of the mountains hydrological system.

The contaminant agents emitted by the Mexico City pollution are transported towards the forests through winds and rain (Miranda *et al.* 2004). The predominant winds during the year blow from the north, where winds that blow from south occur only few days in a month. Therefore we expect more environmental impact in the forests in the south-easts and southern mountains, due to higher concentration of pollution agents, than in the ZNP forests.

For this study two predominant tree species in those forests were chosen: the Montezuma pine, *Pinus montezumae* (Lamb. var. Lindleyi), and the sacred fir, *Abies religiosa* (H.B.K. et Cham). The pine is a tree resistant to changes in the environment while the sacred fir is more sensitive.

The samples were collected at two different sites and altitudes in the ZNP. The first one, called "bottom" (B), is located at 19°20.8'73" N / 98°40'41" W and at an altitude of 2800 m asl.

The second one, called "top" (T), is located at 19°20´55" N / 98°40´11" W and at 3100 m asl. The coordinates of theses places were obtained using a GPS Magellan (SportTrak Pro).

In each site the sampling was done by selecting six trees of each species randomly. In both places the environmental conditions were similar. The average height and the diameter of the pine trees are 24 m and 2.25 m, respectively, while for the sacred fir average values are 30 m and 3.5 m. The age of the pine trees is around 80 years. The sacred fir trees are older. From each tree, two cores were extracted with a 5 mm diameter and 35 cm in length stainless steel Pressler drill at breast height (1.5m). The extracted cores were placed in a wood frame and dried at 50$^{°}$C for 48 hours. Those extractions were done trying to produce few damage as possible to the tree. The identification of the tree rings in the cores was carried out according to the criteria given by Fritts (1975). The widths of each ring were measured with a vernier caliper and the position was marked in the frame.

PIXE analysis

For the elemental composition analysis of the cores, Particle Induced X-ray Emission Spectroscopy, PIXE, was used. The PIXE technique was performed in air using the external proton beam setup located the 3 MV Pelletron tandem accelerator at the Instituto de Física, UNAM. Only the rings corresponding to the last 35 years of each core were analyzed. The proton beam was collimated to a rectangular area of 0.5 x 3 mm^2 to ensure that the beam is irradiating inside each ring area. A 7.5 μm Kapton window and a helium gas flux around the target were used to reduce proton beam dispersion and absorption of emitted X-rays. The sample surface was located in a distance of 10 mm from the beam exit window and the proton energy at the sample surface was 3.0 MeV. The X-rays generated in the target were registered by a LEGe detector with a resolution of 150 eV placed at 135° from the incident beam direction. To enhance the X-rays detection of heavy elements, a 38 μm aluminum absorber was placed in the LEGe detector window. For the X-ray detector efficiency calibration and elemental quantification, compressed pellets of NIST SRM 1573*a* tomato leaves were used as reference material. With this experimental setup (Calva *et al.* 2006), 840 measurements were carried out in the set of 24 trees.

The X-ray peak counts in the PIXE spectra were obtained using the AXIL code. The elemental concentration in each tree ring was determined using the PIXEINT program for thick target analysis considering C and O contents of wood. The uncertainties in elemental concentration were estimated to be 8% to 14%. The detection limits of the system for elements with $19 < Z < 30$ were between 4 μg/g and 20 μg/g.

Results

The average tree ring widths of the six trees, for both tree species, are shown in figure 2. The tree ring widths depend mainly on water availability and display a high similarity among the species. Pine is a rapid growing tree while sacred fir is more sensitive to available water. The major eruption periods of Popocatepetl Volcano since the increase of its activity (1995, 1996, 2003 and 2004), are indicated in this figure by dashed lines (Smithsonian 2007).
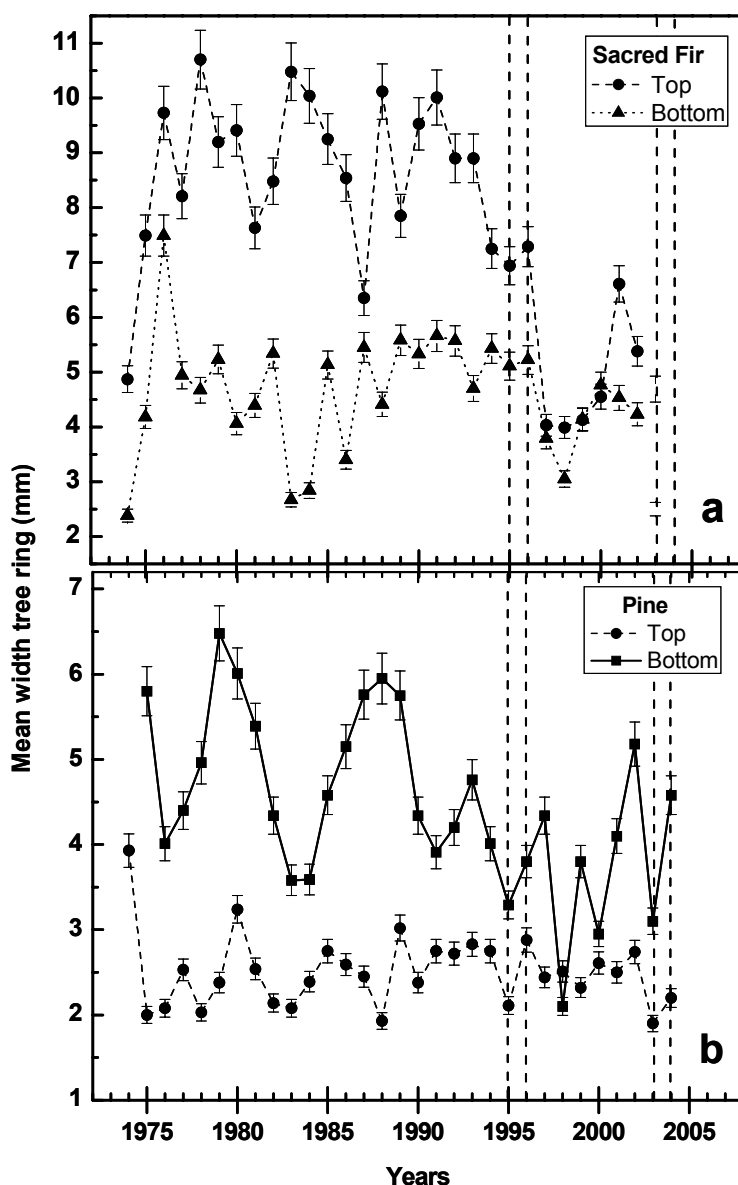
Figure 2: Average ring width of the years, 1974 to 2004, (a) for the sacred fir and (b) for the pine. The dashed lines indicate the years of the major exhalations of the Popocatepetl Volcano (1995, 1996, 2003, 2004).

By PIXE measurements the elements K, Ca, Mn, Fe, Cu and Zn were observed in all the analyzed rings. Other elements only detected in traces were Ti, V, Cr, Ni, Br, Sr, Rb and Pb. In this work, special interest was placed on the metallic elements Mn, Fe, Cu, Zn and Pb. The first four elements are considered to be important for physiological processes in the tree, while the last one is an indicator for environmental pollution.

The average elemental concentrations of Mn, Fe, Cu, Zn and Pb for the rings corresponding to the same year were calculated for the trees of the same species. The average concentrations for the sacred firs and pines, related to the last 35 years, for the sites B and T are shown in figure 3 and 4 respectively. We considered that a real variation corresponds to a change higher than 50% of the mean elemental content. The major exhalations of Popocatepetl Volcano are indicated in those figures by the dashed lines.

Figure 3: Average concentrations of Mn, Fe, Cu, Zn and Pb for Abies religiosa in relation to the time for sampling sites top and bottom. The dashed lines indicate the years of the major exhalations of Popocatepetl volcano.

A comparison among the mean values of Mn, Fe, Cu, Zn and Pb for both tree species and for the bottom and top sites is shown in figure 5. The average values were calculated by a multifactor ANOVA statistical analysis considering a confidence range of 95% and a Tukey HSD proof. The error bars indicate the total variance of the average values.
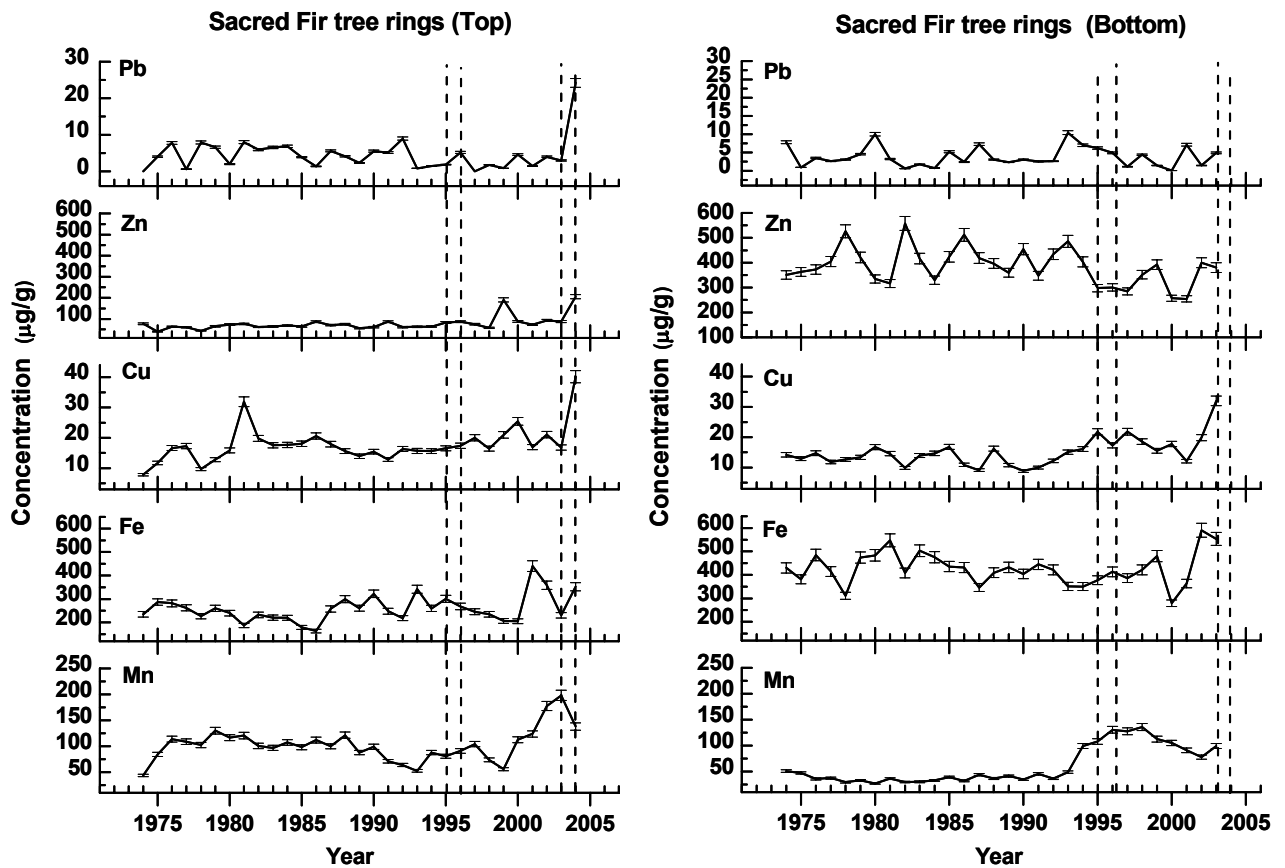
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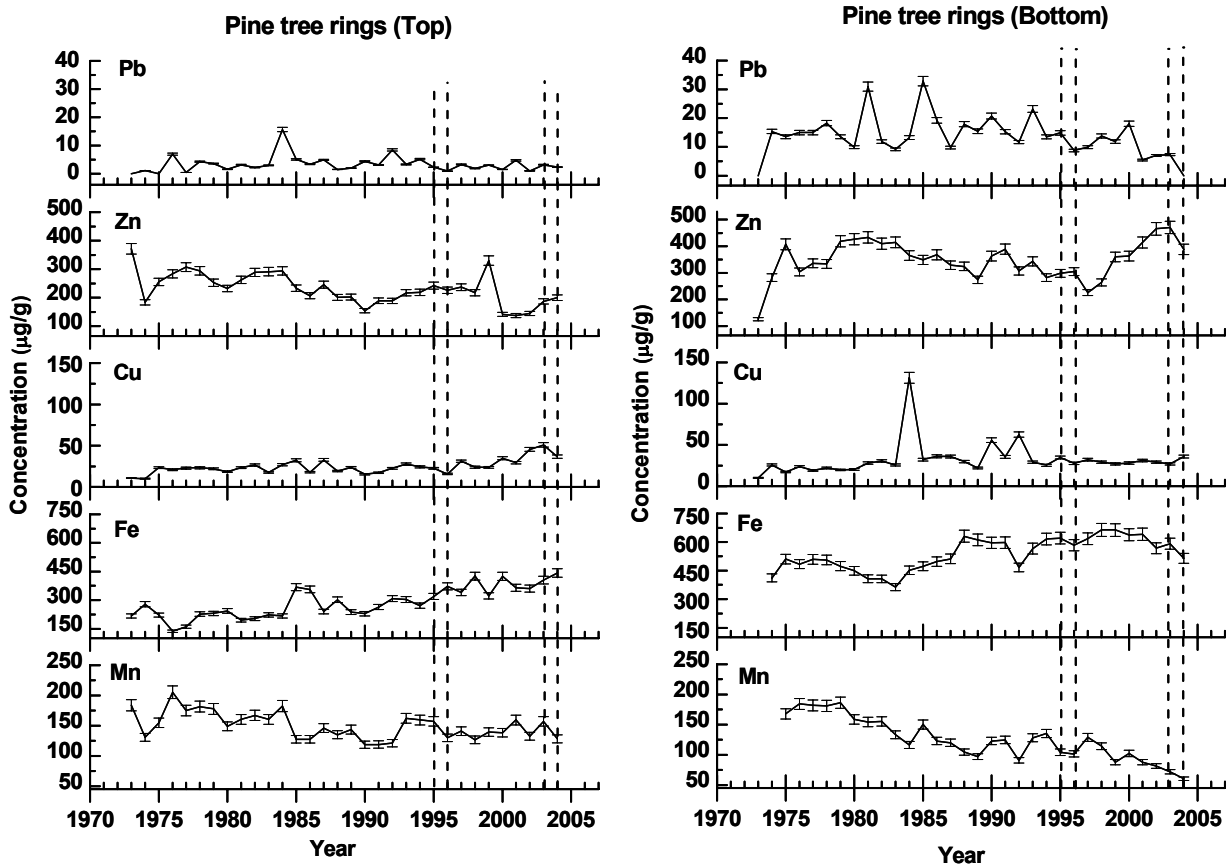
Figure 4: Average concentrations of Mn, Fe, Cu, Zn and Pb for Pinus montezumae in relation to time for sampling sites top and bottom. The dashed lines indicate the years of the major exhalations of Popocatepetl volcano.

Discussion

For sacred fir trees (Fig. 2), we observed larger width for the top site (average 8.5 mm) compared to the bottom site (average 5 mm.). The difference in ring widths may be attributed to the fact that sacred firs on top are older. Nevertheless, the distinctly decreasing trend (average 6 mm) in the ring widths on the top site after 1994 is correlated with the increasing Popocatepetl volcano activity and the modification of water conservation pattern due to a loss of available water. A similar (but slighter) diminution trend may be observed for the bottom site (average 4 mm).
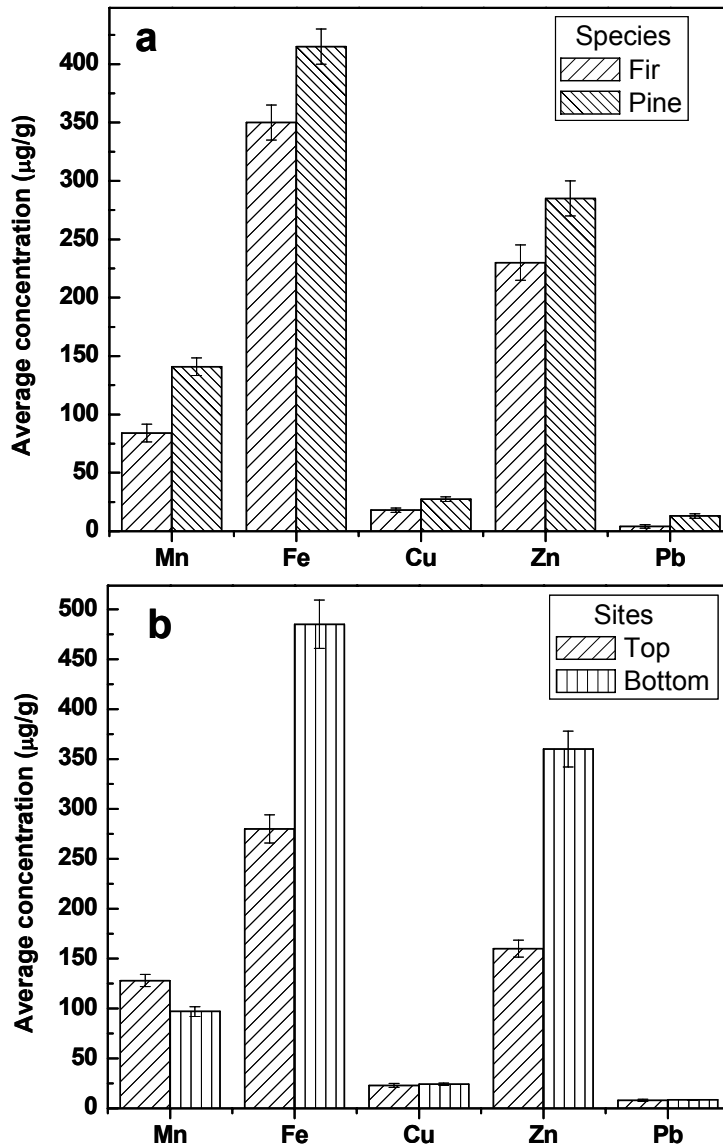
Figure 5: Comparison of the total average concentration of Mn, Fe, Cu, Zn and Pb among (a) species and (b) sampling sites. Error bars indicate the total variance.

On the other hand, the rings widths of the pine trees from the top site (average 2.5 mm) are smaller than at the bottom site (average 4.5mm). A periodic variation is observed before 1994 that may be related to periodic variations of precipitation. The rings widths display a diminution trend with large variations after 1994. This behavior corresponds to the ring width trend of sacred fir for the same period. Sacred fir at the bottom site and the pine at the top site seem to be more resistant to the modifications in the water pattern since both species are located at a more favorable altitude.

For sacred fir tree rings (Fig. 3), it is observed that the Pb mean contents do not change significantly among the top and the bottom sites. A similar behavior has been observed for the mean Cu contents. Nevertheless the mean Fe and Zn contents are higher in the tree

rings of the bottom site, while the Mn mean values are higher for the top site. We may expect that the soils of the bottom site are richer in Fe and Zn due to natural downwash and for this reason these trees may incorporate higher rates of these elements in their cores. In the case of Mn, the lower amounts may indicate a higher acidity in soil in the bottom site by comparison to the top site. In the case of Zn, there is a slight higher trend for the top site but at lower altitude larger variations are observed without a particular trend. Nevertheless, a higher trend in the contents of Pb, Cu, Fe and Mn is observed in the rings of 2000 for both sites. This effect is more obvious for Mn in 1994 for the bottom site and may represent a change in the soil acidity (Watmough 1999). Considering that the volcanic eruptions give rise to an enrichment of metallic compounds in the soil (Miranda, Zepeda & Galindo, 2004; Pearson *et al.* 2005), the increase can be related to the Popocatepetl activity during this period.

For the Pine trees (Fig. 4); Pb, Zn, Cu and Fe mean contents are higher for the bottom than at the top site. The Mn mean values from the top are higher than those from bottom site. Pb and Zn contents on the other hand present larger variations than other metallic contents. An increase for Fe and Cu is observed at the top site in 1995, while the Zn contents increase after 2000 at the bottom site. In contrast, Mn contents decrease at the bottom site after 1980. The higher content of metals in the pine trees in relation to the sacred fir trees is likely due to the fast growth of this species. Nevertheless, the pines seem to be more resistant to volcanic eruption effects, since the elemental increasing trends are slighter than for sacred fir.

In figure 5 it is observed that the mean metal contents are higher for the pine than for the sacred fir trees, this may be related to the faster growth of the pine trees. On the other hand, higher mean Fe and Zn contents are observed for the bottom site, what is in contrast to the top site. This agrees with higher contents of these elements in the soil of the bottom site. On the contrary, Mn mean values are lower for the bottom site probably due to higher acidity of this soil. Cu and Pb do not show any significant difference between the top and the bottom site.

Conclusions

In the ring widths a decreasing trend in the growth of pine and sacred fir trees in the Zoquiapan National Park (ZNP) is observed, which starts in 1994 when Popocatepetl volcano increased its activity. Sacred fir trees display a higher sensibility to the effects of the volcano eruptions, since an increasing trend is observed for the Fe, Mn and Cu contents in tree rings from 1994 onwards in the PIXE results.

On the other hand, the mean values of metal contents (including Pb) are generally higher for pine trees, probably due to the fast growth of this species. Pine trees present higher resistance to the eruption effects since no obvious enrichment of metallic contents can be observed in the rings from 1994.

Zn and Fe contents in the rings are higher in trees from the bottom site. This behavior may be the result of a soil that is richer in these elements. In general, Mn mean contents are lower for the bottom site, probably due to the higher acidity of this soil.

No correlation between the measured elemental concentrations of metals and major human activities, such as the reduction of lead content in the gasoline in 1984 or the closure of the major oil refinery in Mexico City in 1991, has been observed

Acknowledgements

References

Aoki, T., Katayama Y., Kagawa A., Koh, S., 1998: Measurement of trace elements in tree rings using the PIXE method, *Nucl. Instrum. and Meth.* 136, p.919.

Calva-Vázquez G., Razo-Angel G., Rodríguez-Fernández L. and Ruvalcaba-Sil J.L., 2006: Study of Z > 18 Elements concentration in tree rings from surroundings forests of the Mexico valley using External Beam PIXE. *Nucl. Instrum. And Meth. B* 249, p. 588.

Centro Nacional de Prevención de Desastres CENAPRED; Mexico, 2005, in http://redescolar.ilce.edu.mx/redescolar/publicaciones/publi_volcanes/popocatepetl.htm

Fritts H.C., 1976: Tree rings and climate, Academic press, London UK, p.567.

Liao Ch., Hollerman W. A., Glass G. A. and R. Greco, 2001: Study of the elemental composition of yellow pine using Particle Induced X-Ray Emission (PIXE), *AIP Conf. Proc.* 576, p. 425.

Lindeberg J., 2004, X-ray based tree ring analyses. Doctoral Thesis, Department of Silviculture Umeä, Swedish University of Agricultural Sciences. Umeä.

Mäkinen H. and Vannienen P. 1999: Effects of sample selection on the environmental signal derived from tree-ring series. *Forest Ecology and Management* 113, p.83-89.

Miranda J., Calva-Vasquez G., Solís C. and Huerta. L., 2003: PIXE and RBS elemental analyses of tree rings from Mexico Basin forest as a record of pollution, *AIP Conf. Proc.* 680, p. 444.

Miranda J., Zepeda F and Galindo I., 2004: The possible influence of volcanic emissions on atmospheric aerosols in the city of Colima, Mexico. *Environt. Pollut.* 127, p. 271.

Miranda J., Barrera V.A., Espinosa A.A., Galindo O.S., Nuñez-Orosco A., Montesinos R.C., Leal-Castro A. and Meinguer J., 2004: PIXE analysis of atmospheric aerosols from three sites in Mexico City, *Nucl. Instrum. And Meth. B* 219-220, p. 157-160.

Nabais C., Freitas H., and Hagemeyer J., 1999: Dendroanalysis: A tool for biomonitoring environmental pollution?, *Sci. Total Environ.* 232, p. 33

Pearson Ch., Manning S.W., Coleman M. and Jarvis K., 2005: Can tree-ring chemistry reveal absolute dates for past volcanic eruptions? *J. Arch. Sci.* 32, p. 1265.

Pernestal K., Jonsson B., Hällgren J-E., and Li H., 1991: Analysis of tree samples from an acidic and a limed environment by means of PIXE. *International Journal of PIXE* 1, p. 281-296.

Smithsonian National Museum of Natural History. Global volcanism program. Popocatepetl eruptive history. 2007. http://www.volcano.si.edu/world/volcano.cfm?vnum=1401-09=

Schäffer J. and Wilpert K.V., 2001: Chemical elements in tree-rings as related to soil chemical status in the Southern Black Forest, Germany. Proceedings of International Conference Tree Rings and People. Davos Switzerland.

Vanderlei Martins J., Artaxo P., Ferraz E.S.B. and Tabacniks M.H., 1999: Chronological studies of tree-rings from the Amazon Basin using thick target PIXE and proton backscattering analysis, *Nucl. Instrum. And Meth. 150*, p. 240.

Watmough S.A., 1999: Monitoring historical changes in soil and atmospheric trace metal levels by dendrochemical analysis, *Environt. Pollut.* 106, p.391.

Watmough S.A. and Hutchison T.C., 1999: Change in the dendochemistry of Sacred Fir close to Mexico City over the past 100 years, *Environt. Pollut.* 104, p.79.

Threshold of land-use abandonment controls the rate of *Pinus sylvestris* recruitment and the forest dynamics in a Mediterranean mountain (Provence, S-E France)

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Introduction

Mediterranean ecosystems have been impacted for millennia by human activities such as permanent agricultural and pastoral practices (Pons & Quézel 1985, Blondel & Aronson 1999). Since the end of the 19th century, the traditional land-use has largely changed. In the northern rim of the Mediterranean basin, these changes are characterized by two opposite trends, namely intensification in the coastal areas, plains and valleys, and land abandonment in marginal areas that are generally situated in the mountains (Debussche et al. 1999). Land abandonment has lead to the settlement and expansion of scrublands and forests that result in a decrease in landscape heterogeneity, changes of spatial distribution of rare or endemic species (Höchtl et al. 2005), and progression of the species typical of central or northern Europe (Covas & Blondel 1998, Marty et al. 2003). The sustainable land management of former agricultural areas needs to decipher the temporal mechanism of woody expansion to predict the future vegetation pathways. Because land was exploited for several usages that could have been abandoned at different periods, we hypothesize that vegetation dynamics are controlled by these past land-uses. Consequently, we need to analyse the societal transformations back to the 19th century to precisely estimate its influences on present-day forest-cover and its dynamics. The present study aims to investigate the origin, the establishment and the kinetic of the tree community with respect to land-use history.

Study area

The study area is located in the Malay Massif (Fig.1), within the foothills of the Southern Alps (France, 43°42'N, 6°38'E, elevation: 1300-1416 m a.s.l.). The area has belonged to the Canjuers military camp since 1970. The topography is heterogeneous, showing a series of gentle slopes and dolines (bowl-shaped depressions caused by karstic weathering). The dolines contain deeper (>70 cm) and stone-free soils and are surrounded by visible man-made rock piles. They were traditionally ploughed, whereas the stony slopes were only grazed (Fig.1). The climate is of the Mediterranean mountain type, i.e. warm and dry in summer, cold and snowy in winter.
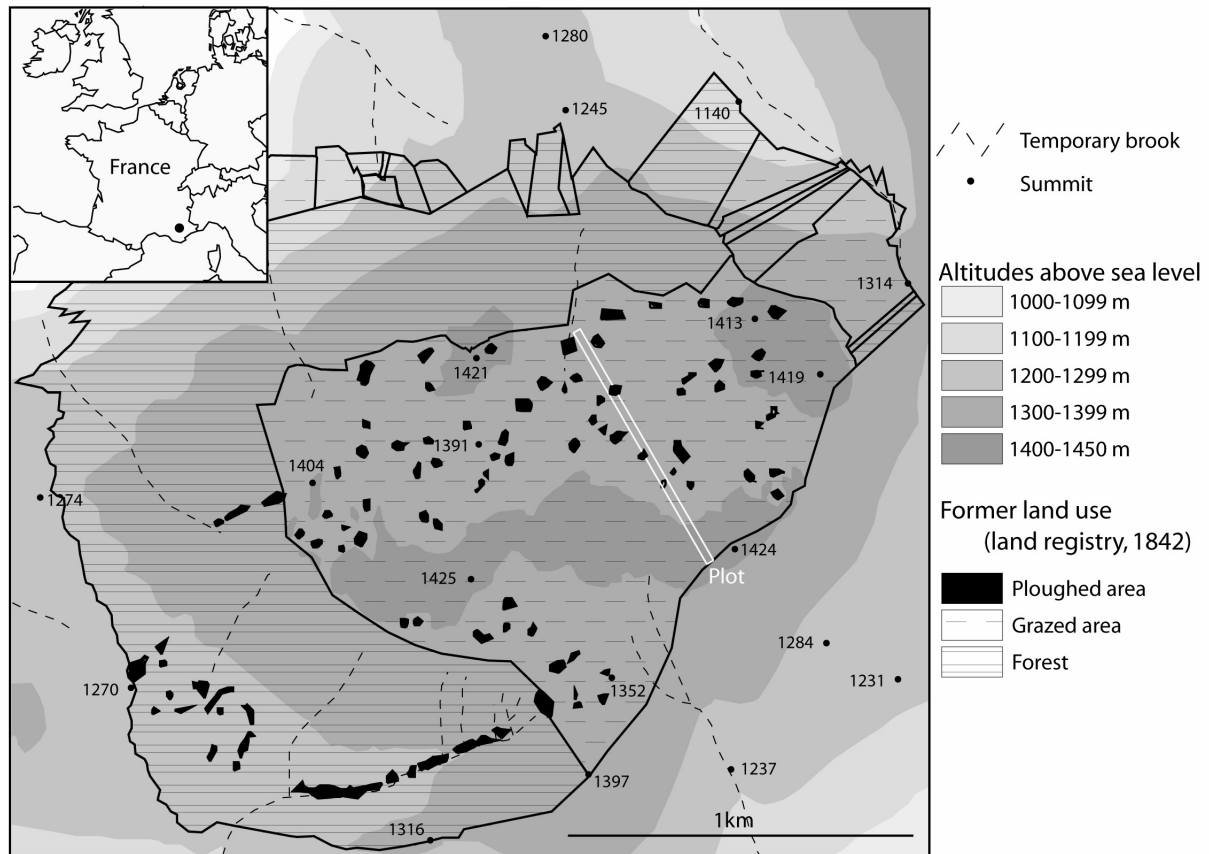
Figure 1: Location of the study site and former land-use of « Plaine du Malay » (Land registry,1842).

Methods

The approach includes analysis of land-use history combined with analysis of forest dynamics. We used population and agricultural census to reconstruct former land use, date, rate and pattern of land abandonment. Forest dynamics was assessed in a 1.55-ha plot perpendicular to the slope and to the ancient forest. In the plot, all trees were identified, labelled and mapped. For each tree a disc was cut from base of stumps using a chain-saw to determine their age, or an increment borer was used. Samples were sanded, then, growth rings were counted and cross-dated by visual observation under a binocular microscope (Schweingruber 1988). Age structure graphs were plotted for the three main species (i.e. *Pinus sylvestris*, *Fagus sylvatica* and *Abies alba*) with respect to the human population and flocks (sheep, goats) data in order to test the relationship between land-use history and stand dynamics. To asses the possible effect of climate on pine establishment, Spearman correlation rank was used between tree establishment (sum of regeneration in 5-year class) and a series of climatic variables (5-year mean) (Miller & Halpern 1998). The relationship between the total regeneration (sum of regeneration in 5-year class) *versus* the mean number of sheep and goats (5-year mean) was tested to estimate the possible effect of grazing pressure change on the recruitment dynamics. We also test the possible effect of former land-use and topography on pine establishment by comparing age-class distribution between the dolines (deeper soil, fertile and traditionally ploughed) and the slopes (thin soil, stony to rocky, traditionally grazed).

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Results and discussion

Forest dynamics follows the local land-use abandonment

The age structure and the land-use history both show that the study area has been under severe transformations since the 1880's (Fig. 2).
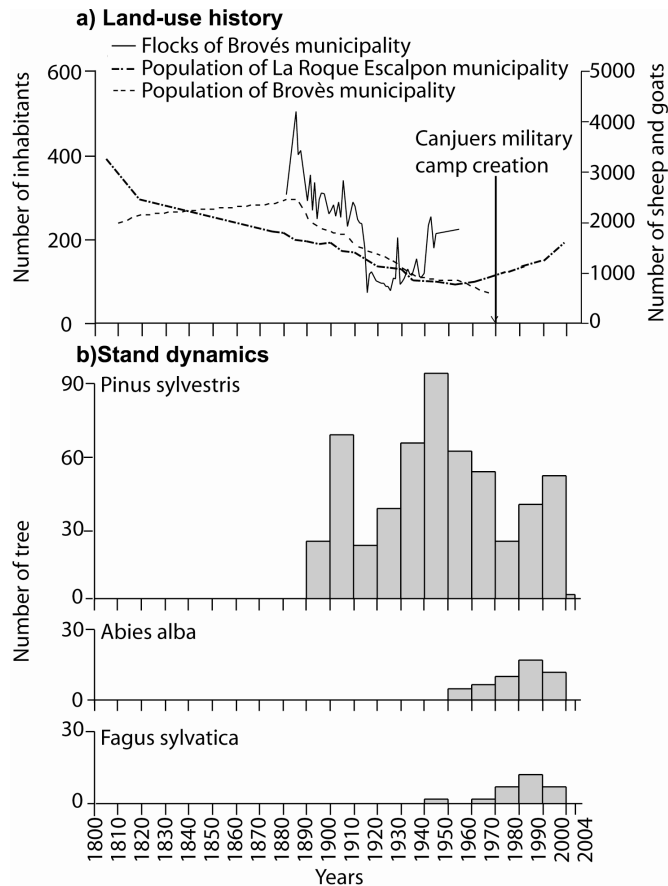

Figure 2: Land use history and stand dynamics of the study site. (a) Land-use history: inhabitant numbers of the municipalities surrounding the Malay massif and flock numbers of Brovès municipality. (b) Stand dynamics: age structure of Pinus sylvestris*, Abies alba and* Fagus sylvatica*.*

Stand dynamics is characterized by three main phases: (1) initial colonisation by *Pinus sylvestris*, (2) development of pioneer stands, (3) recruitment of post-pioneer stands, e.g. *Abies alba* and *Fagus sylvatica* (figure 2b) associated with a rise of tree diversity (not shown here). The first two phases of the forest dynamics are clearly linked with the land-use history. The initial colonisation by pine (*Pinus sylvestris*) started in 1879, against a background of local human population decline, which began 20 years before (Fig. 2a). Efficient pine recruitment started in the 1890s when the livestock underwent a significant drop. After that, pine density irregularly increased: recruitment shows two maxima in 1900-1910 and 1940-1950 separated by 30 years of lower recruitment (1910-1940). Although the initiation and start of efficient pine recruitment follow land abandonment, land-use history does not clearly explain the different stages of pine density increase and the recruitment of post-pioneer cohorts. Recruitment of *Fagus sylvatica* and *Abies alba* is delayed long after the beginning of the land abandonment: they start to regenerate in the 1940s and 1950s respectively.

Consequently, the recruitment of *Abies* and *Fagus* does not seem directly related to land-use history. The delay between the recruitment of *Pinus sylvestris* and that of the two others species may be explained by differences of seed dispersal mode and successional status: *Pinus sylvestris* has higher reproductive rates, a more efficient short- and long-distance dispersal, and higher survival rates of seedlings in open area than *Fagus sylvatica* and *Abies alba* (Castro et al. 1999, Debain et al. 2003) whereas the latter have the capacity to persist in shade under pine canopy (Aussenac 2002, Kunstler et al. 2005). In the coming years, beech and fir should thus play a more important role in the forest dynamics.

Climate and tree recruitment

Precipitation or temperature variation can influence several development stages in *Pinus*: seed production, germination, emergence, seedling mortality, growth (Despland & Houle 1997, Castro et al. 2005) and therefore could explain episodic pine recruitment (League & Veblen 2006). However, in this study no relationship is detected between regeneration and precipitation or temperature patterns (Tab. 1). Although climate does not seem to control pine dynamics, we cannot rule out that the response to land-use abandonment may over-ride the climatic response of recruitment.

Table 1: Spearman rank correlation between Pinus sylvestris *establishment (sum of regeneration 5-year class) and various climatic variables (5-years means) derived from monthly data of Comps sur Artuby meteorological station (distant of around 2.5 km, 943 m a.s.l.).*

Climatic variables	Spearman correlation	p-value	Degree of freedom	Significance
Precipitation (1907-2004)				
Annual	-0.039	0.871	18	n.s.
October-September (growing season)	-0.063	0.792	18	n.s.
June-August (summer)	0.004	0.987	18	n.s.
March-May (spring)	-0.237	0.313	18	n.s.
Temperature (1952-2004)				
Annual	-0.510	0.114	9	n.s.
October-September (growing season)	-0.492	0.129	9	n.s.
June-August (summer)	-0.487	0.133	9	n.s.
March-May (spring)	0.023	0.946	9	n.s.

Grazing rate and differential land-use abandonment influence tree recruitment

The start of tree encroachment is clearly linked to the start and stressing of land abandonment but pine recruitment shows a temporal variability that is not completely explained by the process of land abandonment. Grazing rate better explains the recruitment variability: according to Mountford and Peterken (2003) when grazing rate is high the recruitment is lacking and, when grazing rate decreases recruitment increases. Our observations support such scenario but when grazing rate is very low recruitment of pine also is low. The net pine recruitment peaks when the sheep and goats numbers are on

moderate levels (Fig. 3). The herbivores consume, trample seedlings and therefore increase mortality (Scott et al. 2000, Zamora et al. 2001) but the herbivores also can reduce density and biomass of herbaceous layer creating favourable microhabitat to pine seedling regeneration (Scott et al. 2000, Castro et al. 2002). Consequently pine recruitment appears controlled by grazing pressure and only a medium level rate of grazing allows massive pine regeneration (Fig. 3).
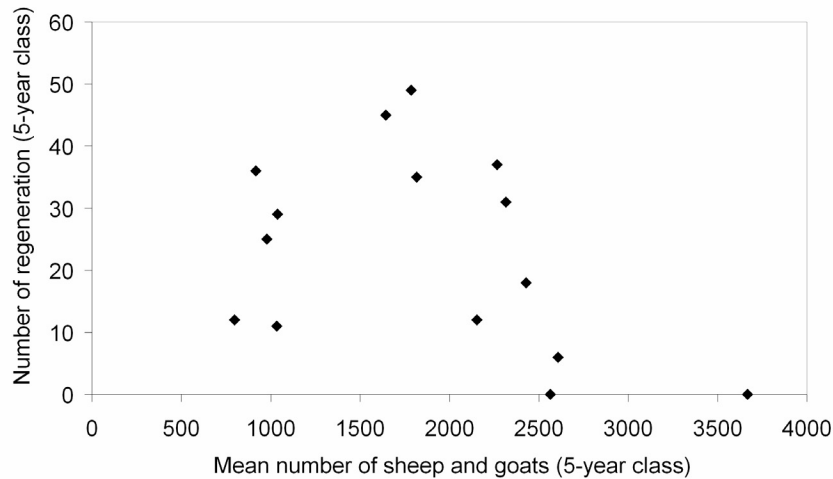
Figure 3: Relationship between grazing mean number of sheep and goats and effective pine regeneration.

The effects of topography are complex, involving differences in soil and air temperature, evaporation and irradiance and, in our site, differences in land-use.

The dolines with deeper and richer soils are less affected by extreme climatic events and are more favourable for regeneration than the slopes. As a result, it would be expected that after land abandonment, pine recruitment started inside the dolines before on the slopes. However, on the contrary, the regeneration starts on the slopes formerly grazed, afterwards inside formerly ploughed dolines, and reaches a maximum on the slopes in the 1940s then inside the dolines in the 1950s (Fig. 4). Different previous land-uses leading to different times of land abandonment, combined with variable herbaceous competition may explain the contrasting recruitment patterns (Fig. 4). Inside formerly ploughed dolines, deeper soils favour grass development, increases the quality of fodder and delay land abandonment. Herbs can form a dense layer that prevents pine encroachment, and different fodder quality associated with progressive land abandonment can attract herbivores inside the dolines.
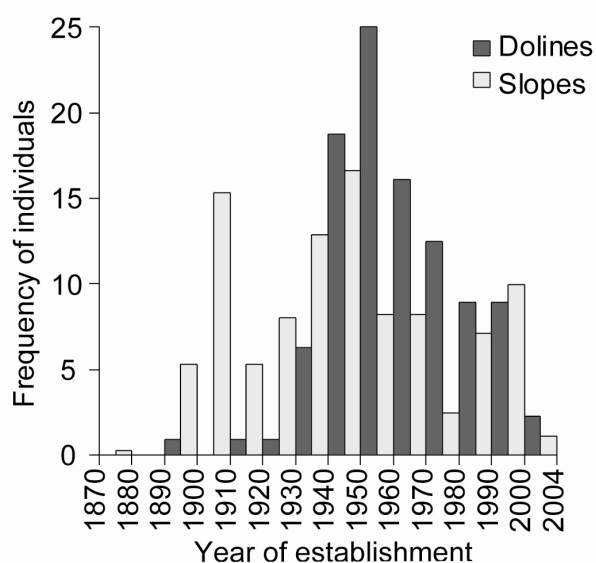
Figure 4: Age structure (%) of Pinus sylvestris *inside the dolines (n=111) and on the slopes (n=452).*

Conclusion

Land-use history provides various insights to understanding forest colonization as revealed by forest structure and temporal patterns of tree establishment. The sequence of forest encroachment agrees well with the dates of abandonment, and contrasting former land-uses are highlighted by subsequent different tree dynamics. In a Mediterranean mountain ecosystem, agricultural history and the rhythm of land-use abandonment are significant driving forces explaining present day forest dynamics. Knowledge of the agricultural history and former land-use is critical to understanding and predicting forest dynamics in the Mediterranean mountains following land abandonment.

References

Aussenac, G. (2002): Ecology and ecophysiology of circum-Mediterranean firs in the context of climate change. *Annals of Forest Sciences 59*: 823-832.

Blondel, J., Aronson, J. (1999): Biology and wildlife of the Mediterranean region. Oxford University Press. Oxford: 328p.

Castro, J., Gòmez, J.M., García, D., Zamora, R., Hòdar, J.A. (1999): Seed predation and dispersal in relict Scots pine forests in the southern Spain. *Plant Ecology 145*: 115-123.

Castro, J., Zamora, R., Hòdar, J.A. (2002): Mechanism blocking *Pinus sylvestris* colonization of Mediterranean mountain meadows. *Journal of Vegetation Science 13*: 725-731.

Castro, J., Zamora, R., Hòdar, J.A., Gòmez, J.M. (2005): Alleviation of summer drought boosts establishment success of *Pinus sylvestris* in a Mediterranean mountain: an experimental approach. *Plant Ecology 181*: 191-202.

Covas, R., Blondel, J. (1998): Biogeography and history of the Mediterranean bird fauna. *Ibis 140*: 395-407.

Debain, S., Curt, T., Lepart, J. (2003): Seed mass, seed dispersal capacity, and seedling performance in a *Pinus sylvestris* population. *Ecoscience 10*: 168-175.

Debussche, M., Lepart, J., Dervieux, A. (1999): Mediterranean landscape changes: evidence from old postcards. *Global Ecology and Biogeography 8*: 3-15.

Despland, E., Houle, G. (1997): Climate influences on growth and reproduction of *Pinus banksiana* (Pinaceae) at the limit of the species distribution in eastern North. America. *American Journal of Botany 84*: 928-937.

Höchtl, F., Lehringer, S., Konold, W. (2005): "Wilderness": what it means when it becomes a reality - a case study from the southwestern Alps. *Landscape and Urban Planning* 70: 85-95.

Kunstler, G., Curt, T., Bouchaud, M., Lepart, J. (2005): Growth, mortality, and morphological response of European beech and downy oak along a light gradient in sub-Mediterranean forest. *Canadian Journal of Forest Research 35*: 1657-1668.

League, K., Veblen, T. (2006): Climatic variability and episodic *Pinus ponderosa* establishment along the forest-grassland ecotone of Colorado. *Forest Ecology and Management 228*: 98-107.

Marty, P., Pélaquier, E., Jaudron, B., Lepart, J. (2003): Spontaneous reforestation in a peri-Mediterranean landscape: history of agricultural systems and dynamics of woody species. In: Fouache, E. (Eds.). The Mediterranean world environment and history. Elsevier. Paris: 183-190.

Miller, E.A., Halpern, C.B. (1998): Effects of environment and grazing disturbance on tree establishment in meadows of the central Cascade Range, Oregon, USA. *Journal of Vegetation Science 9*: 265-282.

Mountford, E.P., Peterken, G.E. (2003): Long-term change and implications for the management of wood pastures: experience over 40 years from Denny Wood, New Forest. *Forestry 76*: 19-43.

Pons, A., Quézel, P. (1985): The history of the flora and vegetation and past and present human disturbance in the Mediterranean region. In: Gòmez-Campo, C. (Eds.). Plant conservation in the Mediterranean area. Dr Junk Publishers. Dordrecht: 25-43.

Schweingruber, F.H. (1988): Tree rings: basics and applications of dendrochronology. D. Reidel Publishing Co. Dordrecht: 276p.

Scott, D., Welch, D., Thurlow, M., Elston, D.A. (2000): Regeneration of *Pinus sylvestris* in a natural pinewood in NE Scotland following reduction in grazing by *Cervus elaphus*. *Forest Ecology and Management* 130: 199-211.

Zamora, R., Gómez, J.M., Hódar, J.A., Castro, J., Garcia, D. (2001): Effect of browsing by ungulates on sapling growth of Scots pine in a Mediterranean environment: consequences for the forest regeneration. *Forest Ecology and Management* 144: 33-42.

Dendrochronology as a tool for historical ecological research. Two case studies from the Netherlands

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Introduction

In the Netherlands, as well as in most parts of Europe, the original vegetation has been converted on a large scale in the past. Forests were cleared and converted to arable land and pastures, or were cut for wood and timber supply. In the beginning of the nineteenth century only 1% of the Netherlands was covered by forest. In those times large heath land and drift sand areas were present. Most of these areas belonged to commons until about 1900. The remaining forest areas consisted of some high forests, but most of them were managed as coppice (with standards) (Buis 1985).

Old forest sites are of great importance for biodiversity. In order to understand biodiversity patterns in the current landscape, it is of great importance to have specific information on the local forest history. However, there are only very few places where the local forest history is known from historical documents. Therefore, research tools are needed to elucidate the ecological and management history of ancient forest sites. There are several tools for such historical ecological research (see for instance Rackham, 2003). In this paper preliminary results are described from two case studies where dendrochronology is used as a tool for historical ecological research in the Netherlands.

Case 1 - Dating of aeolian sediment transport periods in drift sand areas

Introduction and methods

Due to deforestation and overgrazing, wind erosion in the Pleistocene sand areas have initiated and maintained large drift sand areas in the Netherlands (and large parts of northwestern Europe). Nowadays, most drift sand areas are consolidated after reforestation and vegetation encroachment, and only a few square kilometres of active, open drift sand remain (Riksen et al 2006). Since drift sand areas contain some very rare species that are directly reliable on open sand, recent efforts are made to reactivate drift sands. However, knowledge on the natural dynamics of drift sand areas is wanting. There is hardly any information on the periodicity of discrete events in which major sand displacement takes place in drift sand systems.

Figure 1: Drift sand area in the Loonse en Drunense Duinen with scattered oak shrubs.

Sometimes large clusters of oak (*Quercus robur* L. and *Quercus petraea* (Matt.) Liebl.) occur in these (former) drift sand areas (see figure 1). These oaks are characterised by having many stems usually located on tops or slopes of sand dunes. Genetic research has shown that such oak clusters can be genetically identical, but may also contain several genotypes (Copini et al. 2005). About the origin of the hills beneath the oak shrubs Stoutjesdijk (1959) writes: *"A characteristic feature of the landscape formed by the resting inland dunes is solitary dome-shaped hills covered with oak shrub. The base of the oak trunks is covered with sand. As the sand is fixed by the numerous trunks it is less easily borne away by the wind, and this explains why these hills may have very steep slopes".*

Gärtner et al. (2001), amongst others, showed that changes in wood formation as a reaction to external impacts can be used for dating mass movement events such as avalanches and debris flows. Here, we set out to examine the changes in wood anatomy due to aeolian sediment transport.

In many drift sand areas in the Netherlands, for instance in the Deelensche Start, and Loonse en Drunense Duinen, oaks are present that have been overblown by drift sand (Fig. 1). In some cases, the stems were subsequently exposed again after the sand eroded away, exposing the previously buried stems (see figures 2 and 3). These formerly underground systems provide an excellent opportunity to study changes in wood anatomy which could be used to date the time of burial and of exposure. Stem wood anatomy of *Quercus robur* and *Q. petraea* is characterised by distinct ring porous rings, wide rays and flame-like groupings of pores in latewood. In root wood amongst others, ring porous features disappear and pith is lacking or has a different shape (Schweingruber 1990, 2001). However, differences between stem and root anatomy are often gradual and superimposed by age-dependent changes in wood anatomy (juvenile wood, adult wood).

We performed a pilot study to find changes in wood anatomy by studying wood cores taken at different heights of two oak clusters located in the Loonse en Drunense Duinen and in the Deelensche Start. The underground system of the oak cluster at the Deelensche Start consisted of stems that were connected by a layered branch (Fig. 2). Also some roots had developed at the height of the layer just below the wide stem base (Fig. 2). The oak cluster in the Loonse en Drunense Duinen consists of many stems and roots that were sometimes connected by layered branches. Also wide stem bases occurred at different heights as indicated in figure 3. In both areas wood samples were taken both from above and below the wide stem bases. The cores were glued at wooden holders. Afterwards surfaces of the cores were prepared using Stanley knives and razor blades.
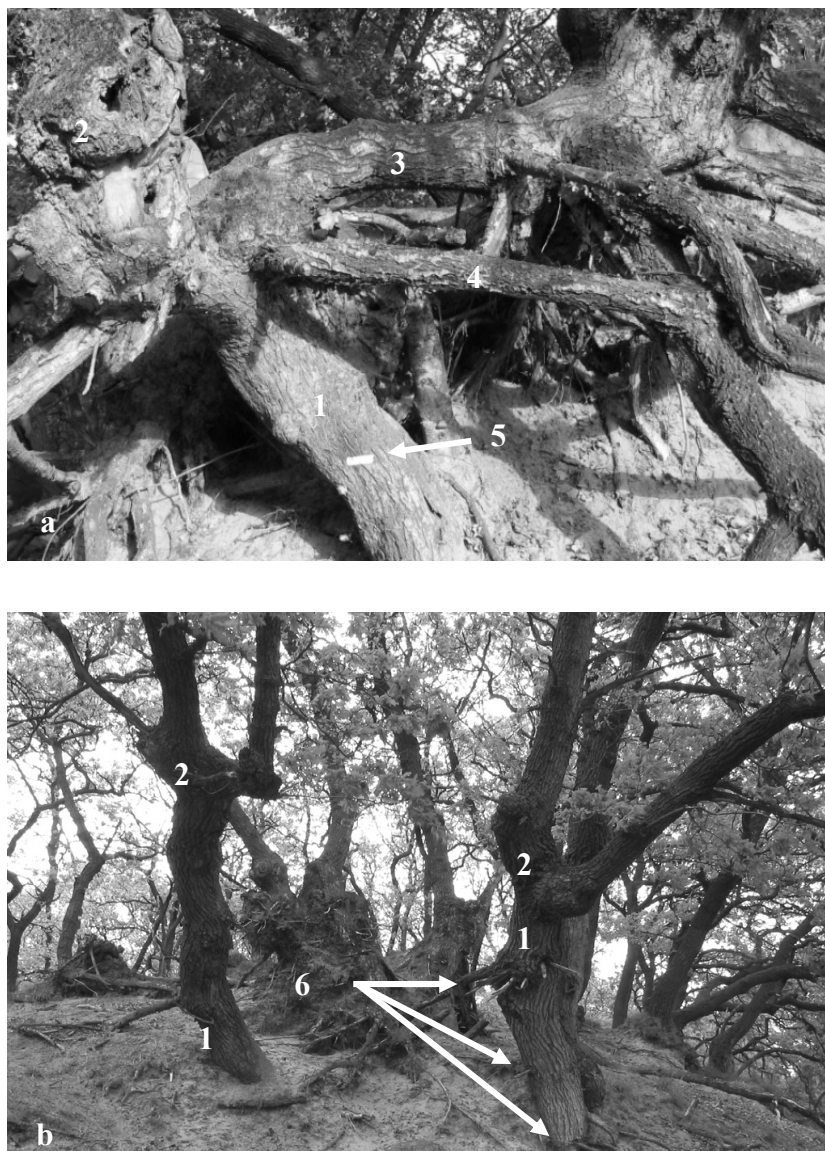
Figure 2: Formerly buried and subsequently exposed stems of oaks in the Deelensche Start.
1 = Buried and later exposed stems 2 = Wide stem base; 3 = Horizontal connection between two stems (=layer); 4 = excavated roots; 5 = location of wood core sample as is shown in figure 4A; 6 = roots.

Figure 3: Oak cluster in the Loonse en Drunense Duinen. The line indicates the level where wide stem bases occur. Below this line stems show a growth depression.
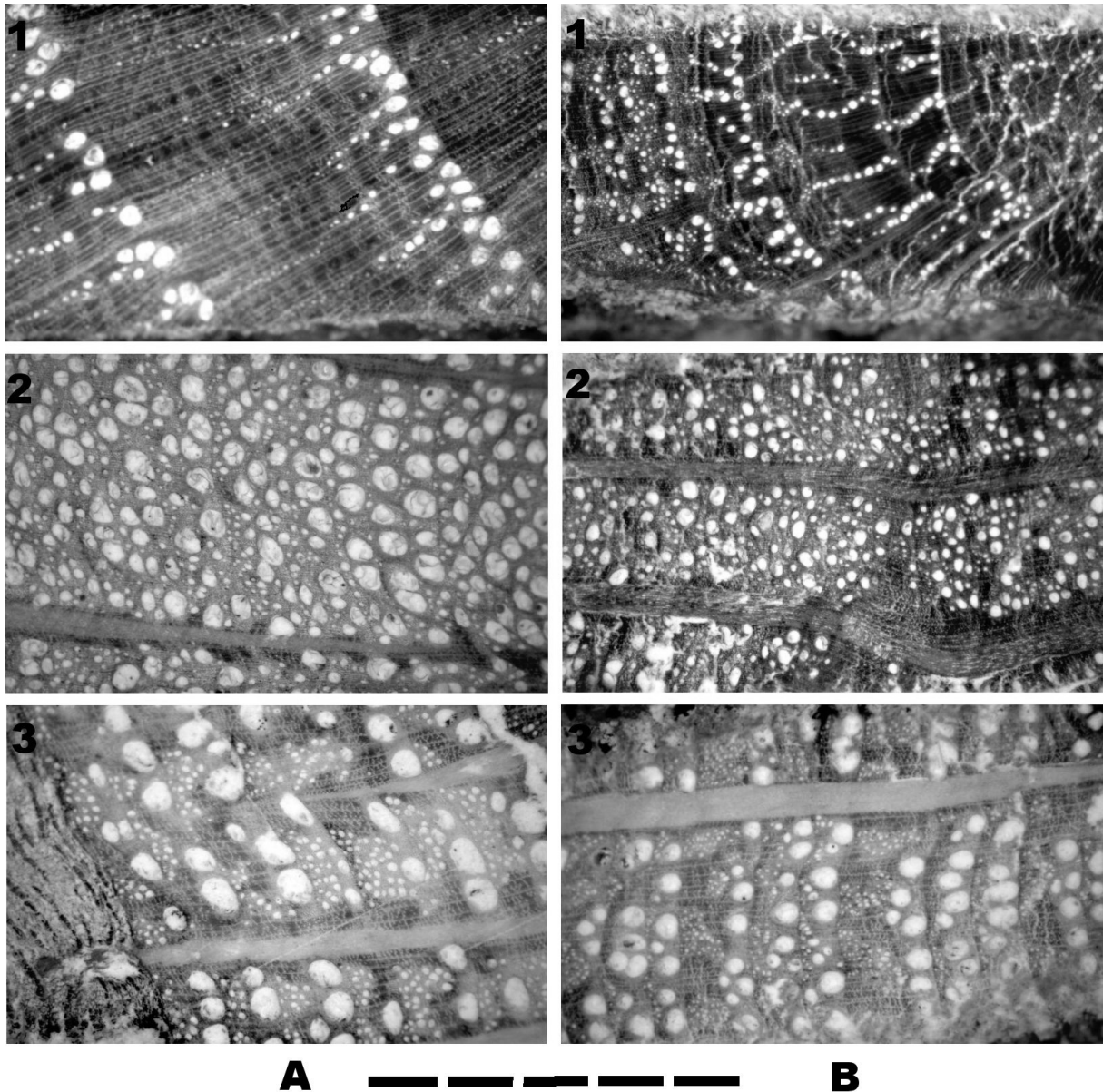
Figure 4:

A) *Wood anatomy of a formerly buried stem that was later exposed again.*
1. *Rings around the pith show distinct tree rings (=stem wood anatomy) that were formed above ground.*
2. *Extremely narrow rings with root wood anatomy (rings formed below ground) located at the middle of the core and formed during the period when the stem was buried by drift sand.*
3. *Distinct tree-rings (=stem wood anatomy) directly under the bark indicating above-ground formation.*

B) *Wood anatomy of a buried root, which was later exposed in the Loonse en Drunense duinen.*
1. *Rings close to the pith with a clear root wood anatomy.*
2. *Long lasting growth depression (root wood) from the middle of the core belonging to the period in which the root was buried (deeper) by drift sand.*
3. *Distinct tree rings under the bark formed above ground showing normal rings again*

The dashed line at the bottom represents 0.5 cm.

Results and discussion

Figure 4A shows three photographs of one of the collected wood samples of the oak cluster in the Deelensche Start. Near the pith the sample has large rings of about 0.5 cm in width. Figure 4A-2 shows a large growth depression in the middle of the sample. The last 7 rings up to 2005 are shown in figure 4A-3. No such growth depressions were found above the wide stem base.

In the Loonse and Drunense Duinen, wood samples were collected both above wide stem bases (indicated by the dash-dotted line in figure 3) as well as from below these stem bases. All lower samples showed long lasting growth depressions. Wood samples taken from above the wide stem bases showed no growth depressions. Figure 4B shows three photos from different parts of one collected wood core. The first photo (Fig. 4B-1) shows a part close to the pith characterised by semi ring porous rings (root wood). The second picture shows a part with extremely small tree rings formed below ground. Figure 4B-3 shows distinct tree rings near the bark with normal stem anatomy again.

First results of this study indicate that changes in wood anatomy occur in parts of the tree that become buried by sand or are later exposed after erosion. Stem-wood structure can change into root-wood structure and *vice versa*. Prolonged growth depressions are the result of getting buried. Also, roots show differences in ring width and can change to distinct rings when no longer exposed to sand. Growth depressions were not present above the line as shown in figure 3. This line probably represents the height of the former dune. Wide stem bases that are present at this height are most likely a result of a cutting event. Dating of these cores and periods of growth depressions can give a three dimensional view of sand dune development.

Case 2 - Use of cambial age trends to reconstruct forest management systems

Introduction and methods

In the Netherlands basically three different forest management systems have been used over many centuries: coppice, coppice with standards and high forest. Haneca et al. (2005 & 2006) suggested that dendrochronology could be used to infer information about forest management systems from wood samples of trees with an unknown history. They found clear differences in cambial age trends between oaks belonging to different forest management systems. They used this approach to determine past forest management by comparing historical wood samples with these cambial age trends.

We performed a systematic study at the Veluwe (centre of the Netherlands) and sampled oaks (*Quercus robur* L. and *Quercus petraea* (Matt.) Liebl.) with a known forest management history to investigate whether the cambial age trends in these trees significantly differs between forest management systems. We selected trees from oak coppice, standards and high forest (seeded oaks). Sites were selected, amongst others, based on cadastral maps of 1832 and the National Forest Inventories of the Netherlands. Stem discs or two cores per stem were collected of 10 trees per site at a height of 30-40cm. Note that for coppice sites all stems were sampled of ten coppice stools. Stem discs were sanded to obtain a smooth surface. The cores were glued to wooden holders. Afterwards, surfaces of the cores were

prepared using Stanley knives and razor blades. Tree-rings of cores and discs (two radii) were measured and analyzed with a precision of 1/100 mm (LINTAP: Rinntec) in combination with TSAP software (Rinn 1996). Visual cross-dating was checked using the COFECHA software (Holmes 1983, Grissino-Mayer 2001). Cambial age classes were computed for ten successive years. Since Vera (2000) and Billamboz (1990) showed that oaks which are coppiced grow much faster compared to seeded oaks during the first seasons, also cambial age plots were computed over the first twenty years.
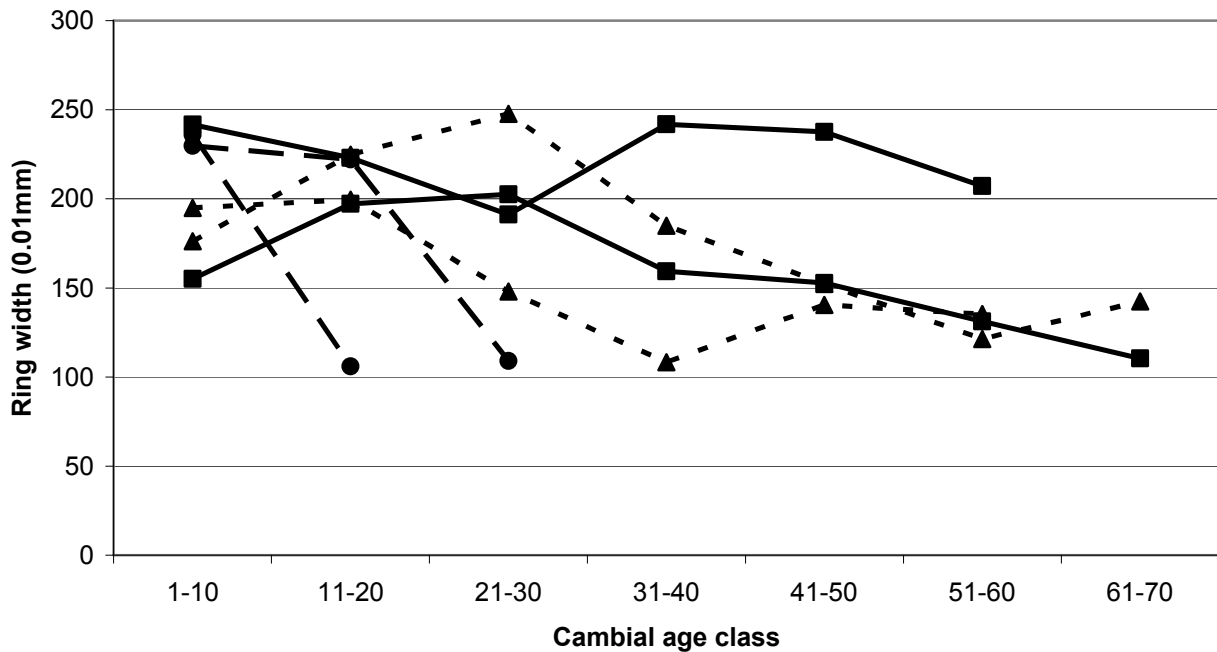

Figure 5: Average ring width for cambial age classes of 10 successive years, starting from the pith.
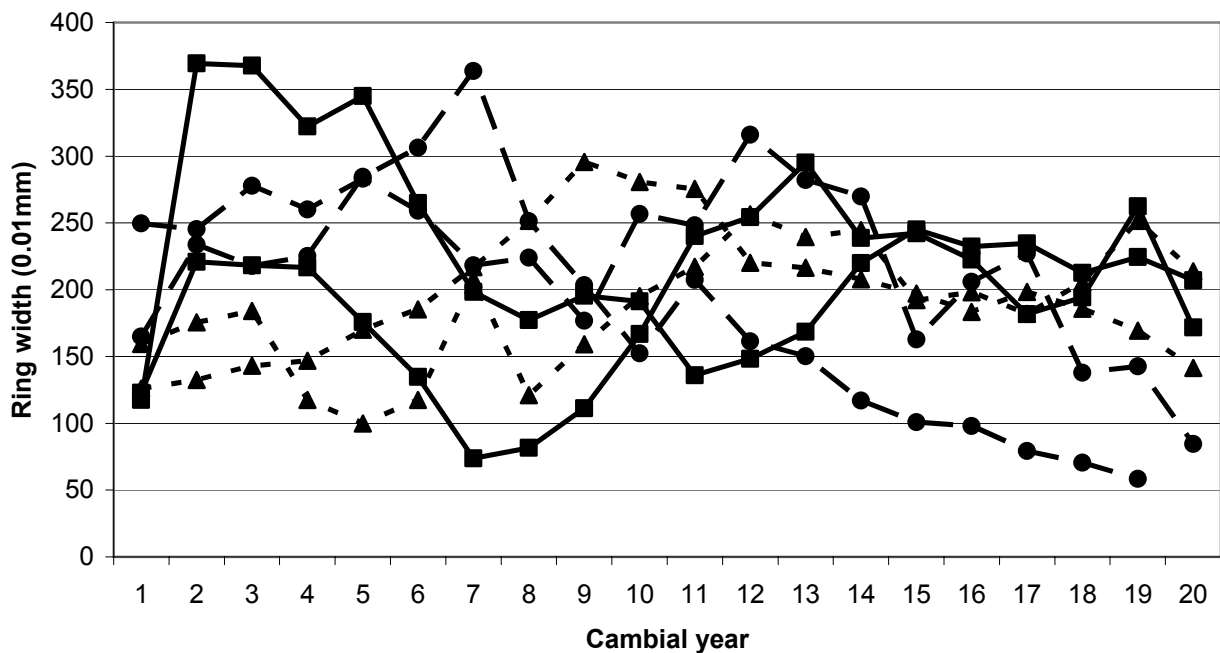● coppice (broken line); ■ standards (solid line); ▲ high forest (seeded) (dotted line)

Figure 6: Average ring width for cambial age (1-20), starting from the pith. ● coppice (broken line);
■ standards (solid line); ▲ high forest (seeded) (dotted line)

Results and discussion

Figure 5 shows cambial age trends of ten successive years up to 70 years. It is evident that for coppiced oaks the growth decreases rapidly. However, no clear trends were found for the different forest management systems. When the cambial age is plotted together with ring width of the first twenty years (Fig. 6) some differences between oaks with a different origin can be found. Oaks originated by resprouting in general show a higher initial growth compared to seeded oaks. We did not find a clear-cut difference between oaks from different forest management systems.

These results are in contrast to Haneca et al. (2005) and indicate that there is a substantial variation between sites with a similar forest management system. Besides regeneration methods, variation also occurs because of different site conditions, climate, etc.

Analyses of the first twenty years indicate a high initial growth for trees that have been coppiced (Fig. 6) and thus originated by resprouting. This result is in line with Vera (2000) and Billamboz (1990). Vera (2000) mentioned that a sprout of a coppiced oak can grow up to 2 m while seedlings grow only about 20 cm during the first year. Also, Billamboz (1990) indicates that resprouted oaks can be distinguished from seeded oaks because of wide rings during the first years of resprouted oaks stems.

General conclusion and future perspectives

Our first case study indicates that wood anatomy changes when stems are buried by drift sand or exposed. The exact dating of growth depressions and conversion to a different anatomy can provide information on the time period when stems were overblown or became exposed. Further research could involve 3D mapping of such oak clusters and analysing and dating changes in wood anatomy to determine periods of aeolian sediment transport. Moreover, further research must focus on mechanisms behind root wood formation. Also, a systematic description of root and stem wood anatomy including aspects as pith, ray morphology, tree-ring, vessel characteristics is recommendable for a better understanding of wood formation. Changes in wood anatomy provide a promising tool in investigating landscape dynamics in drift sand areas.

Our second case indicates that the cambial age trend is not a reliable indicator of (past) forest management. There is a lot of variation between oaks belonging to the same forest management system when cambial age classes of 10 successive years were computed over the whole tree life. The critical period of distinction between coppiced and seeded oaks is probably within the first decade of growth. Afterwards, climate, stand density and other environmental variables have an overriding influence on the tree ring pattern. Further research is now underway, building an extensive database of tree ring chronologies from sites of known history and focussing on the tree ring pattern close to the pith.

Acknowledgements

References

Buis, J. (1985): Historia Forestis. Nederlandse bosgeschiedenis, Wageningen (AAG Bijdragen 26 en 27) 472 p.

Billamboz, A. (1990) Das Holz der Pfahlbausiedlungen Sudwestdeutschlands. Jahrringanalyse aus archeodendrologischer Sicht. *Ber. Der Romisch-Germanischen Kommission* 71: 197 - 207

Cook, E.R. (1985): A time series analysis approach to tree-Rring Standardization. Ph.D. Thesis, University of Arizona. 171 p.

Copini, P., Buiteveld, J., Den Ouden, J., Sass-Klaassen U.G.W. (2005): Clusters of Quercus robur and Q. petraea at the Veluwe (the Netherlands). CGN Report 1, Wageningen. 46 p.

Gärtner, H., Schweingruber, F.H., Dikau, R. (2001): Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots. In: *Dendrochronologia* 19: 81 - 91.

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

Haneca, K., Acker, J.V., Beeckman, H. (2005): Growth trends reveal the forest structure during Roman and Medieval times in Western Europe: a comparison between archaeological and actual oak ring series (Quercus robur and Quercus petraea) *Ann. For. Sci.* 62: 797-805.

Haneca, K., Boeren, I., Acker, J.V., Beeckman, H. (2006): Dendrochronology in suboptimal conditions:from medieval oak from Flanders (Belgium) and archives of past forest management. *Veget Hist Archaeobot.* 15: 137–144

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

Rackham, O. (2003): Ancient woodland. Its history, vegetation and uses in England. London; Castlepoint Press. 584 p.

Riksen, M., Ketner-Oostra, R., Van Turnhout, C., Nijssen, M., Goossens, D., Jungerius, P. D. and Spaan. W. (2006): Will we lose the last active inland drift sands of Western Europe? The origin and development of the inland drift-sand ecotype in the Netherlands. *Landscape Ecology* 21: 431-447.

Rinn, F. (1996): TSAP (Time Series Analysis and Presentation) Version 3.0. Heidelberg. 262 p.

Schweingruber, F. H. (1990): Microscopic Wood Anatomy. 3rd edition. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf. 226 p.

Schweingruber, F. H. (2001): Dendroökologische Holzanatomie. Paul Haupt, Bern. 472 p.

Stoutjesdijk, P. (1959): Heaths and inland dunes of the Veluwe. A study of some of the relations excisting between soil, vegetation and microclimate. *Wentia* 2: 1-96.

Vera, F. W. M. (2000): Grazing ecology and forest history. Cabi publishing, Wallingford. 528 p.

Dendrochronological monitoring of air pollution in the Ghent canal area (Belgium)

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Introduction

The uptake of heavy metals is assumed to be a possible limiting factor for tree growth. In addition, it may also induce toxic effects. In the past, several studies have been conducted on the effect of industrial emissions on the growth of trees and the fixation of heavy metals in their wood (e.g. Baes & McLaughlin 1984, Stoeckhardt 1871 & Bakke 1913 in Cook & Kairiukstis 1990). Unfortunately, the results of this research are often contradictory. Furthermore, the past studies were mainly based on American tree species (USA) while this project focuses on three European, indigenous trees. In this study, we investigate the link between aerial pollution by heavy metals and the growth response of trees located in the heavily industrialized Ghent canal area (Belgium).

An important Belgian steel producing company is situated in the heart of the Ghent canal area and owns a forested area of approximately 250 ha within its operating limits. The tree-ring patterns and the content of heavy metals in the wood of three indigenous species, abundant in the industrial area (high emission values) and two nearby reference forests (lower emission values), were used to test the following hypotheses:

- Aerial emissions of heavy metals influence the tree-ring pattern of trees in and around the Ghent canal area.
- The content of heavy metals in the wood of trees in the Ghent canal area differs from the content in trees at the reference sites.
- Trees can be used to monitor aerial pollution by heavy metals over time.

Material and methods

Three indigenous tree species were sampled with an increment corer: 50 pedunculate oaks (*Quercus robur* L.), 30 beeches (*Fagus sylvatica* L.) and 30 pines (*Pinus sylvestris* L.). This sums up to a total of 110 trees on 11 sampling sites. Each sampling site contains 10 trees. One sampling site per forest and per tree species was chosen, with exception of the pedunculate oaks in the forest area of the steel producing company Sidmar NV (Ghent canal area). There, oaks from three sites were analyzed. The mean tree age per sampling site is given in table 1.

Table 1: Overview of the mean age of sampled trees per sampling site (unit: years).

	Pedunculate oak			Beech	Pine
Ghent canal area	71	76	76	91	64
Reference forest Kloosterbos	79	-	-	60	75
Reference forest Heidebos	77	-	-	96	57

The two reference forests, Kloosterbos and Heidebos, are situated 1 and 4.5 km eastward of Sidmar NV, respectively, and both of the reference forests have similar stand and soil properties. The selected species have a comparable age in all the sampling sites, except for the beeches of the Kloosterbos. They were all planted on dry sandy soils. Figure 1 visualizes the study area.

Figure 1: Study area (1: industrial site of Sidmar NV, 2: Kloosterbos, 3: Heidebos)

Per tree, two cores were taken to account for inter-tree variability (Watmough, 1999). The wood cores were dried and glued to avoid warping. After sanding, the tree rings became visible and ring-width series were measured using a digital positioning table (LINTAB, accuracy: 0.01 mm) and the corresponding software TSAP-Win (Rinn 2003). An average tree-ring series was calculated from the two cores of every tree.

Standardisation was performed with ARSTAN in order to remove the age trend and endogenous trends (Cook & Holmes 1999). Trees that didn't show any visual or statistical correlation (t-value Baillie-Pilcher < 4) (Baillie-Pilcher 1973) were not used to compose a site chronology. The remaining standardised ring-width series were used to build one site chronology per sample site. These site chronologies were compared with air pollution data, available for lead and zinc emissions, for a short period of 9 years. As an alternative approach to study the influence of climate and industrial pollution on the ring-width patterns, *pointer years* were identified using the method cited by Schweingruber et al. (1990). The *pointer years* that can not be explained by climate, might be related to exogenous factors like

air pollution, which also has strong year to year variations in the Ghent canal area (VMM 2002). Due to this strong variations, it will be difficult to detect chronic effects of pollution.

To analyze and quantify the content of heavy metals in wood, the cores were chipped and incinerated in a muffle furnace. The period under study for the chemical analyses spans from 1960 (six years before the onset of steel production) to 2004. After a chemical treatment with nitric acid (10% HNO_3), the metal content of the wood cores was measured with an atomic absorption spectrometer (AAS, type Perkin Elmer 3110). This device has a detection limit of 0.01 ppm and is used to determine the content of lead (Pb), zinc (Zn), copper (Cu) and cadmium (Cd). When it was difficult to obtain the minimum weight of 1 g for the analysis with AAS, several cores of different trees of one sample site were combined. This should be taken into account when interpreting the outcome of the analysis. Statistical analysis (One Way ANOVA) was used to examine significant differences between sample sites and sampled tree species.

Results and discussion

Pointer years and climate

Between the different sampling sites, there are few consistent *pointer years* identified for each species. Those consistent pointer years are marked in bold in table 2.

Table 2: Overview of the negative and positive pointer years (PY) per sample plot (the pine sample plot in Heidebos didn't produce any pointer years and is not included here). Years with an asterix (*) could not be explained by climate analysis.

Sample plot	Negative PY	Positive PY
Pedunculate oak Sidmar 1	1990	
Pedunculate oak Sidmar 2	**1996**	1975*
		1982*
Pedunculate oak Sidmar 3		1971
		1982
Pedunculate oak Kloosterbos		**1982**
		1997
Pedunculate oak Heidebos	1962	
	1975	
	1988	
	1995	
Beech Sidmar	1977	1993*
	1983*	
	1996	
Beech Kloosterbos	1976	1980
	1983*	1987
	1990*	1988
	1996	
Beech Heidebos	1936	1932
	1971	1994
	1984	1999*
	1996	
Pine Sidmar	1988*	1975
	1995	2002*
Pine Kloosterbos	1944	
	1981	
	1991	
	1996	

Only the negative *pointer year* 1996 is on the list of pan-European *pointer years* by Kelly et al. (2002). It should be taken into account that several definitions exist for the term *pointer year*. In the Kelly et al. (2002) study, a *pointer year* is determined when an extreme wide or narrow ring width is found in 75% of the samples. In our study, the definition by Schweingruber et al. (1990), with a threshold of 80%, was followed.

The site chronologies were compared to monthly rainfall and temperature data from June of the previous year until November of the present growing season. Correlation values of temperature with ring width are lower, compared to correlation with precipitation. This was already stated by Vitas (2004) and Lebourgeois et al. (2004). Generally, the influence of rainfall on growth of pedunculate oaks is most significant during the previous autumn and early winter (October to December). In the case of beech, the rainfall of the previous summer (June to August) determines tree growth, while for pine, the rainfall of the previous summer and early autumn (July to October) has the most significant influence. Precipitation accounts for a maximum of 25 % of the variance. An additional analysis was performed on the *pointer years*. Their relative growth changes (in %) were compared to the months with significantly related temperature and rainfall values. This way, the *pointer years* induced by climate, were separated and excluded from further research.

The link with industrial events and emission data series
Sidmar NV provided information on the emissions of heavy metals and a detailed history of the development of the steel company. First, the unexplained *pointer years* were compared with the start-up dates of some of the most important units with a risk of higher emissions. Since this kind of comparison is difficult to be proven statistically, it is not possible to draw clear conclusions. In addition, current influences of traffic and other companies in the area can not be excluded.

Another option is the study of year-to-year variability in radial growth and emissions of heavy metals in the air. Emission data for nine years (1995-2003) were available for lead and zinc. Unlike lead, zinc emissions proved to have a significant influence on the radial increment over this period (Fig. 2). The tree-ring series of every site of pedunculate oak (both Sidmar and reference sites) showed a consistent, significant, negative correlation with the trend in zinc emissions ($p < 0.05$). This means that high zinc emissions corresponded with low radial increments and vice versa. It was not expected that the correlation would also be significant at the reference sites. This might be the consequence of the considerable height of the emitting chimneys (50 to 72 m), causing a larger sphere of influence. Eklund (1995) and Watmough & Hutchinson (2003) carried out successful research on emission sources with a maximum height of 18 and 30 m, respectively. The modelling of the plume of smoke from different chimneys at Sidmar NV could determine if reference sites at a greater distance would be more useful.

Zinc is known to be an essential element for tree growth, what might clarify the link between zinc emissions and tree growth. Zinc takes part in the biosynthesis of enzymes, auxins and some of the proteins but is only needed in small amounts (Dmuchowski & Bytnerowicz 1995). An excessive amount of zinc may adversely affect the formation of growth hormones

like auxins, and therefore, may express itself as an influence on tree-ring widths. However, this hypothesis hasn't been proven yet.
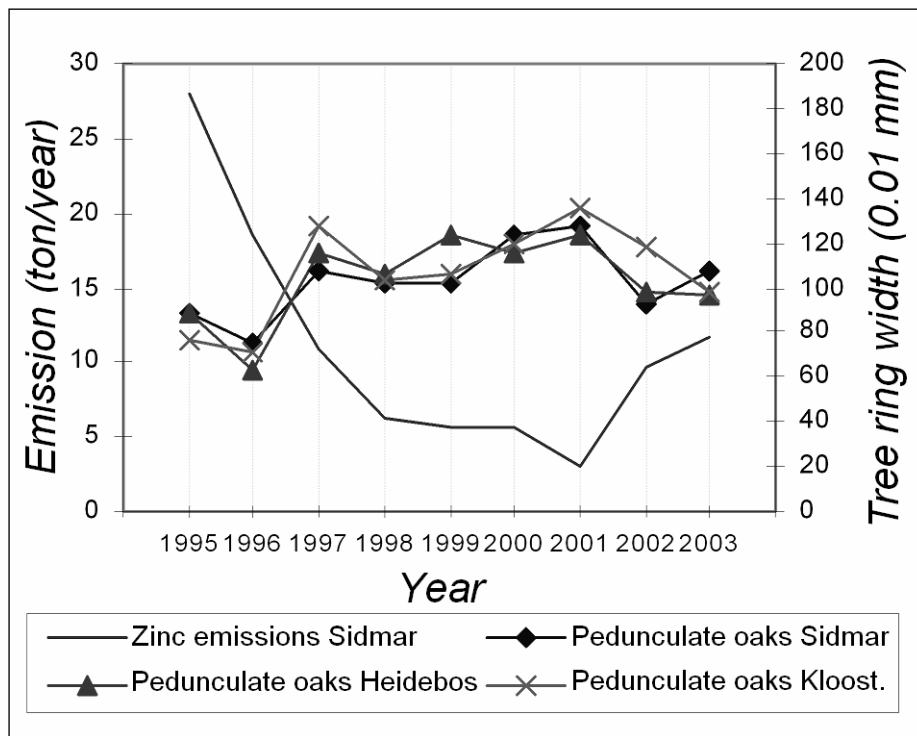

Figure 2: Air emission series of zinc versus the site chronologies of pedunculate oak (1995-2003)

Despite the significant results it is not advisable to draw a final conclusion on the influence of zinc on the tree rings of pedunculate oak. The emission data only covered a short period and was the result of different emission sources. A longer data set, based on the emissions of one source, can provide further evidence.

Chemical analysis
The content of lead, zinc and copper in the wood was measured. Since cadmium values are very close to the detection limit, they have not been included.
The content of lead in the wood of all the species, especially in oak, is extremely high. Latimer et al. (1996) found a lead content of 14 ppm on a site close to a refinery. This is low compared to the values in figure 3. One peak value in pine can be ascribed to lead shot but it is quite implausible to say that hunting is the main cause of the higher lead content in pedunculate oaks in and around the canal area. The explanation for the higher lead content and the within-site variation hasn't been investigated yet.
The average lead content shows the expected decrease with increasing distance from the emission source. However, the average lead content in pine shows the opposite pattern; more lead is found in Heidebos, the most distant reference forest. However, the content of zinc in pine decreases from Sidmar to Heidebos. The relationship between distance to the emission source and heavy metal content seems to depend on the species and on the element that is analyzed.
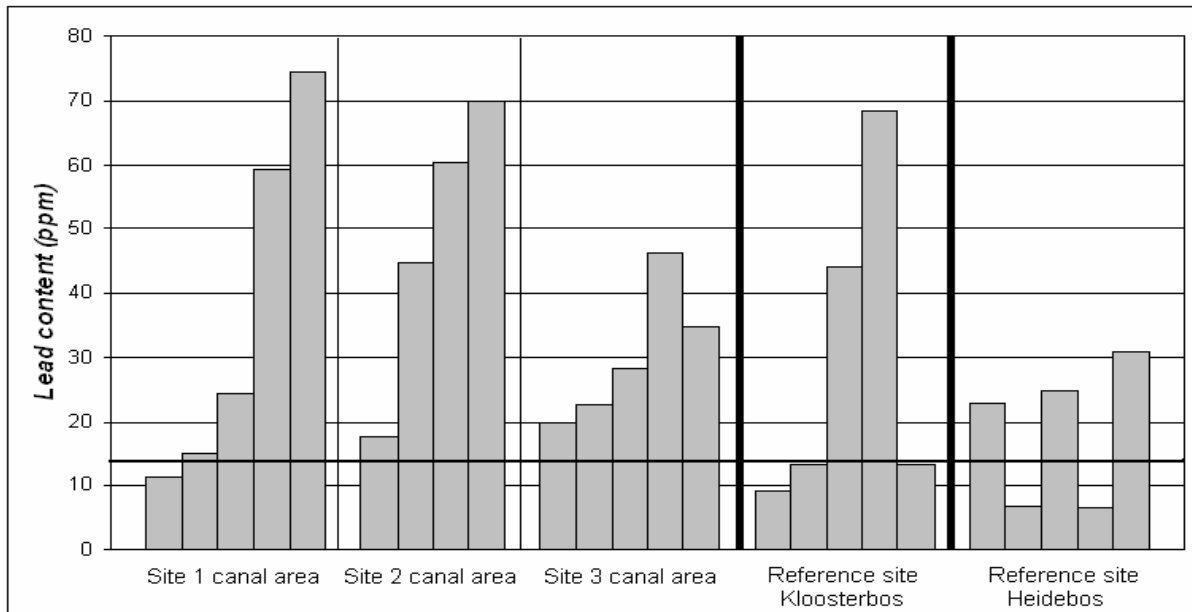
Figure 3: The content of lead in wood of pedunculate oaks (in ppm).
This graph shows the lead content for the period 1960-2004. To reach the detection limit for analysis with AAS, it was necessary lump two or three trees randomly within one site. Each bar represents one sample that passed chemical analysis. The horizontal line indicates the maximum lead content cited in previous research (Latimer et al. 1996). The thick vertical lines separate the three different forests while the thin lines separate the three sampling sites for oak in the Ghent canal area.

Apart from two peaks in the zinc content in pines, all values were situated within the range of previously published research. Latimer et al. (1996) and Schaumloffel et al. (1998) found a minimum of 1.7 and a maximum of 22 ppm zinc. The values in this study range from 2.5 ppm till 27 ppm. The content of copper in the Ghent canal area (1.8-6.1 ppm) is comparable with literature values (Watmough & Hutchinson 2003). Yet, less research has been done on copper because of the higher mobility of this element within the tree. The contents of zinc and copper are strongly correlated, possibly because they are both essential for tree growth. Lead and cadmium are not essential for tree growth and can quickly become toxic (Nabais et al. 1999).

Conclusions

In this study, research was done on the consequences of air pollution from industrial emissions on the growth-ring pattern of three native species and the accumulation of heavy metals in the wood. The following conclusions are drawn with respect to the three hypotheses:

- Emissions of heavy metals in the air influence the tree-ring patterns of trees inside and outside the Ghent canal area. This hypothesis is true for the element zinc, especially when regarding the radial growth of pedunculate oak. Zinc is an essential element for tree growth, taking part in the formation of growth hormones.
- The content of heavy metals in wood in the Ghent canal area differs from the content in trees at the control sites. Here, everything depends on the chemical element and the tree species.

- At present, it was not possible to determine one specific species as a monitor species for air pollution by heavy metals in the Ghent canal area.

The presented results can be considered as preliminary. Further research could include a model to determine the extent of the plume of smoke, longer emission series and more specialised equipment for chemical analysis so that the minimum required sample weight could be reduced and cores of different trees do not need to be combined. When longer emission series are available, research on the combined effects of climate and emissions could provide more detailed information on the growth of trees in industrial areas.

References

Baes, C.F., McLaughlin, S.B. (1984): Trace elements in tree rings: evidence of recent and historical air pollution. *Science 224:* 495-496.

Baillie, M.G.L., Pilcher, J.R. (1973): A simple cross-dating program for tree ring research. *Tree-Ring bulletin 33:* 7-14.

Bakke, A.L. (1913): The effect of smoke and gases on vegetation. *Proceedings of the Iowa Academy of Science 20*: 169-188.

Cook, E.R., Holmes, R.H. (1999): Users manual for program ARSTAN. University of Arizona, Tucson, USA. 12p.

Cook, E.R., Kairiukstis, L.A. (1990): Methods of dendrochronology. Applications in the environmental sciences. Dordrecht, Nederland, Kluwer Academic Publishers. 394p.

Dmuchowski, W., Bytnerowicz, A. (1995): Monitoring environmental pollution in Poland by chemical analysis of Scots pine (*Pinus sylvestris* L.) needles. *Environmental pollution 87*: 87-104.

Eklund, M. (1995): Cadmium and lead deposition around a Swedish battery plant as recorded in oak tree rings. *Journal of environmental quality 24(1)*: 126-131.

Kelly, P.M., Leuschner, H.H., Briffa, K.R., Harris, I.C. (2002): The climatic interpretation of pan-European signature years in oak ring-width series. *The holocene 12 (6)*: 689-694.

Latimer, S.D., Devall, M.S., Thomas, C., Ellgaard, E.G., Kumar, S.D., Thien, L.B. (1996): Heavy metals in the environment. Dendrochronology and heavy metal deposition in tree rings of baldcypress. *Journal of environmental quality 25(6)*: 1411-1419.

Lebourgeois, F., Cousseau, G., Ducos, Y. (2004): Climate-tree-growth relationships of *Quercus petraea* Mill. stand in the Forest of Bercé ("Futaie des Clos", Sarthe, France). *Annals of forest science 61*: 361-372.

Nabais, C., Freitas, H., Hagemeyer, J. (1999): Dendroanalysis: a tool for biomonitoring environmental pollution? *Science of the total environment 232(1-2)*: 33-37.

Rinn, F. (2003): TSAP-Win. Time Series Analysis and Presentation for Dendrochronology and Related Applications. User Reference. Heidelberg, Duitsland. 91p.

Schaumloffel, J.C., Filby, R.H., Moore, B.C. (1998): Ponderosa pine tree rings as historical monitors of zinc and cadmium pollution. *Journal of environmental quality 27(4)*: 851-859.

Schweingruber, F.H., Eckstein, D., Serre-Bachet, F., Bräker, O.U. (1990): Identification, presentation and interpretation of event years and pointer years in dendrochronology. *Dendrochronologia 8*: 9-38.

Stoeckhardt, A. (1871): Untersuchungen über die schädliche Wirkung des Hütten- und Steinkolenrauches auf das Wachstum der Pflanzen, insbesondere der Fichte und Tanne. *Tharandter Forstliches Jahrbuch 21:* 218-254.

Vitas, A. (2004): Tree rings of Norway spruce (*Picea abies* (L.) Karsten) in Lithuania as drought indicators: dendroecological approach. *Polish journal of ecology 52(2)*: 201-210.

VMM (2002): Lozingen in de lucht 1980-2001. Aalst, België, Vlaamse Milieumaatschappij. 364 p.

Watmough, S.A. (1999): Monitoring historical changes in soil and atmospheric trace metal levels by dendrochemical analysis. *Environmental pollution 106(3)*: 391-403.

Watmough, S.A., Hutchinson, T.C. (2003): A comparison of temporal patterns in trace metal concentration in tree rings of four common European tree species adjacent to a Cu-Cd refinery. *Water, air and soil pollution 146(1-4)*: 225-241.

Nature conservation – influencing factor on radial tree growth? A conceptual approach of a new project

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Introduction

In line with an increasing ecological awareness in our society, nature conservation gains of importance. Due to the lack of economical demands in protected areas these areas are characterized by different conditions for tree growth compared to conventionally managed forests. On the one hand there is a climatic effect common to both protected as well as economically used forests. This effect can be quantified in different temporal sequences like for example pointer years, year-to-year or decadal variations and long term trends. On the other hand nature conservation might have a contrary effect on growth like forestry. One important difference is the absence of sudden increases in growth triggered by cutting of surrounding trees. As a consequence, a dissimilar tree growth, as investigated by tree ring width, will be expected in protected areas. These considerations result in the following questions:

- In which way does the protection of forest sites affect radial tree growth?
- Are there differences triggered by conservation measures, tree species or site ecological conditions?
- Will it be possible to separate the conservation signal from the climatic one? Do there exist changed climate/growth relationships for different temporal frequencies?

Strategy

Sampling will take place in both, protected and non protected areas. According to Schweingruber (1996) two samples of 12 to 15 trees per site and tree species will be taken. Thereby it will be aspired to include the whole spectrum of woodland types represented by, for example, different altitudes, expositions, soils and tree species. Only trees of an age of 100 years and older - due to statistical considerations - will be investigated.

In order to determine the impact of nature conservation, the dataset will be subdivided into two time intervals of 30 years: one before and one after the onset of conservation measures. For each time period a certain grouping is planned. Thereby it will be necessary to test the appropriate methods - cluster analysis (Neuwirth 2005) or principal component analysis (PCA) according to Wilson et al. (2001) or a combination of both. The resulting groups should combine sites with similar growth behaviour. This growth behaviour will be quantified with regard to different aspects:

- change of the average growth, for example within a nine year moving average;
- extreme years, e.g. z-transformed Cropper-values (Neuwirth 2006);

- site internal homogeneity expressed by statistical parameters like NET (Esper et al. 2001) or Gleichläufigkeit (Schweingruber 1985);
- similarity of growth behaviour, for example the Cross-Date Index (Rinn 2005);
- decadal variations, investigated with a 13 year moving average;
- long-term growth trend behaviour.

Afterwards, the attributes of the different groups have to be interpreted with regard to meta-data including site-specific information (see the following chapter). Subsequently, single year and time series analyses will be applied to evaluate the climate/growth relationship. The separation of the conservation signals will be carried out by comparing the results with those of a similar group analysis of the whole period under investigation.

Research area and Database

As research area Nordrhein-Westfalen and surrounding environs have been chosen. This decision is based on two aspects. At first, Nordrhein-Westfalen shows a multitude of topographical variations due to its location at the transition of North German Plane to the low mountain range. Secondly, due to the establishment of so called "Naturwaldzellen" (NWZ) in Nordrhein-Westfalen since the 1970´s by order of the Landesamt für Ökologie, Bodenordnung und Forsten (LÖBF) (see circles in figure 1) there exists a comprehensive ecological dataset resulting from a special kind of bio-monitoring for these sites.
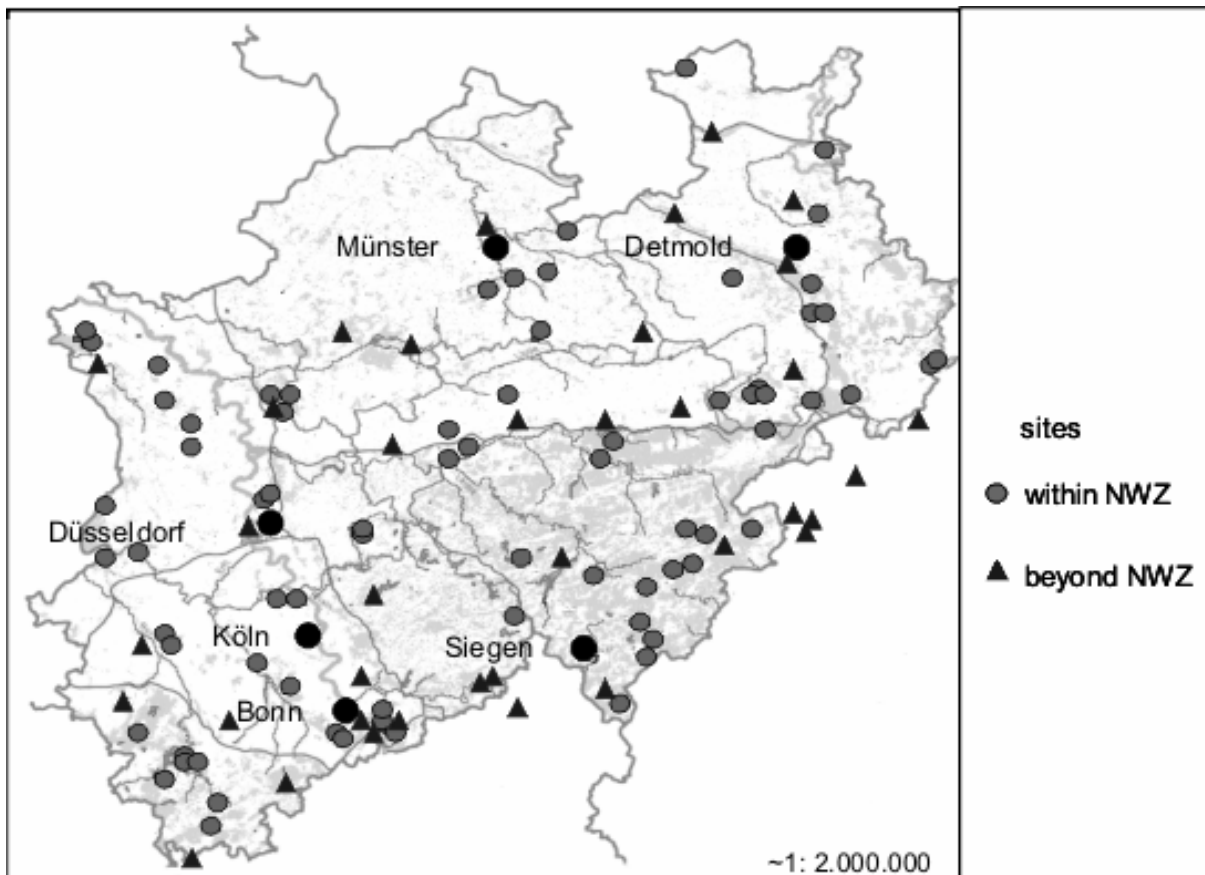

Figure 1: Research area of Nordrhein-Westfalen and surrounding regions with positions of protected (circles) and non protected sites (triangles). Every signature can include some chronologies, one for each tree species (altered after Schulte & Scheible 2005).

The NWZ are ecological forest test areas to control and understand natural tree growth. Any kind of human impact like forestry or collecting plants is strongly prohibited in these parcels. They should represent the most important woodlands concerning tree species, altitude, soil, flora, fauna, and other environmental and ecological factors and conditions.

Within this study a special dendroecological database consisting of dendrochronological, climatic and so called meta-data will be established. Concerning the dendrochronological part, the main focus will be set on collecting samples in the NWZ. In addition, data of the network of the dendrochronological working group at the University of Bonn (see triangles in Fig.1) will be used. In total, the network will include more than 200 chronologies for the important species in NRW (*Fagus sylvatica*, *Quercus robur*, *Quercus petreae*, *Picea abies,* and *Pinus sylvestris*). Climatic information will be supplied by the Climate Research Unit in Norwich (Mitchell et al. 2004). GRID data are available for the time span from 1901 to 2004 in a monthly resolution and a spatial resolution of 10 minutes. These data will be completed by daily data of the German Meteorological Service.

The meta-data include on the one hand site ecological information, like tree species, soil type, and altitude as well as information about conservation measures.

Aims and Potentials

With this presented strategy it will be possible to reach the following goals:

- completion of the forest ecological database of the LÖBF with tree-ring data;
- regional study of climate/growth relationship for NRW;
- new forest classification, e.g. a classification according to similar growth behaviour of trees derived from different sites;
- growth reaction on protection of woodland;
- a catalogue listing the effects of different conservation measures on radial tree growth; in this manner the conservation signal in the growth behaviour of trees at different sites (altitude, varying time of protection started, etc.) will be considered with regard to distinct conservation intensities of the sites, like NWZ, FFH, etc.

This project supplies a basis to create forest growth models and can also serve as decision tool to choose suitable conservation measures.

References

Esper, J., Neuwirth, B., Treydte, K. (2001): A new parameter to evaluate temporal signal strength of tree-ring chronologies. Dendrochronologia 19 (1).

Mitchell, T. D., Carter, T. R., Jones, P. D, Hulme, M., New, M. (2004): A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Tyndall Centre Working Paper No.55.

Neuwirth, B. (2005): Interannuelle Klima/Wachstums-Beziehungen zentraleuropäischer Bäume von AD1901 bis 1971 – eine dendroklimatologische Netzwerkanalyse. Dissertation Uni Bonn, 162 pp. (http://ulb.uni-bonn.de/diss_online/)

Neuwirth, B., Schweingruber, F.H., Winiger, M. (2006): Spatial patterns of Central European pointer years. *Dendrochronologia* (in press).

Rinn, F. (2005): TSAP-WIN. Time Series Analysis and Presentation for Dendrochronology and Related Applications. Version 0.53 for Microsoft Windows. User Reference.

Schweingruber, F. H. (1985): Dendro-Ecological Zones in the Coniferous Forests of Europe.*Dendrochronologia 3*: 67-75.

Schweingruber, F. H. (1996): Tree rings and environment - Dendroecology. Paul Haupt, Bern, Stuttgart, Wien: 609.

Schulte, U., Scheible, A. (2005) (Hrsg.): Atlas der Naturwaldzellen in Nordrhein-Westfalen. Landesanstalt für Ökologie, Bodenordnung und Forsten des Landes Nordrhein-Westfalen. Recklinghausen.

Wilson, R. J. S., Hopfmueller, M. (2001): Dendrochronological investigations of Norway spruce along an elevational transect in the Bavarian Forest, Germany. *Dendrochronologia 19*: 67-79.

The influence of wood ants on forest tree growth

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Introduction

The impact of wood ants' activity (*Formica polyctena*, Foerster) on the growth of the Norway spruce (*Picea abies* (L.) Karst.) was studied in Central Bohemia. The ants (*Formicidae*) are regular members of forest ecosystems. Not only they are important predators, they also support aphid populations and honeydew production, and have a significant influence on the physical, chemical and biological properties of the soil. They change the physical properties of the soil by transporting lower soil layers to the surface. The chemical content of the nest material is modified by the excrements the ants produce, as well as by the residuals of their nourishment and by the transportation of organic material which occurs as they are building their nests. That is why a considerable amount of nutrients (P, N, K etc.) is concentrated in their nests. Subsequently they spread these nutrients around the nest. The accumulated amount of phosphorus in a nest can be four times as high as in the soil around the nest (Frouz 1997). The temperature inside the nest is higher than the temperature outside the nest. As a result, the microbial degradation of organic to the inorganic compounds occurs faster and the accessibility of the nutrients in the soil is therefore increased. Besides temperature, the pH is another important factor that has an influence on the speed of organic compound degradation. Phosphorus is more accessible for plants in neutral or slightly acidic soils. Due to the ants' activity the pH in the nest is shifted towards the neutral value. Since the higher number of aphids results in a higher production of honeydew that is transported to the nest, the attacked tree's ring increments are lower (Rosengeren & Sundström, 1991). The overall impact of the ants' activity on plants is influenced by the nest density, the number of workers and their territory (Frouz et al. 2005, Frouz 2002). The tree growth is affected by the amount of accessible soil nutrients (Procházka et al. 1998). Since ATP is used for the biosynthesis of many plant biomolecules, phosphorus is important for the growth of plants and the flower/seed formation. Potassium regulates the opening and closing of the stoma by a potassium ion pump. Since stomata are important in water regulation, potassium reduces water loss from the leaves and increases drought tolerance. Calcium constitutes a part of the cell walls. It also regulates the transport of other nutrients into the plant. Nitrogen is an essential component of all proteins, and as a part of DNA, it is essential for growth and reproduction. Nitrogen deficiency typically results in stunting (Mengel & Kirkby 1987).

Given the above mentioned ants' influence on the concentration of nutrients in the soil, we came to the conclusion that the ants' activity might influence the growth of the trees near

their nest. On this assumption we proceeded to explore the effects of ants' activity on the soil and forest trees growth, using soil and tree-ring analysis as assessment tools.

Material and methods

The study was conducted in a spruce dominated forest (49° 27′ 53" N, 14° 49′ 43" E) with a large complex of *Formica polyctena* nests. The examined sites were situated and classified as follows:

- A1: trees located directly in the ant nest or within 1 m from the nest,
- A2: trees located at a distance of 1–5 m from the nest
- B: trees located at a distance of 5–50 m from the nest,
- C: trees growing at control sites, 100–300 m from the closest ant nest.

The soil samples collected at the above listed sites were taken from a layer of 0 – 5 cm under the surface. The pH was measured in a water solution (1:5 sample:water ratio), the available P by the ion exchange technique, and the available K, Na, Ca, and $N-NO_3^-$ by the ion selective electrodes in a 1% citric acid solution. To determine the statistical significance between particular variables in the soil analysis, the Statsoft Statistica 6.0 software was used. The results were evaluated by means of the multi-factorial analysis ANOVA.

The collection of wood samples was carried out with a Pressler increment borer. In total more than 80 samples were analysed from the vicinity of ten nests. The annual ring widths were measured using a special measuring table with a stereomicroscope. The tree-ring analysis was performed by the PAST software. The rings were measured to the nearest 0.01 mm. The tree rings analyses were performed according to the standard dendrochronology methods (Cook 1990). The degree of the resemblance between the mean curve and the standard chronology was assessed in terms of the correlation coefficient and the coefficient of parallel variation.

Results

A statistically significant difference in the mean pH of the soil was observed between A1 and B sites and between A1 and C sites (Fig. 1). None of the other sites showed any statistically significant differences.
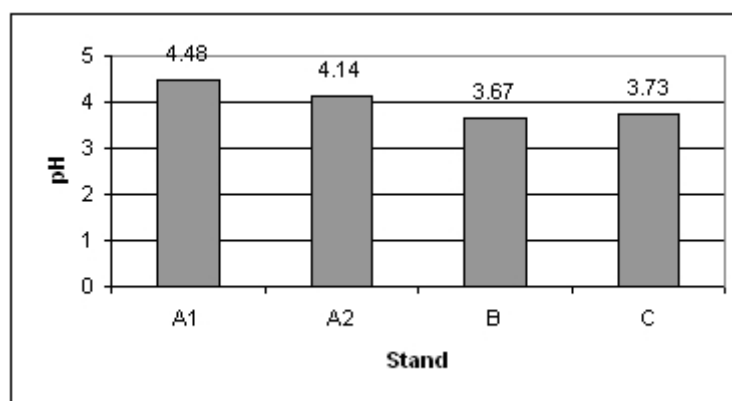

Figure 1: The pH of soil at different sites.

The biggest amount of accessible phosphorus was detected at the A1 site. The phosphorus levels at the A1 site were at least 2.6 times higher in comparison to the B site and at least 3.3 times higher as on the C site (Fig. 2). The mean value of the phosphorus content at the A1 site showed a statistically significant difference, compared to the other sites.
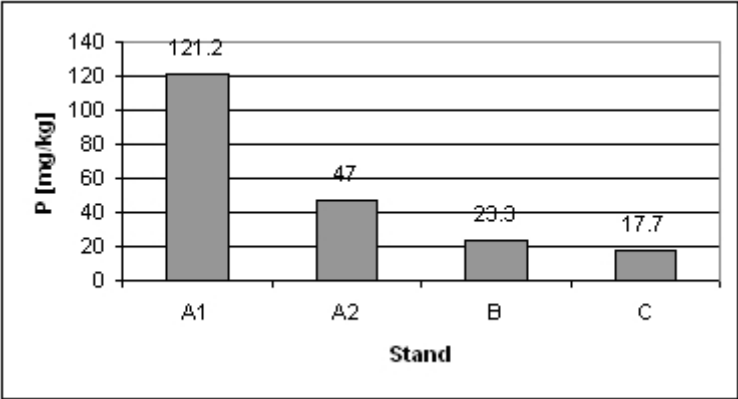

Figure 2: The content of P in soil from different sites.

The mean value of $N-NO_3^-$ content at the A1 site proved to be statistically different in comparison to the other sites. There were no mutual statistically significant differences in $N-NO_3^-$ content among the remaining sites (Fig. 3).
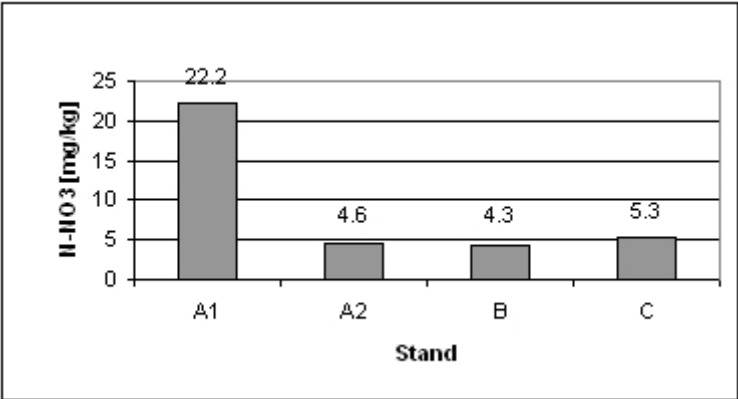

Figure 3: The content of $N-NO_3^-$ in soil from different sites.

The maximum content of potassium was detected at the A1 site. There was an evident decrease in the mean amount of potassium related to the growing distance between the A1 site (the ant nest) and the examined sites (Fig. 4). The statistic tests pinpointed statistically significant differences in the mean potassium amount between the A1 and B sites and between the A1 and C sites.
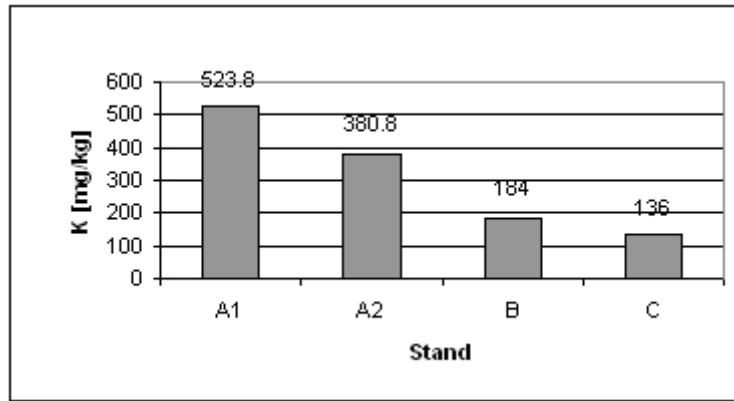
Figure 4: The content of K in soil from different sites.

The maximum mean value of sodium was detected at the A2 Site (Fig. 5). However, it was demonstrated by ANOVA that there is no statistically significant difference between the different sites.
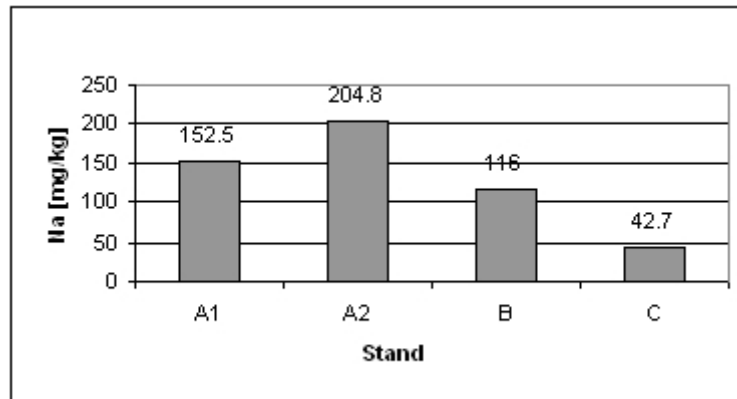

Figure 5: The content of Na in soil from different sites.

The A1 and A2 sites display high mean values for calcium content in the soil. The B and C sites showed lower values, however, there were no significant differences in the amount of calcium between the sites (Fig. 6).
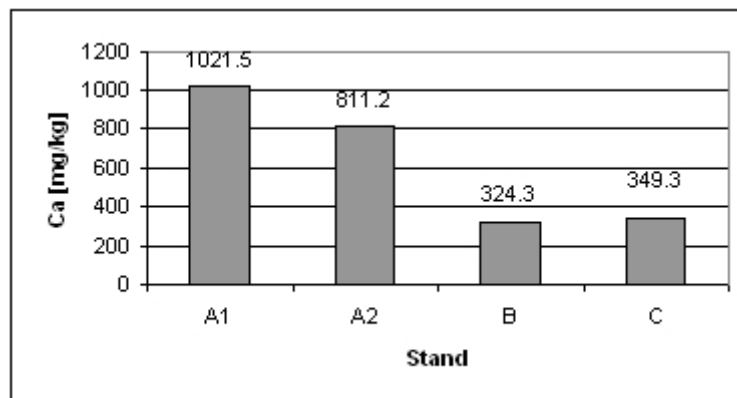

Figure 6: The content of Ca in soil from different sites.

The results of the dendrochronological analysis showed that the mean value of the annual ring width (2.178 mm) at the A1 site (distance from the nest up to1 m) is higher in comparison with the A2 (1.916 mm) and B (1.922 mm) sites. The control site showed the mean value of the annual ring width at 2.499 mm. As ascertained by ANOVA, the sites showed statistically significant differences in mean ring width.

It is evident that there had been a 20-year period of a very low ring width increment at the A2 site. A different growth trend occurred over the last 10 years where ring width gradually increased. The trees from the B site show lower ring width values all the time. Trees from the control site (C) show higher ring widths over the whole examined time span (Fig. 7).
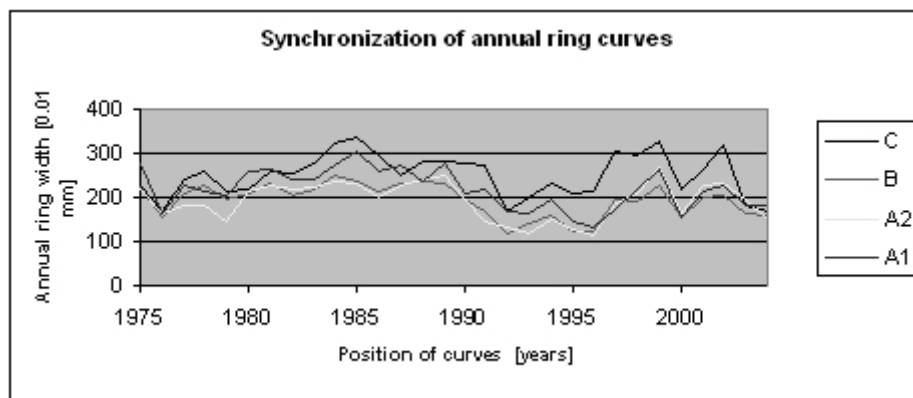

Figure 7: Synchronization of annual ring curves from different sites.

Discussion and conclusions

Our research has showed that the ants' activity shifts the pH of soil towards the neutral value. The increase in the pH to slightly acid or neutral levels results in a higher accessibility of phosphorus in soil. It has been demonstrated that the ants' activity increases the content of some nutrients in the soil (P, K, N). The highest content of the accessible phosphorus has been identified in the nest (A1 Site), which is a conclusion that is underpinned by other soil analyses (Frouz 2002). It is evident that the content of phosphorus in the nest is significantly higher than at the other sites. As far as the content of $N-NO_3^-$ is concerned, the values are similar. The highest levels have been measured within the nest. Furthermore, it was found that $N-NO_3^-$ levels decrease with an increasing distance from the nest. The highest mean value of potassium was both encountered at the A1 and A2 sites. This means that the ants have an influence on potassium content not only in the nest itself but also in its vicinity. The statistical analysis on nutrient content in soil demonstrates the influence of wood ants' activity (*Formica polyctena*, Foerster) on the pH value, as well as on the P, N and K levels. No statistically significant difference has been observed in the content of the other monitored nutrients.

The ring width analyses have revealed that the trees located directly in the ant nest or in its immediate vicinity (within 1 m from the nest), i.e. the A1 site, have a higher radial increment than trees located at a distance between 5 and 50 m from the nest (B site). Nonetheless, the trees within 1 m from the ant nests have a lower increment of the ring widths compared to

the trees growing at the control sites without the presence of wood ants (about 300 m from the closest nest). We suppose that the highest increment of the ring widths at this site can be put down to the lack of aphits. The presence of aphits may be considered as a stress factor.

All the achieved results are in compliance with Rosengren and Sundström (1991). To summarize, the study has demonstrated that the tree growth might be affected by a complex influence of the ants' activity.

Acknowledgement

References

Cook, E.R., Kairiukstis, L.A. (1990): Methods of Dendrochronology. Dordrecht: International Institute for Applied Systém Analysis. 393.

Drápela, K., Zach, J. (2000): Dendrometrie (Dendrochronologie). Brno: Mendel Univ. of Agriculture and Forestry Brno. 152.

Frouz, J. (2002): Úloha mravenců v půdních procesech. *Formica, 2002:* 27–33.

Frouz, J., Holec, M., Kalčík, J. (2003): The effect of Lasius niger (Hymenoptera, Formicidae) ant nest on selected soil chemical properties. *Pedobiologia, 2003, č. 47:* 205–212.

Frouz, K., Kalčík, J., Cudlín, P. (2005): Accumulation of phosphorus in nests of red wood ants *Formica s. str. Helsinky: Ann. Zool. Fennici 42, 2005:* 269–275.

Frouz, J., Šantrůčková, H., Kalčík, J. (1997): The effect of wood ants (Formica polyctena Foerst.) on the transformation of phosphorus in a spruce plantation. *Pedobiologia, , č. 41*: 437–447.

Hölldobler, B., Wilson, E.O. (1997): Cesta k mravencům. Praha: Academia. 192.

Rosengren, R., Sundström, L. (1991): The interaction between red wood ants, Cinara aphids, and pines. A ghost of mutualism past? In: *Ant – Plant Interactions*. New York: Oxford University Press: 80–91.

Procházka, S., Macháčková, I., Krekule, J., Šebánek, J. (1998): Fyziologie rostlin. Praha: Academia. 484. ISBN 80-200-0586-2

Mengel, K., Kirkby, E.A. (1987): Principles of plant nutrition. International Potash Institute, Bern, 687 p., ISBN 3-906-535-03-7

Effects of water availability on the growth and tree morphology of *Quercus pubescens* Willd. and *Pinus sylvestris* L. in the Valais, Switzerland

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Introduction

Problem statement

Since climate affects forests in many different ways, assessing the impact of climate change on forest ecosystems presents a major scientific challenge. Drought is an important climate factor, which influences tree-growth as well as morphological and functional features of trees (Floret et al. 1990). For the Valais a significant warming during the past century was reported (Rebetez & Dobbertin 2004, Begert et al. 2005). The expected future warming (IPCC 2001) could aggravate a higher frequency and intensity of drought conditions in the Valais, which would have negative effects on the growth and survival of Pubescent oak and Scots pine due to an increased risk of stress to the hydraulic system. Since the end of the last century a high mortality of Scots pine has been observed in the Valais whereas sub-Mediterranean species such as *Quercus pubescens* are spreading (Eilmann et al. 2006).

Approach

To better understand drought-tolerance mechanisms in *Quercus pubescens* and *Pinus sylvestris* in the Valais we studied tree morphology, tree growth, and wood-anatomical features of both species growing at two sub-sites with a different water regime, i.e. along a water channel running through a dry hill with South exposition (wet) and at some distance from the water channel (dry). Tree morphology at the dry and wet site was compared. Classical dendrochronological techniques were applied to trace those weather/climate factors that mainly influence the growth of oak and pine under wet and dry site conditions in the Valais.

Objective

Tree growth and hydraulic architecture of oak and pine from a dry and a wet site, respectively are determined. Differences are discussed in order to gain (i) a better understanding of the impact of water supply and changes in water supply during the growing season on tree-ring formation (ii) insight into drought response in hydraulic architecture in both species.

Material and Methods

Study area

The study was carried out in the south exposed slopes located in the Rhone valley in Valais Switzerland (Fig. 1). The field data was collected in two sites (*wet,* directly at the water channel and *dry*, far away from the water channel) in Salgesch (46°19'27" N, 7°34'40" E) at an elevation of 975m a.s.l. (Fig.2).
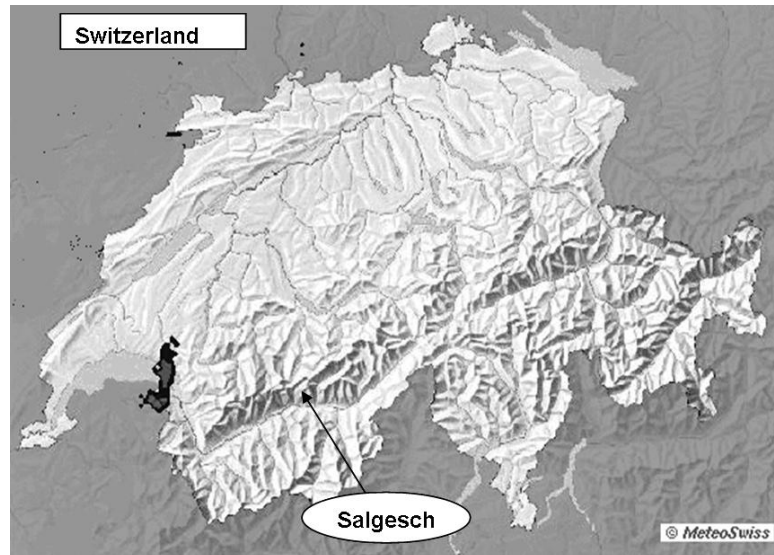
Figure 1: Study area

Figure 2: Location of wet and dry sites
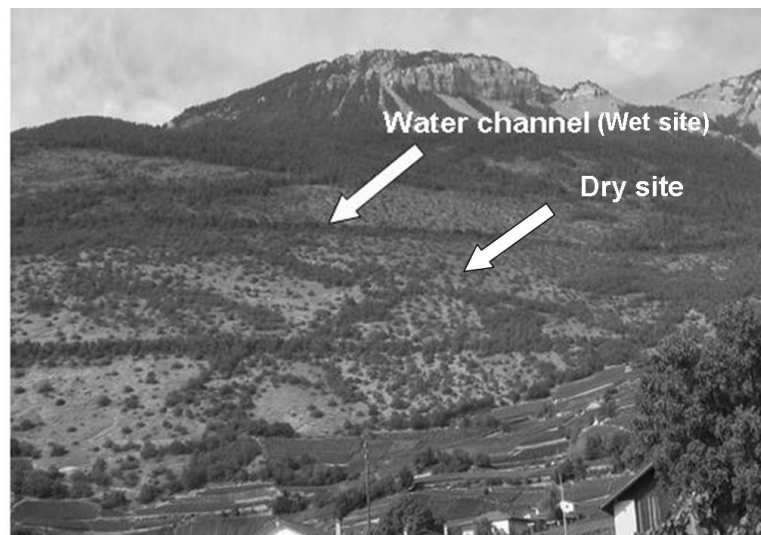
The Wallis is an inner-alpine valley with a dry climate because of its East-West direction that prevents it from wet air from the South and the Northwest, the main directions of air streams in the Swiss Alps. According to the FAO classification system the soil of this area is classified as a rendzic leptosol on solid rock limestone and with low water-holding capacity (Rigling et al. 2002).

Climate

Data records were obtained from the meteorological station at Sion, about 20 km from the study site and at an elevation of 547m. Annual precipitation amounts to 664 mm per year with a monthly maximum in summer (Fig.3). The annual mean temperature is 9.7^{0}C. Winter precipitation has great importance on the water regime of the channel (Rigling et al. 2002). Drought periods frequently occur in summer and can last several weeks (Kuhn 1973). At that time even the channel can fall dry. To quantify the drought severity, monthly drought indices are calculated (Bigler et al. c.f. Eilmann et al. 2006). The monthly drought index is defined as the difference between monthly precipitation and the monthly potential evapotranspiration (Thornthwaite 1948). From these monthly indices an annual drought index was calculated by taking the monthly index values from September of the previous year to August of the current year. Drought years are indicated by negative values; mesic years by positive values.
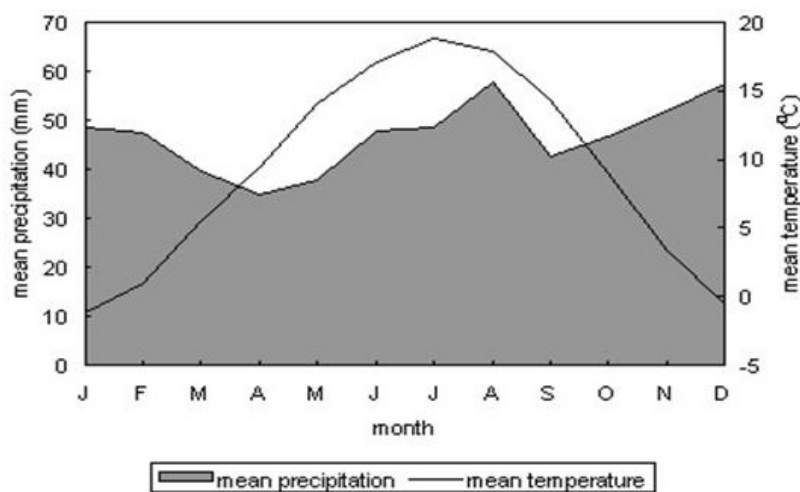

Figure 3. Mean sum of monthly precipitation and mean monthly temperature as recorded at Sion Station, Switzerland (CLIMAP, METEOSWISS).

Study trees and data collection

For this study *Quercus pubescens* (Pubescent oak) was selected as a representative of a broadleaved tree species and *Pinus sylvestris* (Scots pine) as a conifer. Twenty individuals of each species (ten from each site) were selected on the basis of similar diameter (DBH). Table 1 gives a survey about the variables that were measured and calculated.

Table 1: Measured variables

	Variables
Tree morphology *visual inspection*	DBH, tree height, height of lowest (green) branch, crown radius
Leaf area *Measured with image-analysis system*	Average leaf area (LA), average leaf mass (LM)
Radial tree growth *Measured from cores with dendrochronological equipment*	Tree ring (RW), earlywood (EW) and latewood (LW) width
Wood anatomy *Measured from cores with image-analysis system*	Sapwood area, conduit (vessel, tracheid) area and conduit (vessel, tracheid) density

Tree-morphology variables were measured in the field. Average leaf area was measured from a collection of leaves by using an automated image analysis system and the *Image Tool* software (Version 3.0). Tree-ring width (RW), earlywood width (EW) and latewood width (LW) was measured and analyzed by using standard dendrochronological methods (programs *TSAP,* Rinn 1996, *COFECHA,* Holmes 1983). Wood anatomical features were measured from digital photographs by using *Image Tool, Version 3.0.* Measurements were taken from cross sections prepared with razor blades, soaked with 10% NaOH and chalked. Digital images were taken with a digital camera (*Leica* DFC320). Ten earlywood and 10 latewood conduits (vessels/tracheids) were randomly selected per tree ring and the radial diameter was measured in a sequence of seven consecutive tree rings with *UTHSCSA Image Tool* software (Version 3.0). Earlywood- and latewood conduit density was measured as the numbers of vessels per square millimeter on the transverse section in successive measuring frames of 450 x 2000 µm.

Statistical analysis

To calculate relationships between the tree morphology, leaf area, tree growth and wood anatomy in relation to site conditions, i.e. wet and dry, General Linear Model (GLM) was used (*SPSS for Windows, Version 10.1*).

Statistical characterization of the RW, EW and LW tree-ring series was done by calculating *Mean RW, EW, LW, Mean Sensitivity, and EPS.*

Dendroclimatological analysis was done by using correlation analysis (*DendroClim 2002*; Biondi & Waikul 2004). RW, EW and LW tree-ring chronologies (derived from the single tree-ring series after detrending with a 30-year moving average, *TSAP* program) of oak and pine from the wet and dry sites were compared with monthly mean temperature and monthly sum of precipitation records from the climate station Sion. The reference period was set to 1950 to 2004 and we included temperature and precipitation data from October of the previous year to September of the actual year.

In the wood anatomical analysis the size and density of the conduits was visually compared to the annual drought index (previous September to current August) throughout the 7-year investigation period.

Results and Discussion

Morphological and wood-anatomical variables at the wet and dry site

Morphological traits and wood-anatomical variables differ significantly between oaks and pines at the wet and the dry site (Fig. 4). The General Linear Model (GLM) yielded significant values for site effect in both oak and pine for all morphological (trees size, leaf parameters), growth (RW, EW, LW width) and wood-anatomical (sapwood area, conduit size and density) variables (results not shown).

Oberhuber et al. (1998) and Rigling et al. (2002) observed the same trends in changes of DBH and leaf area for Scots pine in an inner alpine dry valley of Austria and in the Valais. They found that leaf area increased with DBH because larger trees maintain their energy balance for physiological needs by increasing the photosynthetic area. This size differences

are most likely related to hydraulic limitations (Ryan & Yoder 1997) in both species due to (temporary) higher water stress at the dry site.

Dendrochronological results

In total 12 tree-ring chronologies (RW, EW and LW chronologies for each species at each site) were constructed for oak and pine. The chronologies of the wet and dry site are very similar for both species (Fig. 5) suggesting that tree growth in both sites is triggered by the same environmental factor(s) (Fig. 6). Mean tree-ring width was smaller in the dry site in comparison to the wet site in both species (Tab. 2). The generally higher growth rate of pine might be related to its phenological characters: pine produces needles which remain between one to five years on the branch (Kurkela & Jalkanen 1990) whereas oak is deciduous and needs to renew its leaves every year.

Mean sensitivity was higher for the tree-ring (RW, EW, LW) chronologies of oak and pine at the dry site which indicates a stronger relation to annually changing environmental conditions such as precipitation. This fits the assumption that the oaks and pines at the wet site profit from the effect of ample water supply from the water channel buffering the effect of precipitation. As can be expected from high values of mean sensitivity the autocorrelation was generally low in both species and at both sites. Interestingly, the autocorrelation was slightly higher at the dry site for both oak and pine. This is most likely due to the occurrence of prolonged growth depressions in both oak and pine at the dry site in response to drought years or drier periods (Fig. 5). The *Expressed Population Signal* (EPS) of the pine and oak chronologies indicates that the number of study trees is well chosen to represent the tree collectives (Briffa & Jones 1990). If comparing the 'signal strength' of the RW, EW and LW chronologies in *Q. pubescens* it is striking that mean sensitivity of the EW chronologies is in the same range as for RW and LW. Together with high values in EPS this indicates that annual changes in EW width reflect a strong environmental signal. This phenomenon has also been observed by Eilmann et al. (2006). *Q. robur* and *Q. petraea* from temperate sites in NW Europe are known to show a low mean sensitivity and only weak 'common ´signal´ in EW time series (Eckstein & Schmidt 1974).
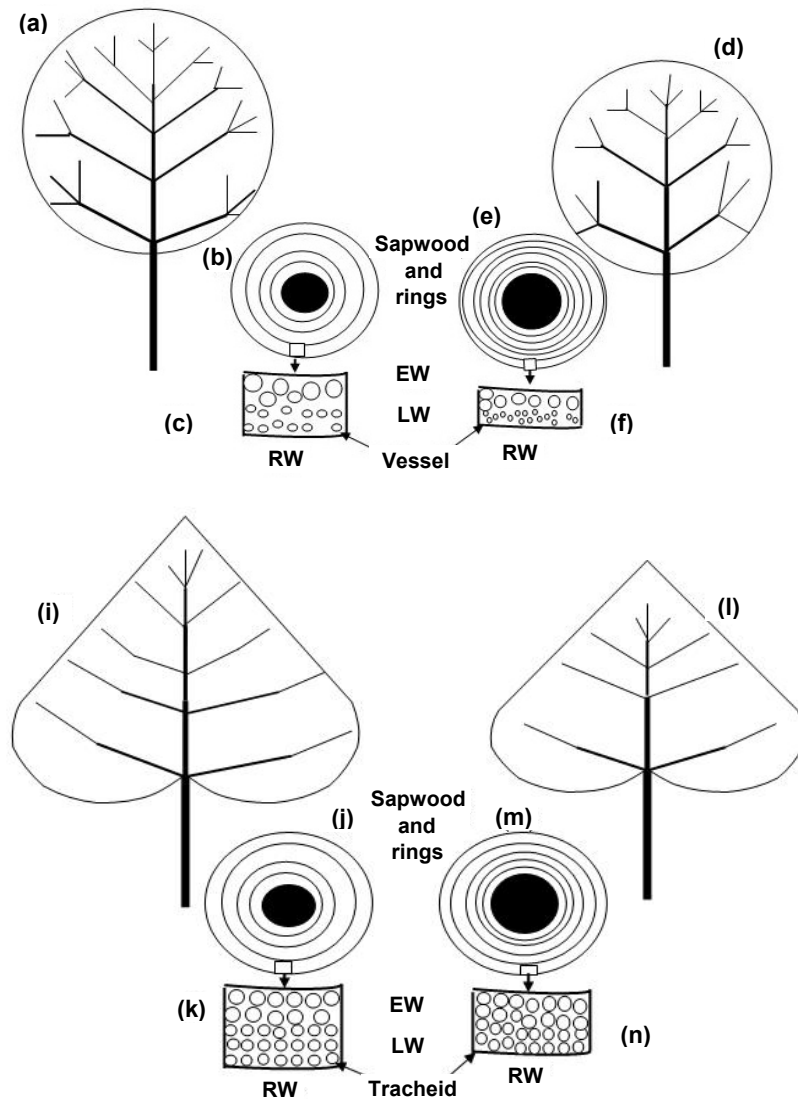
Figure 4: Difference in morphological and anatomical traits (a) oak wet, (d) oak dry, (i) pine wet and (l) pine dry; sapwood area and sapwood rings, (b) oak wet, (e) oak dry, (j) pine wet and (m) pine dry; RW, EW, LW, vessel and tracheid, (c) oak wet, (e) oak dry, (k) pine wet and (n) pine dry.

Table 2. Descriptive statistics of ring width (RW), earlywood width (EW) and latewood width (LW)

Species	Site	variables	Mean [mm]	mean sensitivity	autocorrelation	EPS
Oak	wet	RW	1.00	0.42	0.26	0.85
		EW	0.55	0.45	0.08	0.83
		LW	0.45	0.44	0.34	0.86
	dry	RW	0.71	0.39	0.36	0.86
		EW	0.30	0.37	0.29	0.85
		LW	0.41	0.51	0.30	0.83
Pine	wet	RW	1.19	0.35	0.20	0.88
		EW	0.71	0.36	0.20	0.86
		LW	0.48	0.39	0.11	0.85
	dry	RW	1.10	0.40	0.28	0.87
		EW	0.50	0.43	0.27	0.85
		LW	0.60	0.44	0.15	0.82

Dendroclimatological results

The ring width (RW) chronologies of both oak and pine (Fig. 5) indicate severe drought years in 1921, 1934, 1944, 1949, 1964, 1972, 1976, and 1998 as reflected by a sharp reduction of ring width in these years. Rigling et al. (2002), Eilmann et al. (2006) and Zweifel et al. (2006) found the same climate-growth response in oak and pine from the same area in the Valais.
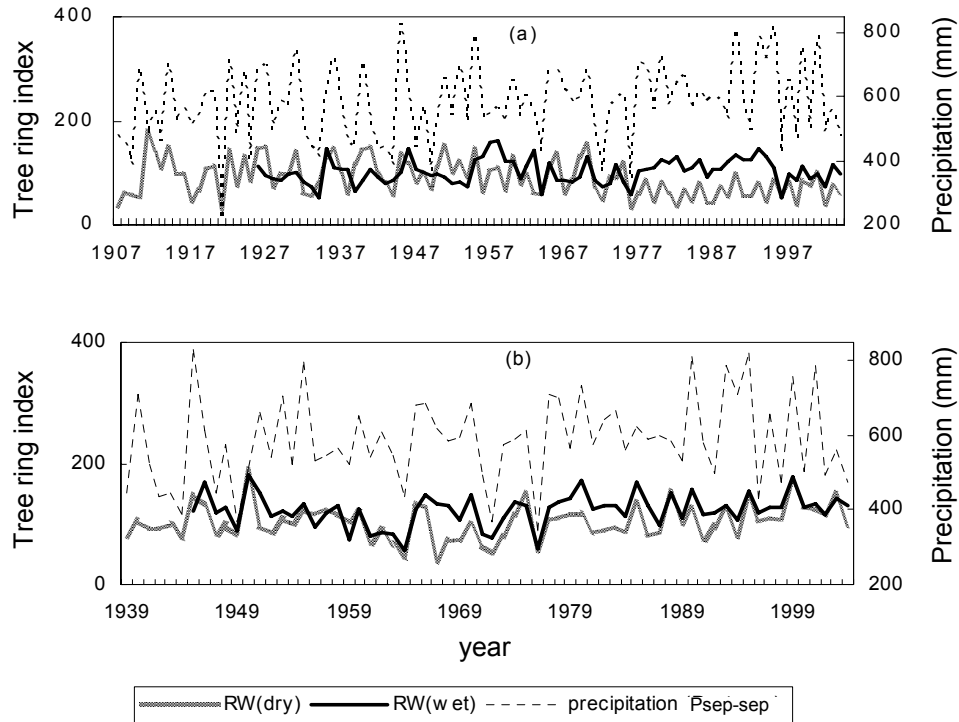

Figure 5: Ring width chronologies of oak (a) and pine (b) with the sum of precipitation from previous September to current October (dashed line).

The climate-growth relationships (Figs. 5 & 6) illustrate a strong positive correlation between the tree-ring width chronologies and the sum of precipitation from previous September to current October in both sites and for both species. The relation with temperature (not shown) was generally negative during the growing season and significantly negative during the summer month in the dry site for both oak and pine. This proves a negative impact of hot and dry (=drought) conditions in summer. Figure 5 shows similarities between time series of RW and precipitation from previous September to current October. The correlation coefficients calculated for the period from 1950 to 2004 are: oak r_{wet} =0.43, r_{dry} =0.48; pine $r_{wet=}$ 0.42 and r_{dry} =0.46. In the dry site, chronologies showed a slightly closer relation to precipitation than in the wet site. In detail, oak on both sites reveals a positive correlation with the precipitation of the current year whereas pine at the dry site also shows a strong response to the autumn precipitation of the previous year (Fig. 6d). Together with the low response to precipitation in summer (Fig. 6d) this might indicate that pine at the dry sites generally stops growing early in the growing season. A surplus of assimilates that is produced under wet weather conditions in late summer is thus not invested in LW production but stored and invested in growth of the next growing season. Nevertheless, at the wet site LW of pine is significantly related to precipitation at the end of the growing season, i.e. in August and September (Fig. 6c). This indicates that the cambium is still active and sensitive in late summer and assimilates are

invested in LW. Oak, however, seems to use another strategy: in the wet site, the relation with precipitation is less concentrated on single months, instead a positive 'precipitation signal' from previous December to actual October is visible (Fig. 6a). A strong impact of the March precipitation i.e. the period just before or at the start of the growing season (see Zweifel et al. 2006) is evident and strongly determines RW, EW and (to a lesser extend LW), respectively. A second 'block' with high positive correlations with LW occurs in late summer, in August and September LW (Fig. 6b). This strong late-summer precipitation impact was surprising and disagrees with the results by Zweifel et al. (2006) who found that 90 % of the annual increment in both oak and pine is already finished between the end of June and beginning of July.

It can be summarized that RW (and EW) of oak and pine on both the wet and dry site are positively correlated with the precipitation just before and/or at the beginning of the growing season. Good starting conditions are thus of major importance for tree growth throughout the growing season (Zweifel et al. 2006).
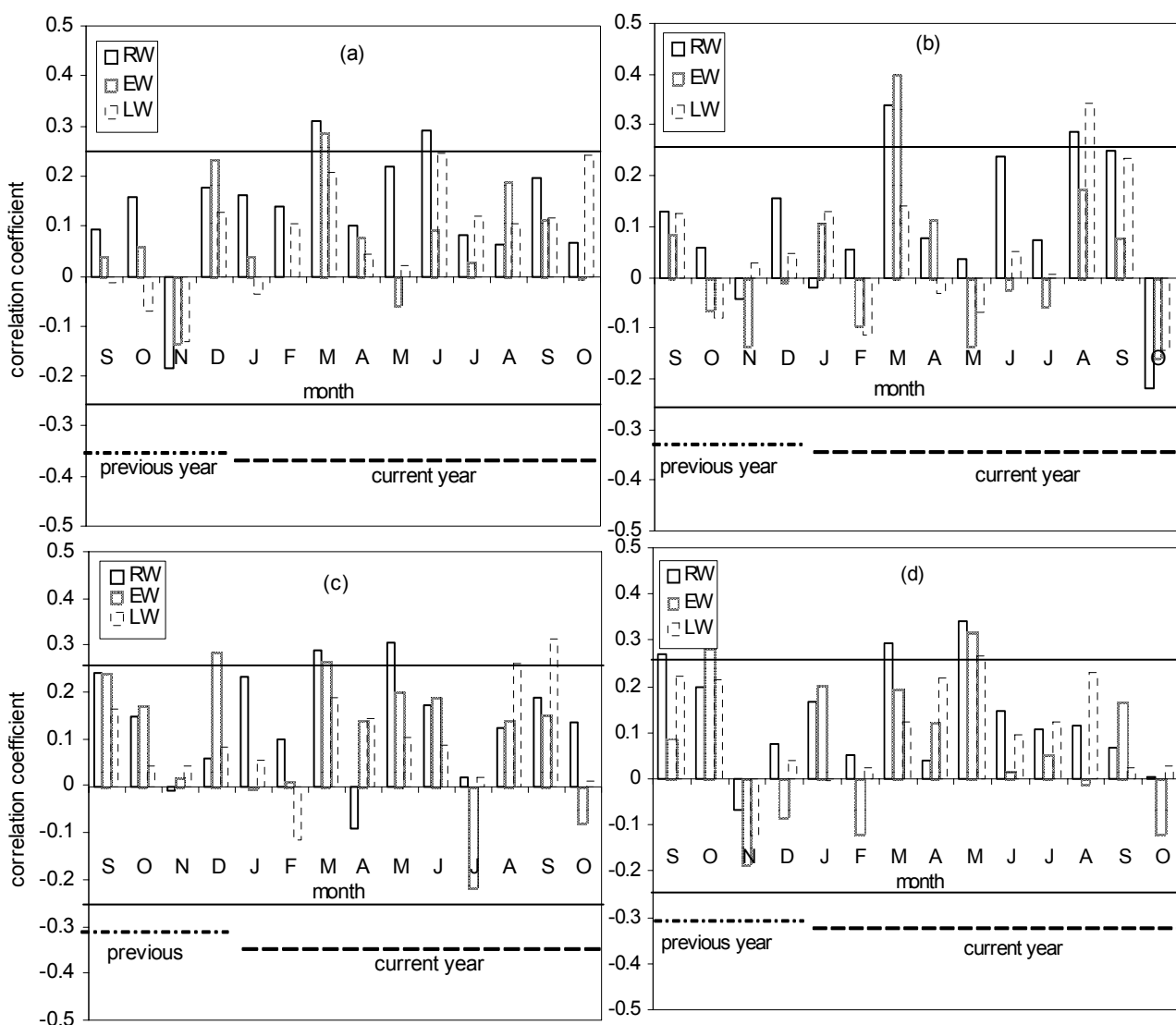

Figure 6: Correlation values of chronologies with monthly precipitation from (1950-2004); oak wet (a) and oak dry (b); pine wet (c) and pine dry (d); horizontal lines indicate the significance level (p=0.05).

Wood anatomy and drought index

The impact of water availability (expressed as drought index) on annual changes in conduit size and density of oak and pine is evident (Fig. 7). The visual comparison with the annual drought index (calculated from previous September to current August) shows a remarkable synchrony: years with high values for the drought index (=wet years) correspond with wider vessels and tracheids in EW and LW and a lower vessel and tracheid density and *vice versa*. Even if the investigation period includes seven years only this is a strong indication that variation in conduit size and density are a strong indicator for changes in water supply. Figure 7 also illustrates that annual changes in conduit size and density are occurring in trees at the wet and the dry site respectively – with somewhat higher amplitude at the wet site. Hence it is obvious that oak and pine show elastic growth behaviour (RW, EW, LW) and are able to adapt to both, local (site specific) as well as temporal changes in water availability.

Conduit size and density have earlier proved to be good indicators of changing environmental conditions (Dünisch & Bauch 1994, Sass & Eckstein 1995, Garcia-Gonzales & Eckstein 2003) and provide the potential for studying the relation between water availability and wood anatomy with a high temporal resolution.
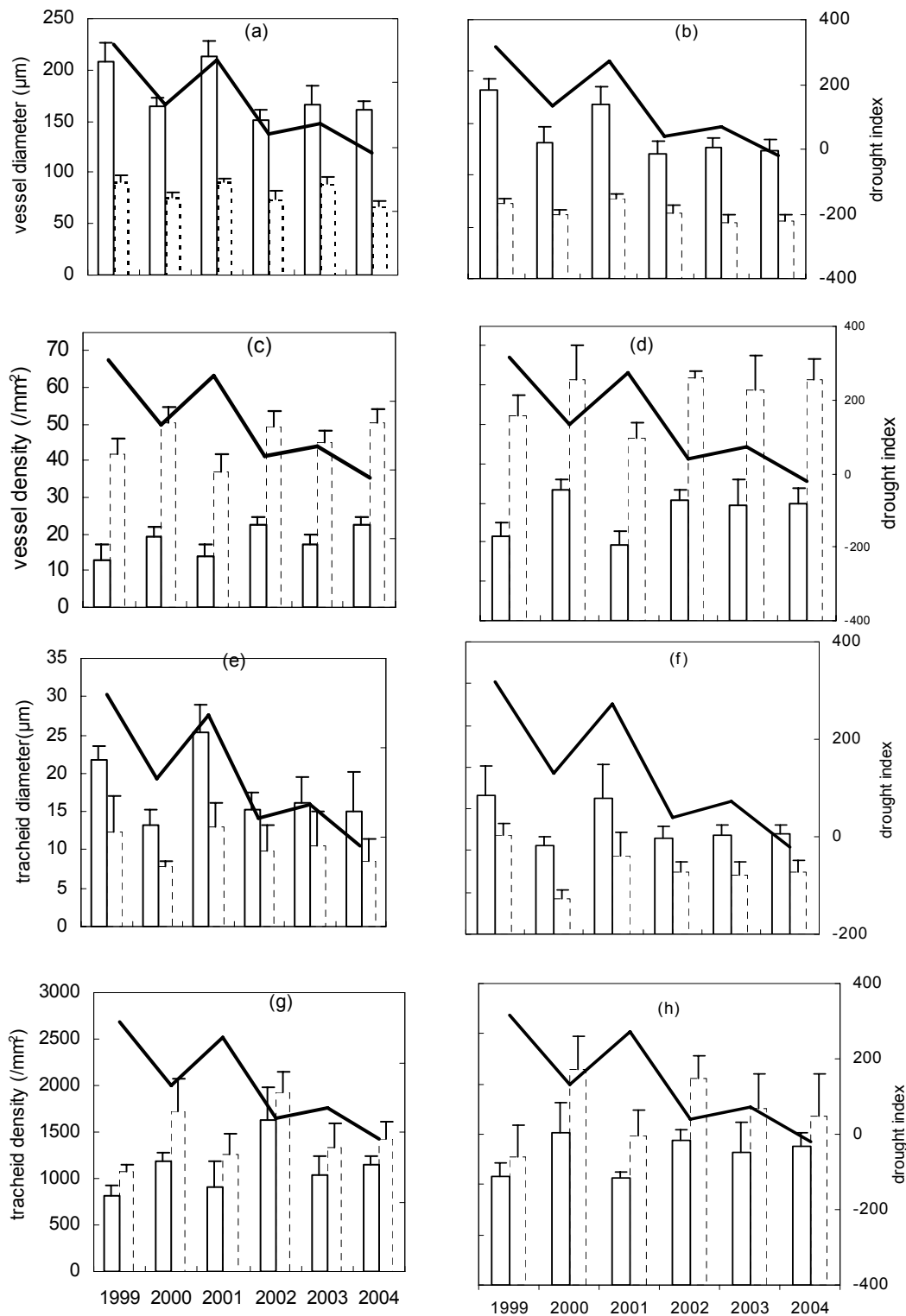
Figure 7: Variation of average conduit size and conduit density from 1999 to 2004 in EW (closed boxes) and LW (dashed boxes) and the relation to the annual drought index (black line); a+c =oak wet, b+d =oak dry, e+g =pine wet, f+h=pine dry .

Conclusions

This study on Pubescent oak and Scots pine growing under harsh weather conditions with frequent summer droughts in the Valais indicated that:

(1) both species, Pubescent oak and Scots pine, strongly respond to the specific water regime at the dry and the wet site which is reflected by significant differences in morphological factors (DBH, tree height, crown radius, leaf area, leaf mass), growth (RW, EW, LW) and wood anatomy (sapwood area, conduit size and density). All components of the hydraulic architecture, i.e. the continuous water-conducting system, were significantly different with generally smaller trees developing under conditions with lower water availability (Fig. 4). Future studies are planned involving the roots as well in order to get a complete picture about adaptation patterns in hydraulic architecture.

(2) Despite differences in water availability at the wet and dry site, growth and wood anatomy of both species is strongly influenced by the amount of rainfall during the growing season and prior to it. Additional water supply by the channel significantly reduces the impact of water shortage during summer droughts. The climate-growth relationships suggest that cambial activity of pine at the dry site ceases early. This means that LW and RW of a certain year are mainly related to rainfall conditions during the prior year(s) and at the beginning of the growing season. In oak from the dry site, however, LW formation is strongly influenced by water supply from precipitation during late summer. This assumption of a different response of both species to cope with summer drought has to be supported by additional studies on the intra-annual dynamics of cambial activity.

Hence it can be concluded that Pubescent oak and Scots pine are able to adapt their morphology and wood anatomy to long-term (site specific) and short-term (temporal) changes in water availability. We found no indication of a reduced growth activity during the last years in our sample trees.

Acknowledgements

References

Begert, M., Schlegel, T., Kirchhofer, W. (2005): Homogeneous temperature and precipitation series of Switzerland from 1864 to 2000. *International Journal of Climatology* 25:65–80.

Biondi, F., Waikul, K. (2004): DENDROCLIM2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. *Computers and Geosciences* 30: 303-311.

Briffa, K.R., Jones, P.D. (1990): Basic chronology statistics and assessment. In: Cook, E.R. and Kairiukstis, L.A. (Eds.) *Methods of Dendrochronology: Applications in the Environmental Sciences*. Kluwer Academic Publishers, Dordrecht.

Floret, C., Galan, M.J., Leafloch, E., Orshan, E., Romane, F. (1990): Growth forms and phenomorphology traits along environmental gradient: tools for studying vegetation? *Journal of Vegetation Science* 1:71-80.

Dünisch, O., Bauch, J. (1994): Influence of mineral elements on wood formation of spruce. (Picea abies (L.) Karst.). *Holzforschung* 48: 5–14.

Eckstein, D., Schmidt, B. (1974): Dendroklimatologische Untersuchungen an Stieleichen aus dem maritimen Klimagebiet Schleswig-Holsteins. *Angewandte Botanik* 48, 371-383.

Eilmann, B. Weber, P, Rigling, A., Eckstein, D. (2006): Growth reactions of Pinus sylvestris L. and Quercus pubescens Willd. to drought years at a xeric site in Valais, Switzerland. *Dendrochronologia* 23: 121–132.

Garcia-Gonzalez, I.G., Eckstein, D. (2003): Climatic signal of earlywood vessels of oak on a maritime site. *Tree Physiology* 23, 497-504.

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

IPCC. Climate change. (2001): Synthesis report. A contribution of working groups I, II and III to the third assessment report of the intergovernmental panel on climate change. *Cambridge University Press*. pp 398.

Kuhn, N. (1973): Frequenz von Trockenperioden und ihre oekologische Bedeutung. *Vierteljahresschrift der Naturforschenden Gesellschaft Zuerich* 118: 257-298.

Kurkela, T., Jalkanen, R. (1990): Revealing past needle retention in Pinus spp. *Scandinavian Journal of Forest Research* 5:481–485.

Oberhuber, W., Stumböck, M., Kofler, W. (1998): Climate-tree-growth relationships of Scots pine stands (Pinus sylvestris L.) exposed soil to dryness. *Trees* 13:19-27.

Rebetez, M., Dobbertin, M. (2004): Climate change may already threaten Scots pine stands in the Swiss Alps. *Theoretical and Applied Climatology* 79: 1-9.

Rigling, A., Bräker, O., Schneiter, G., Schwiengruber, F. (2002): Intra-annual tree-ring parameters indicating differences in drought stress of Pinus sylvestris forests within the Erico-Pinion in the Valais (Switzerland). *Plant Ecology* 163: 105-121.

Rinn, F. 1996. *TSAP (Time Series Analysis and Presentation),* Version 3.0. Heidelberg.

Ryan, M.G., Yoder, B.J. (1997): Hydraulic limits to tree height and tree growth. What keeps trees from growing beyond a certain height? *BioScience*, 47(4): 235-242.

Sass, U., Eckstein, D. (1995): The variability of the vessel size of beech (Fagus sylvatica L.) and its ecophysiological interpretation. *Trees* 9: 247-252.

Thornthwaite, C.W. (1948): An approach towards a rational classification of climate *Geographical Review* 38:55-94.

Zweifel, R., Zimmermann, L. Zeugin, F., Newbery, D.M. (2006): Intra-annual radial growth and water relations of trees-implications towards a growth mechanism. *Journal of Experimental Botany* 57(6):1445-1459.

Dominant trees alter growing conditions in their surroundings

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Introduction

Tree growth is, besides endogenous factors, influenced by various exogenous factors such as light and nutrient availability. Whereas competition for light has been regarded as a main driver for forest development, as expressed in many forest succession simulation models, belowground processes have been considered as less important for competitive interactions. This is probably partly due to the fact that processes in the soil are in general difficult to study and for this reason are still poorly understood. However, similar to changes in light availability, changing patterns of soil nutrient availability can be expected to play an important role in forest succession. Over time, single trees will alter the conditions in their surroundings in many ways. As the trees grow, light availability at the forest floor decreases. Litter accumulation and the actions of roots are influencing the decomposer community composition, which will consist of differing portions of fungal and bacterial biomass, depending on litter characteristics and abiotic conditions. As a consequence, patterns of light and nutrient availability in forests are typically heterogeneous. A better knowledge of these patterns and their influence on tree growth and regeneration will help to enhance our understanding of competitive and mutual interactions in forests, which can play a crucial role in the way forests will respond to future natural and anthropogenic changes.

Our aim here is to give a first estimate of the importance of belowground factors for tree growth and regeneration. We combine dendroecological with soil ecological methods to investigate how single freestanding trees influence soil properties and thereby the growth of regenerating trees in their neighbourhood zone. We test the hypothesis that soil properties affect the radial growth of the regeneration besides light availability and browsing pressure.

Material and Methods

In a remnant of the old Caledonian forests in Scotland, 16 old and freestanding Scots pine (*Pinus sylvestris* L.) trees were chosen. These trees can be described as making up patches in the forest and causing gradients in light and soil conditions from their stems to their outer crowns. To analyse differences in above and belowground conditions related to the distance to the centre of the large trees, we defined three zones of influence around each tree: the inner zone (I), comprising the area from the stem to the middle of the crown projection, the middle zone (M), comprising the area from the middle to the full crown projection and the outer zone (O) including the adjacent area outside of the crown projection (Fig. 1).

In each of these three zones around the 16 large trees, 5 topsoil samples were added up to one bulk sample per zone and tree. Increment cores of both the old dominant and the adjacent regenerating trees (up to five per plot) were extracted to measure the age and the

radial growth of each tree. If possible, at least one regenerating tree in each of the three zones of influence per large tree was chosen.

A light index for each of the regenerating trees was calculated based on its position relative to the crown (categories: <50cm distance from stem, I, M, O) and its orientation (categories: S, SE/SW, W/E, N) relative to the stem of the large tree. Furthermore, this index was modified by the height of the start of the crown of the large old tree.
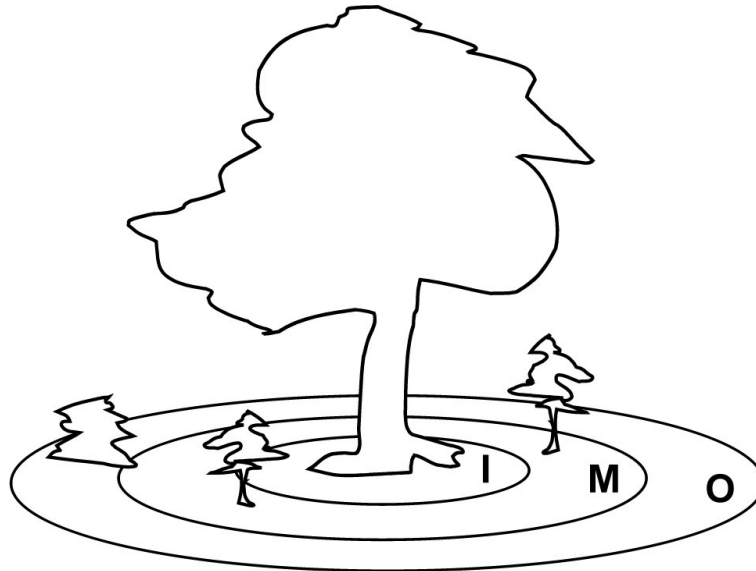
Figure 1: Sampling design. Each of the 16 plots includes one large and several regenerating Scots pine trees. On each plot, bulk soil samples were taken in each of the three zones of influence: I = inner, M = middle, O = outer zone.

Tree-rings of both the large and regenerating trees were measured and crossdated on a Lintab3 measuring system (F. Rinn S.A., Heidelberg, Germany) with a resolution of 0.01 mm and the TSAP tree-ring software (Rinn 1996). As a measure of the individual growth rate, mean annual growth of the last 10 years was calculated for each regenerating tree.

Soil samples were analysed for moisture content, pH, extractable inorganic N (NO_3^-, NH_4^+), dissolved organic N (DON) and C (DOC), microbial C and N, and microbial activity measured as basal respiration (for details cf. Harrison & Bardgett 2004).

First statistical analyses of the data included (1) testing for differences in the soil parameters between the three zones of influence and (2) linear regressions between the growth of the small trees and aboveground (light index) and belowground (soil property parameters) growing factors.

Results and Discussion

Soil properties, such as moisture content and availability of different nutrient forms, were found to differ among the three zones. First of all, soil moisture was significantly lower in the middle and in particular in the inner zone (close to the stem) than in the outer zone of influence (results not shown). These differences can be expected as a result of the trees'

water uptake and transpiration. Moisture availability itself is known to be an important parameter in influencing the microbial activity and rate of decomposition (Bardgett 2005).

Second, among all measured nutrient compounds, availability of nitrate (NO_3^-) and dissolved organic C (DOC) showed also significant differences between the three zones (Fig. 2). Whereas NO_3^- was significantly lower underneath the crown (zones I and M), DOC was strongly decreasing with increasing distance from the stem.
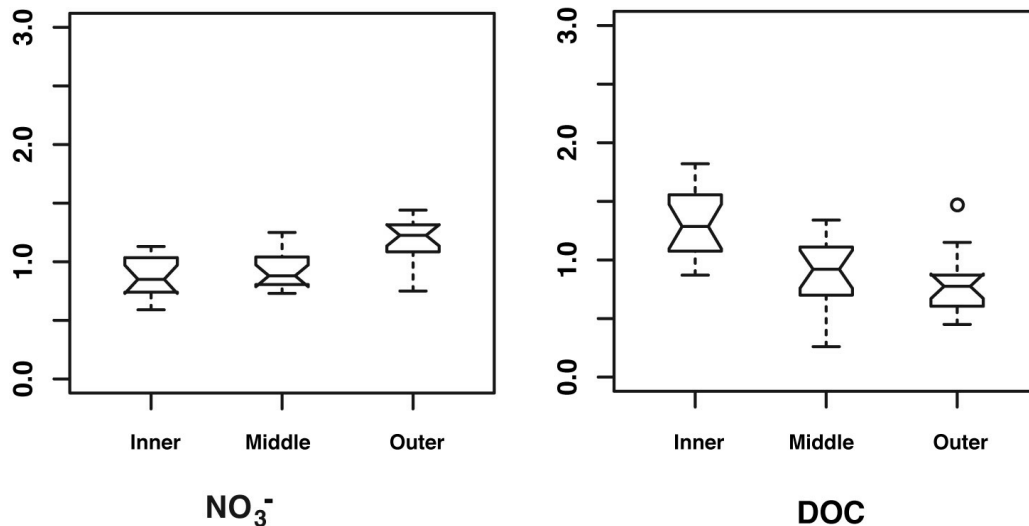

Figure 2: Notched boxplots of NO_3^- (left) and DOC (right) from the inner to the outer zone of influence (standardised on the plot). N=16. If the notches are not overlapping, the zones are significantly different at the 5%-significance level.

Low nitrate availability in the rooting area can result from the direct or indirect (via mycorrhizae) uptake of nitrate by the tree. Additionally, nitrate availability may also be low due to low mineralization rates (Bardgett 2005).

Our analyses of microbial biomass C and N support this second interpretation. Although the C:N ratio of the microbial biomass did not change between the three zones, microbial C was significantly higher in zone O (Fig. 3). At the same time, microbial C was strongly related to total extractable nitrogen (Fig. 3), indicating that microbial biomass was limited by nitrogen availability. Therefore, we can assume that available inorganic nitrogen is immobilized rather efficiently leading to a low net mineralization.

The comparatively high DOC values in the inner zone of influence can be interpreted as being the result of (1) high litter input from leaves and roots, which usually contains high amounts of carbon-based secondary compounds (Hättenschwiler & Vitousek 2000, Northup *et al.* 1998), and (2) root exudates, which typically have a higher C:N ratio than microbial biomass (Grayston *et al.* 1997). These high DOC values as well suggest that the availability of inorganic nutrients limits the incorporation of carbon into biomass, which goes well together with the above-described dependency of microbial C on total extractable nitrogen (Fig. 3).
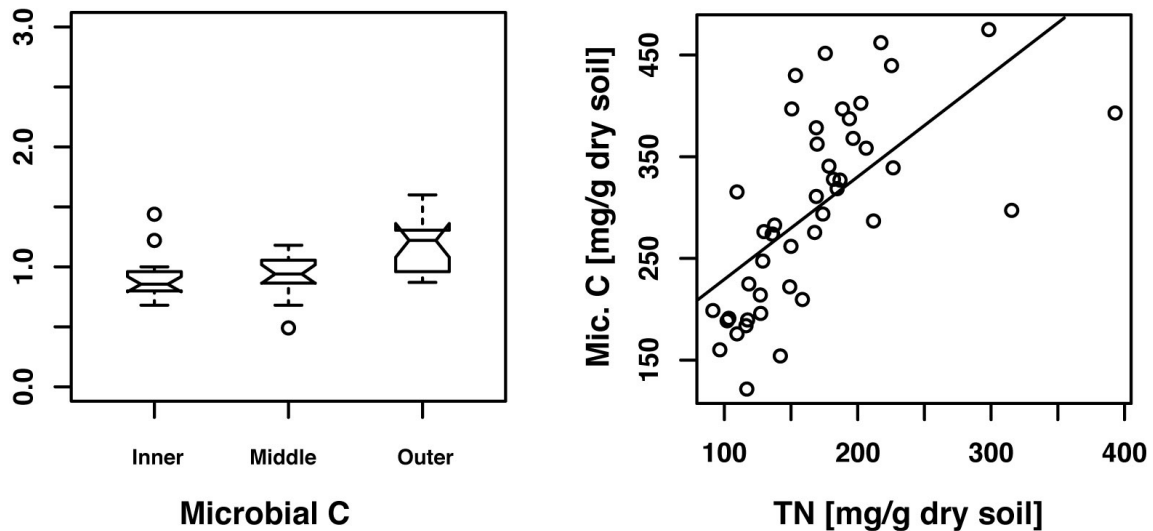
Figure 3: Notched boxplot (left) of microbial C from the inner to the outer zone of influence (standardized on the plot). N=16. Microbial C is linearly related (p<0.001) to total extractable N (right).

Conclusions

From these first results, we conclude that old large trees have a significant influence on soil conditions in a zone where litter fall and roots are acting. In this zone, they alter soil moisture content, nutrient forms and availability by affecting microbial community composition and activity. At this stage of the project it's too early to make a statement about how the here analysed gradients in soil and light conditions control radial growth of regenerating trees in the neighbourhood of the large old trees. However, first analyses suggest that the patterns of nutrient availability described here will also have an influence on tree-ring width of young trees.

Acknowledgements

References

Bardgett, R.D. (2005): The Biology of Soils: A Community and Ecosystem Approach Oxford University Press, Oxford.

Grayston, S.J., Vaughan, D., Jones, D. (1997): Rhizosphere carbon flow in trees, in comparison with annual plants: The importance of root exudation and its impact on microbial activity and nutrient availability. *Applied Soil Ecology 5:* 29-56.

Harrison, K.A., Bardgett, R.D. (2004): Browsing by red deer negatively impacts on soil nitrogen availability in regenerating native forest. *Soil Biology & Biochemistry 36:* 115-126.

Hättenschwiler, S., Vitousek, P.M. (2000): The role of polyphenols in terrestrial ecosystem nutrient cycling. *Trends in Ecology & Evolution 15:* 238-243.

Northup, R.R., Dahlgren, R.A., McColl, J.G. (1998): Polyphenols as regulators of plant-litter-soil interactions in northern California's pygmy forest: A positive feedback? *Biogeochemistry 42:* 189-220.

Rinn, F. (1996): TSAP - Reference manual. Version 3.5 Rinntech, Heidelberg, Germany.

SECTION 5

GEOMORPHOLOGY

Wood anatomy and Dendrogeomorphology - Reaction wood varieties caused by different experimental treatments

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Introduction

Geomorphic events, likely to increase in magnitude and frequency under the influence of global warming, usually have a significant impact on tree growth. In the past, dendroecological techniques have been developed for the determination of frequencies of these events (Schweingruber 1996). However, hardly ever has it been possible to retrieve information such as type and intensity of the geomorphic event which would be particularly helpful because currently the tree-ring signals for different mass movements such as debris flows and avalanches cannot be separated when occurring at the same site and consequently are potentially all mixed into one reconstruction not distinguishing between the different processes (Clague & Souther 1982). A comprehensive wood anatomical analysis of reaction wood induced artificially as part of a growth experiment has the potential to obtain more complete information on the potentially different tree reactions to these dissimilar events. We suggest that the application of wood anatomical techniques can deliver additional information of past impacts on tree growth. In order to verify this proposition we conducted growth experiments imitating impacts of different geomorphic events. The wood anatomical reactions were analysed and some results are presented here.

Study sites and methods

We conducted growth experiments, inspired by earlier studies (*e.g.*, Robards 1966, Wardrop 1956, 1964), on four tree species (*Fagus sylvatica, Alnus glutinosa, Larix decidua* and *Picea abies*) growing under natural conditions in Switzerland.

Table 1: List of groups with different treatments (four trees per group).

T1	Stem bent to 80° from the vertical
T2	Stem bent to 45° from the vertical
T3	Stem bent increasingly in time starting from small angles up to 80°
T4	Stem bent to 80°, but with the apex remaining vertical
T5	Stem bent to 80°, with apex cut
T6	Stem bent to 80°, but with the bark & cambium partly removed from the upper side
T7	Stem bent to 80°, but with the bark & cambium partly removed from the lower side
T8	Stem bent to 80° and sideways
T9	Stem and root system tilted to 80° from the vertical, with roots partly destroyed
T10	Reference group

The experiments comprised ten treatments involving, for example, different bending intensities of the trees with or without removal of the apex or the cambium (Table 1). The treated specimens at both sites were mainly young trees, except for an additional treatment called the rockfall group in which we severely damaged the stems of four older trees per species using a 5kg sledge hammer (not listed in table 1). In addition to the treatments listed in table 1 the lower parts of the stems of five *Alnus glutinosa* were partly covered with soil imitating burial due to mass movement events such as debris flows or landslides. So far, such events have only been dated by means of identifying the initiation of adventitious roots in conifers. However, not all species possess the ability to form adventitious roots and hence a new technique would be crucial for further advancements in dendrogeomorphology (Bayard & Schweingruber 1991).

All experiments were set up twice, that is, March and October 2004, the beginning and end of the winter period, respectively, to imitate different mass movement events such as debris flows and avalanches typically occurring in autumn and winter, respectively. The repetition of the treatments seemed necessary because debris flows and avalanches have very similar impacts on trees. At the end of the experiment in October 2005 all trees were felled, disc samples and thin sections were cut for further microscopy and digital photos taken. Wood anatomical structures, that is, cell wall and lumen area of all cells and lumen area of vessels were recorded by digital imagery and analysed utilising the software programs Adobe Photoshop Elements and WinCELL Pro 2005a.

Results and discussion

Main results for conifers

The visual comparison of the micro-sections demonstrates that the experiment was successful in inducing compression wood (figure 1). The left and middle photos show distinct compression wood in comparison to the normal tree ring of the reference group visible in the right photo. Furthermore, in several instances a distinct difference of the compression wood formed between the groups was discernible visually.
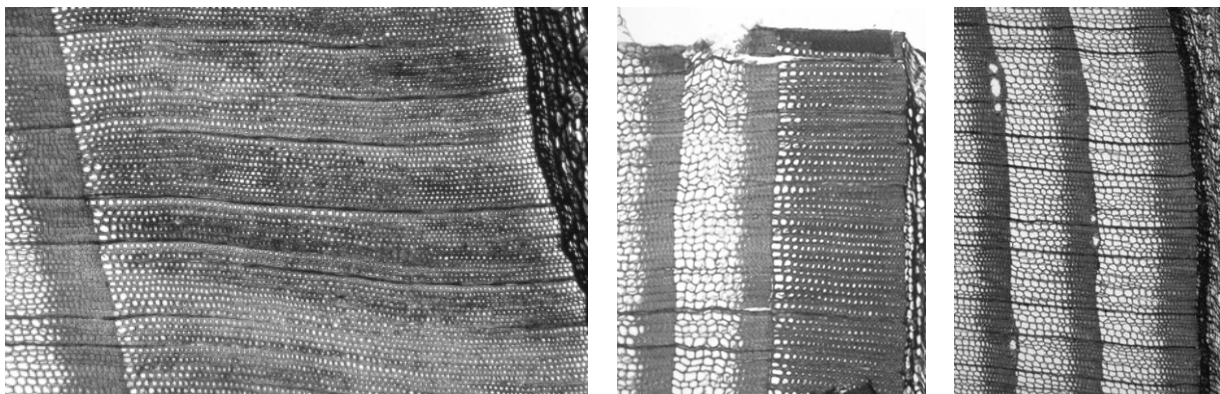

Figure 1: Visual comparison of micro-sections illustrating the differences in compression wood and ring width in Larix decidua; from left to right: treatment 1, 2 and reference group. (mag.: 40x)

For example, the left and middle photos both contain compression wood but the compression wood in the left photo is more intense than in the middle photo which is likely due to the more severe bending of the tree in treatment group 1 compared to that in group 2.

However, the box-plots analysing the distribution of the tracheid lumen area measurements indicate that there is not much variation between the groups (figure 2). Although the box-plots do not suggest significant differences in both spruce and larch some noticeable trends are visible. For example, in larch the tracheid lumen are smallest in group T1 compared to T2 and T3 indicating that treatment severity and compression wood intensity are correlated positively. The results of the quantitative analysis of the compression wood formed in the two conifer species led us to the conclusion that conifer trees possess only a limited ability to reconstruct the severity of geomorphic events in more detail due to the small variability of the tracheid dimensions.

The visual microscopic examination revealed that most samples contain at least one row but often several rows of normal earlywood tracheid cells exhibiting relatively thin walls and large lumen (figure 1, left and middle photos). Although the treatments were applied well in advance before the onset of cambium activity (end of previous and beginning of current vegetation period) these rows of earlywood cells strongly suggested a delayed reaction when examined macroscopically only. However, further microscopic investigations applying magnifications of up to 1000x clarified that the cells with large lumen seeming to be normal earlywood cells are in fact thin-walled compression wood cells. Typical compression wood cells only have S1 and S2 layers with the S2 layer exhibiting distinct wall thickenings and abundance of helical cavities.
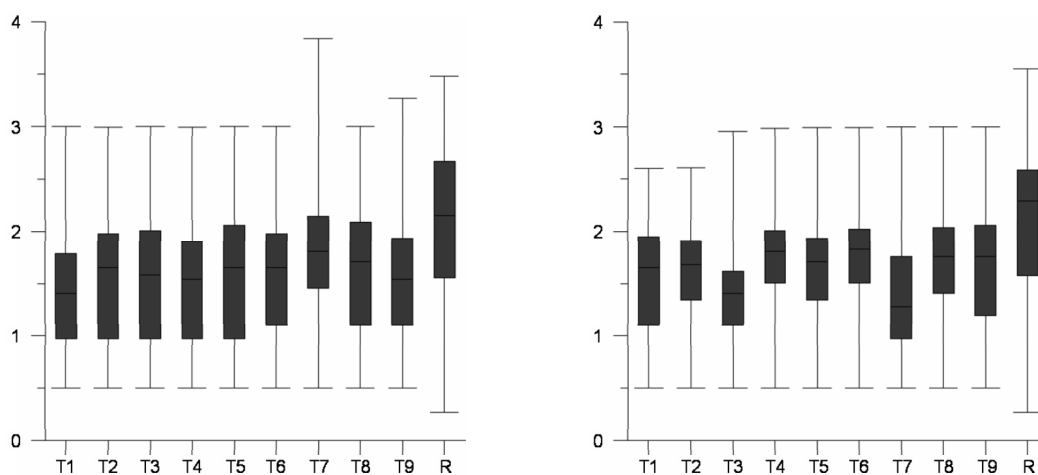
Figure 2: Tracheid lumen areas of Larix decidua (left) and Picea abies (right); data were log-transformed before analysis to conform to a normal distribution.

The cell walls in normal earlywood contain three layers S1, S2 and S3. However, the cell walls of the earlywood-like compression wood comprise only two layers because the S3 layer is missing which is a typical feature of compression wood. Furthermore, the S2 layer is somewhat thicker than in normal earlywood cells and contains helical cavities. The high-magnification microscopic examination brought to light that exact dating by means of conifer

tree rings can only be conducted reliably if wood anatomical methods are applied in addition to the commonly used tree-ring analysis. The important lesson learned is that if only a normal tree-ring analysis is conducted, as it is currently done in dendrogeomorphology, the dating of geomorphic events might be inaccurate. For instance, we applied the treatments in October and in the following tree ring the first cells formed seemed to be normal earlywood cells. Hence, the observer would be mislead and derive a wrong impact date of late spring May to June. Our results strongly suggest that accurate dating can only be achieved if tree-ring analysis is combined with wood anatomical methods.

In treatments T6 and T7 parts of the cambium were removed and in an additional treatment a large wound was applied to the stem by means of a large sledge hammer in order to simulate the impacts of avalanches and rock falls, respectively (figures 3 and 4). The wounds resulted in rows of resin ducts which in the past have often been used as indicators in tree rings for such geomorphic events. The inspection of the stem discs of both conifer species exposed that the occurrence of these resin ducts turns out to be highly variable. Often the resin duct rows were found in the middle of the tree ring suggesting that the mechanical impact happened in the summer of the current year while in fact it occurred 4 to 10 months earlier. In some instances several rows of resin ducts were formed suggesting incorrectly that more than one impact occurred and in other cases distinct rows of resin ducts were missing at all implying that the tree either did not react as markedly as the neighbouring trees or had not reacted within the time of the experiment.
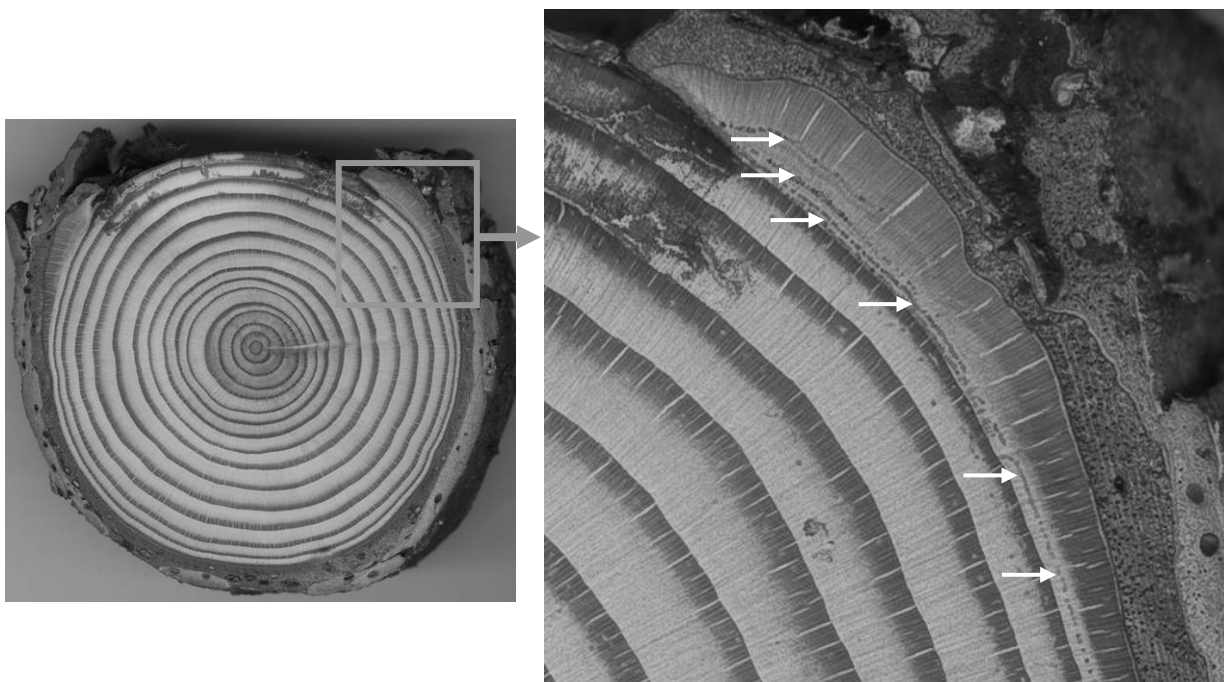
Figure 3: Rockfall simulation; wound tissue and rows of resin ducts (white arrows) in Larix decidua.

However, the most striking feature was frequently found when the rows of resin ducts were analysed along the entire circumference. Depending on the distance from the wound tissue the resin ducts were located at relatively different tangential positions within the tree ring, that

is, near the wound the resin ducts were positioned in the early part of the earlywood but farther away from the wound they were found at the boundary between earlywood and latewood sometimes even running into the latewood (see white arrows in figures 3 and 4).

Figure 4: Avalanche simulation; wound tissue and row of resin ducts (white arrows) in Larix decidua. (mag.: 50x)

If only core samples are taken, which in current research is often the case due to sampling or other restrictions (*e.g.*, Stoffel et al. 2006), the consequential analysis results might differ immensely depending on the location of the samples relative to the wound within the individual trees. While in some instances no resin ducts might be present in others they might be located at the beginning or the middle of the tree ring making a reliable intra-seasonal dating of the event impossible. Thus, reconstructions utilising wound tissues and the resulting resin ducts in conifers need to be aware of this flexible temporary and spatial behaviour of resin duct formation. The results suggest that the feature "occurrence of resin ducts" cannot be used for a reliable intra-seasonal reconstruction and only to a limited extend for inter-seasonal dating due to the fact that some trees did not form resin ducts within the first year after the treatments. The recommendations to buffer this variability in resin duct formation are to take as many samples as possible or even better of entire stem discs. Currently, if only a limited number of samples per tree are permitted, the samples are normally taken directly adjacent to the wound because here the resin duct formation is most reliable which was confirmed by our results. However, this method can only be applied when scars are visible from the outside while resin ducts in earlier tree rings resulting from hidden overgrown scars are again difficult to date. In this particular case it seems essential to include other reaction wood features such as compression wood or eccentricity to increase the reliability of the reconstruction.

Main results for angiosperms
The visual comparison in figure 5 shows that both fibre cell and vessel dimensions have been influenced by the different treatments in comparison to the normal growth visible in the right image. While the severest treatment T1 has resulted in very dense fibre tissue and a

limited number of vessels in the less severe group T2 the fibre cell tissue is less dense and more vessels are present.
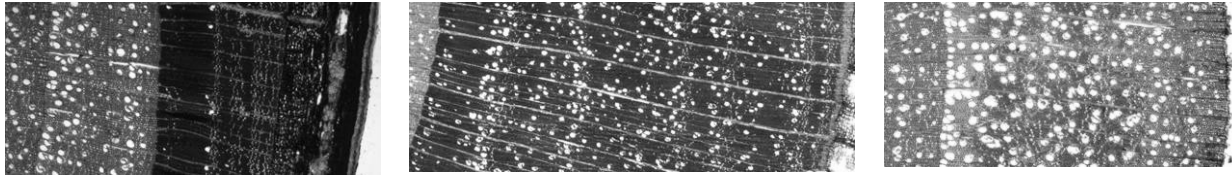

Figure 5: Visual comparison of microscopic cross-sections illustrating the differences in vessel size and numbers in Fagus sylvatica; from left to right: treat. 1, 2 and reference group. (mag.: 40x)

The box-plots confirm the visual impression, that is, the differences between some treatment groups are significant, for example, between T1 and T3 in *Alnus glutinosa* (figure 6). The results indicate that the reaction wood intensity characterised by vessel and fibre cell dimensions is positively correlated with the severity of tree tilting.
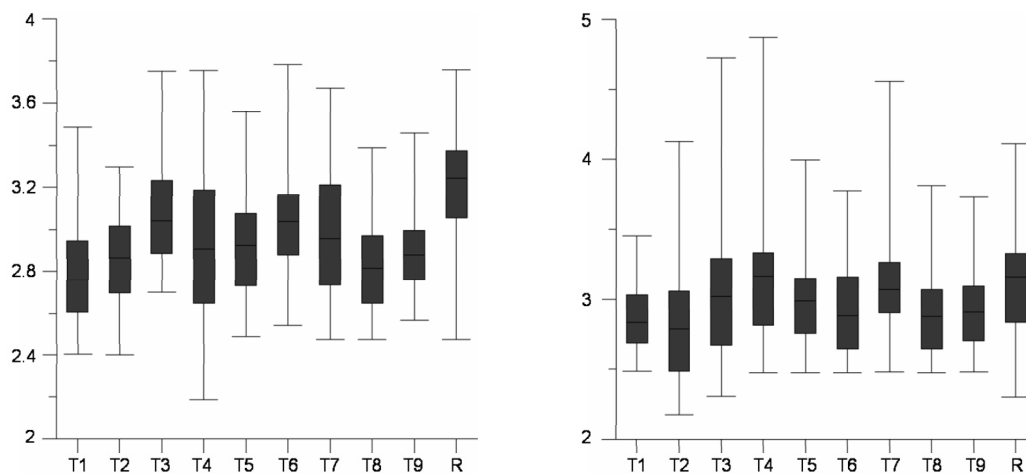

Figure 6: Vessel lumen areas of Alnus glutinosa (left) and Fagus sylvatica (right); data were log-transformed before analysis to conform to a normal distribution.

Furthermore, the box-plots also imply that additional alterations such as partial removal of the bark and cambium in groups T6 and T7 or severance of the apex in T5 change the reaction wood as well. For instance, in group T4 and T5 the apex either remained vertical or was cut resulting in the formation of less intense reaction wood compared to group T1 supporting the hypothesis that the apex is one of the main locations for a tree's ability to respond to gravitational forces. According to the current results reaction wood can be classified into intensity classes with changed dimensions of both fibre cells and vessels resulting from mechanical impacts of varying strength and hence can be used in future applications to reconstruct the severity of individual geomorphic events.

Moreover, the results have also important implications for related disciplines such as dendroclimatology in which vessel dimensions have recently been used more frequently as proxies for climate reconstructions (Sass & Eckstein 1995; Fonti & García-González 2004). Our new results show that vessel dimensions are not only sensitive to climate patterns but

also to mechanical stresses hence potentially incorporating signal noise into climate reconstructions based on vessels only. This is further complicated due to the fact that tension wood is not easily discernible macroscopically and hence easily overlooked during normal tree-ring analysis. If that is the case, substantial signal noise due to altered vessel dimensions can be expected in vessel-measurement chronologies aiming to reconstruct climate.

In a separate experiment the stems of five alder were buried under 30cm of soil for the time of one growing period.
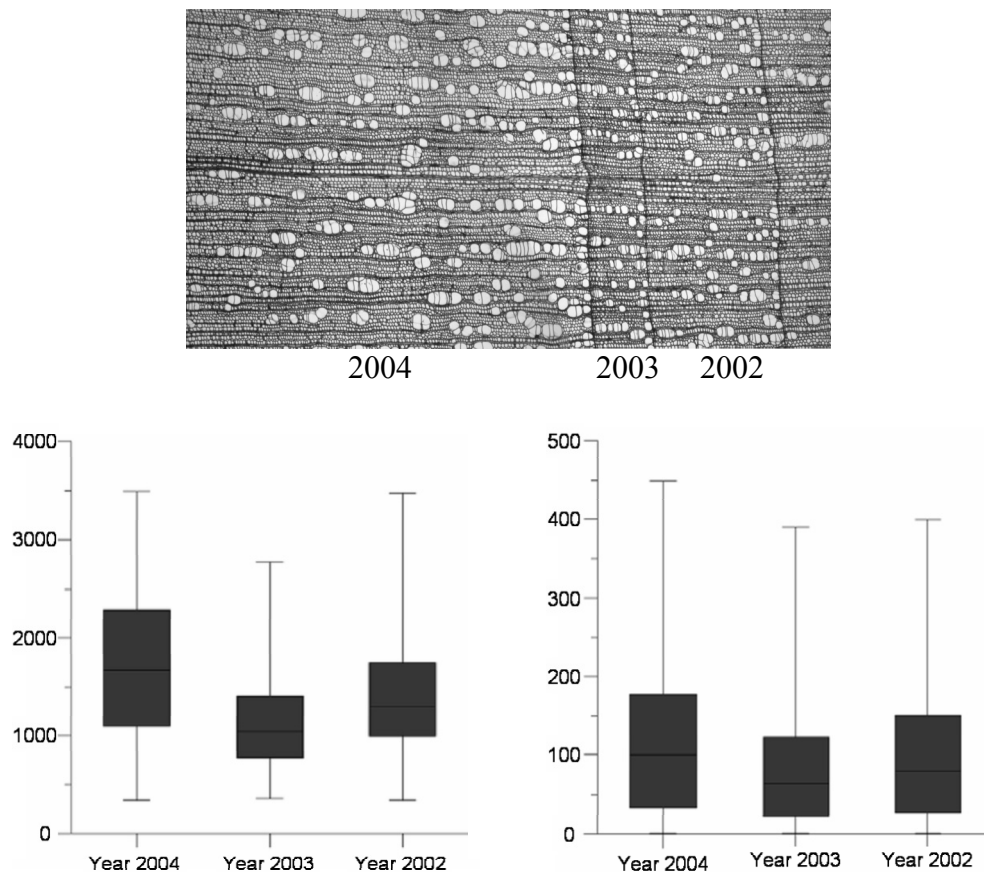

Figure 7: top: micro-section taken from the lower part of a stem of Alnus glutinosa buried for one vegetation period showing the last three tree rings 2002 to 2004 (mag.: 40x); bottom: box-plots of lumen areas of vessels (left) and fibre cells (right) in five trees of Alnus glutinosa for the corresponding years 2002 to 2004; note the significant change in vessel size after burial in March 2004 of the lower part of the stems.

At the end of the experiment the soil was removed and the buried stems cut for further analysis. Figure 7 demonstrates how the trees reacted; the micro-section shows the last tree rings of the years 2002 to 2004. The box-plots show the respective measurements of vessels (left) and fibre cells (right) both indicating that the burial of the stems has resulted in an increased cell lumen during 2004, the year of the treatment. Similar results were presented for *Fraxinus pennsylvanica* by Cournoyer and Bégin (1992). They showed that an ash buried under 3.2 m of sediment along the St. Lawrence shore reacted spontaneously to burial. The wood changed from ring porous to diffuse porous. The tree stems in our experiment were

only buried under 30cm of soil and only for one growing period. A more distinct reaction could have been expected in the following years especially if the soil layer would have been thicker. While the inverse reaction has recently been described for exposed roots forming cells with smaller lumen (Gärtner *et al.* 2001), this particular reaction towards burial has not been published yet and constitutes a new technique to date sedimentation processes utilising angiosperms such as alder or ash likely to grow along water ways.

Outlook and recommendation

Our project has demonstrated that modern dendrogeomorphology needs to combine both tree-ring analysis and wood anatomy warranting reliable reconstructions of different geomorphic events. The inclusion of wood anatomical techniques ensures better intra-seasonal dating and reveals further information such as intensity of the mechanical stress. Generally, the reaction wood formation in conifers and angiosperms differ significantly, that is, conifers seem to be less sensitive to different mechanical stresses and thus potentially exhibit problems when used for intra-seasonal reconstructions and for the identification of the impact severity.

Angiosperms, in contrast, possess the ability to deliver more information regarding the severity of the impact. This is due to several reasons: they seem to be more sensitive to disturbance and have a more complex wood structure offering additional wood anatomical features, that is, vessels and parenchyma, for further analysis. In particular, vessels have exhibited a high sensitivity to environmental changes and mechanical impacts. Moreover, conifers have displayed a delayed form of reaction wood. Several rows of earlywood cells seemingly normal earlywood cells can only be identified as compression wood cells utilising very high-magnification light microscopy which necessitates comprehensive analysis techniques often not available to researchers conducting dendrogeomorphology.

It seems that although until now dendrogeomorphic research has mainly concentrated on using conifer trees for the reconstruction of mass movements angiosperm trees are more suitable for dendrogeomorphic investigations. Our new results recommend concentrating more on angiosperms if a reliable intra-seasonal resolution of the dating and a more detailed description of the different mass movements are sought after.

Acknowledgements

References

Bayard, M., Schweingruber, F.H. 1991. Ein Baumgrenzstandort: Das Wildwasserbett der Maggia im Tessin, Schweiz. Eine dendroökologische Studie. *Botanica Helvetica* 101: 9-28.

Clague, J.J. & J.G. Souther. 1982. The dusty creek landslide on Mount Cayley, British Columbia. Canadian Journal of Earth Science 19: 524--539.

Cournoyer, L., Bégin, Y. 1992. Effets de l'érosion riveraine sur les structures anatomiques de *Fraxinus pennsylvanica* Marsh. dans le haut estuaire du Saint-Laurent, Québec, Canada. Dendrochronologia 10: 107-120.

Fonti P., García-González I. 2004. Suitability of chestnut earlywood vessel chronologies for ecological studies. New Phytologist 163: 77–86.

Gärtner, H., Schweingruber, F.H., Dikau R., 2001. Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots. Dendrochronologia, 19: 1-11.

Robards, A.W. 1966. The application of the modified sine rule to tension wood production and eccentric growth in the stem of crack willow (Salix fragilis L.). Ann. Bot. 30: 513--523.

Sass, U., Eckstein, D. 1995. The variability of vessel size in beech (*Fagus sylvatica* L.) and its ecophysiological interpretation. Trees 9: 247-252.

Schweingruber, F.H. 1996. Tree rings and environment. Dendroecology. Swiss Federal Institute for Forests, Snow and Landscape Research, Birmensdorf and Paul Haupt, Bern, Stuttgart, Vienna.

Stoffel, M., Bollschweiler, M., Hassler, G. R. (2006): Differentiating past events on a cone influenced by debris-flow and snow avalanche activity – a dendrogeomorphological approach. Earth Surface Processes and Landforms 31: in press.

Wardrop, A.B. 1956. The nature of reaction wood. Australian Journal of Botany 4: 152--166.

Wardrop, A.B. 1964. Reaction anatomy of arborescent angiosperms. In: M.H. Zimmermann (ed.), Formation of wood in forest trees: 405--456. Academic Press, New York.

The dendrochronological records of debris flow activity in SE Quebec

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Introduction

Debris flows, rapid mass movement of water-saturated sediments, are one of the main processes shaping high mountainous slopes (Eisbacher & Clague 1984, Van Asch & Van Steijn 1991, Jakob 1996, Berti et al. 1999). However, this phenomenon may occur on each steep hill covered by unconsolidated sediments. The postglacial relief of south-east Quebec, rich of steep-slope, fjord type valleys, is inviting to study debris flows activity in non-mountainous environment. The comparison of recent publications (Couture et al. 2002, Vandine & Bovis 2002) shows the lack of either dendrogeomorpholigical or strictly geomorphological studies of debris flows in this part of Canada. The debris flows as movement of highest energy cause particular danger for human lives and properties. Even though this hazard is limited to forested, low populated regions of Quebec, debris flows create potential risk for roads and infrastructure there.

Tree-rings are employed as proxy record to reconstruct past activity of debris flows by using dating of scars and other growth anomalies such as reaction wood or resin ducts.

In this paper we present first results of a study whose main purpose was to assess spatial and temporal dynamics of debris flows and reconstruct post-event evolution of that type of mass movement.
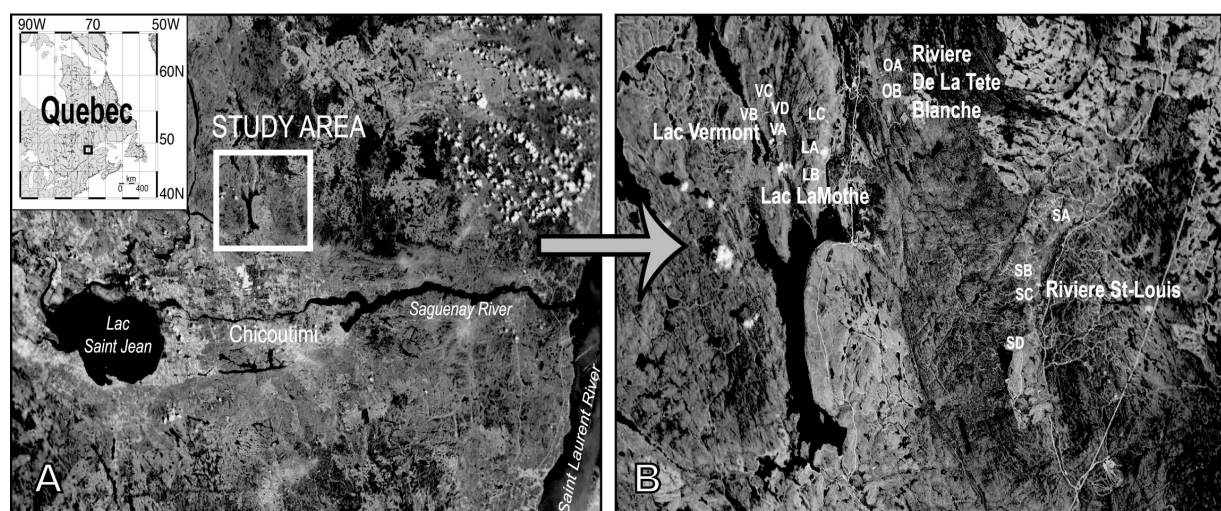

Figure 1: Location of the study area in Quebec Province and Saguenay Region (A) and spatial distribution of debris flows within sites (B)

Study area

The sites of investigation are located in the Monts-Valin area, part of Laurentian Highlands, a rugged, heavily dissected region of the Canadian Shield. The Monts-Valin, a massif which dominates the Saguenay landscape with peaks over 900 m asl is build by crystalic rocks. The old, Precambrian mountains are intensively eroded and covered by glacial and glaciofluvial deposits (Hébert et al. 2005). The morphology of that region is characterised by low plateaus intersected by deep u-shaped valleys. The summits of the hills are rather flat and the mass movements mainly occur on the slopes of the valleys. The investigation has been carried out in 4 sites located in 3 valleys north of the Saguenay River, in the boreal forest (Fig. 1, Tab. 1). The stands are located within the bioclimatic domain of balsam fir-paper birch. Most of examined debris flows represent channalised type, only two of them are unchannalised (VD, LC) and one (SC) is typically shallow debris flow.

Table 1: Characteristics of the investigated debris flows

Site	Debris flow	Location	Elevation [m a.s.l.]	Width [m]	Length [m]	Slope [m*m-1]
Lac Vermont	VA	48°53'56.8"N 71°07'22.3"W	530 337	45	560	0.321 0.182
	VB	48°54'20.0"N 71°07'21.0"W	562 469	29	218	0.478 0.245
	VC	48°54'18.7"N 71°07'14.0"W	605 421	26	670	0.363 0.205
	VD	48°54'18.4"N 71°07'12.0"W	546 504	20	124	0.391 0.185
Lac LaMothe	LA	48°51'46.8"N 71°04'57.9"W	510 341	28	398	0.457 0.270
	LB	48°51'50.8"N 71°04'55.0"W	517 345	33	635	0.344 0.110
	LC	48°52'51.0"N 71°03'55.4"W	445 380	32	203	0.469 0.435
Riviere De La Tete Blanche	OA	48°53'39.4"N 71°00'15.3"W	527 402	35	298	0.494 0.278
	OB	48°53'33.0"N 71°00'14.2"W	510 410	50	280	0.384 0.294
Riviere St-Louis	SA	48°46'41.8"N 70°51'49.8"W	585 479	30	583	0.210 0.120
	SB	48°45'31.5"N 70°54'27.6"W	578 464	23	516	0.244 0.110
	SC	48°45'22.8"N 70°54'32.0"W	578 464	160	473	0.380 0.045
	SD	48°43'32.0"N 70°55'41.5"W	546 460	35	321	0.391 0.046

Material and methods

The sites of dendrochronological investigation were selected based on satellite images of nearly 50 debris flows existing in that region. Scars, reaction wood and tree ring patterns (growth reductions) were used as sources of information on debris flows activity. The stage of development of the exposed part reflects the period of the growing season when injuries of trees and cambial damages occurred (Fig. 2). Disc samples (approximately 20 per site) were taken from trees growing on edges and fans (tongues) of debris flows. Sampled coniferous species such as balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench)

Voss) and black spruce (*Picea mariana* Mill. B.S.P.) were used for both, scar and reaction wood analyses. Samples from broad-leaves species, mainly paper birch (*Betula papyrifera* Marsh.) and yellow birch (*Betula alleghaniensis* Britton), were only used to date scars.
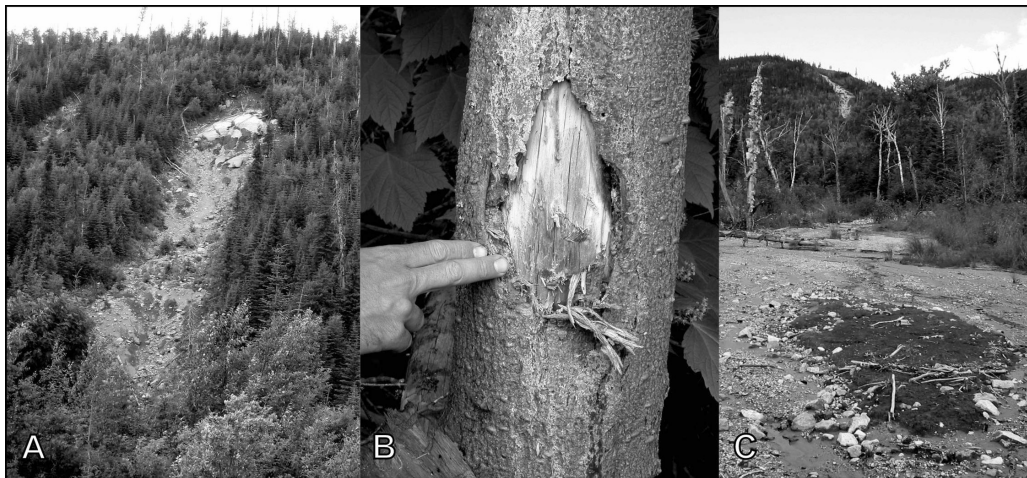
Figure 2: Debris flow SB at Riviere St-Louis site on a steep slope and thin veneer of soil in headscarp zone (A). Scar caused by rapid movement of coluvial debris and other trees (B). The buried forest at the fan of debris flow visible on the slope (C).

Results and discussion

Records of debris flows activity

Sequences of reaction wood were analysed and the beginning of tilting caused by mass movement events determined. To reduce signals triggered by other factors, mainly snow pressure of particular importance for seedlings, compression wood of juvenile rings, whose diameter is smaller than 5cm in DBH was not counted. Analysis of the initial year of reaction wood appearance, site-by-site, is summarized in Figure 3. The period of 1800 – 2005 reaction wood appearance was scanned.

Figure 3: Summarized frequency of first year of reaction wood occurrence for all four investigated sites.

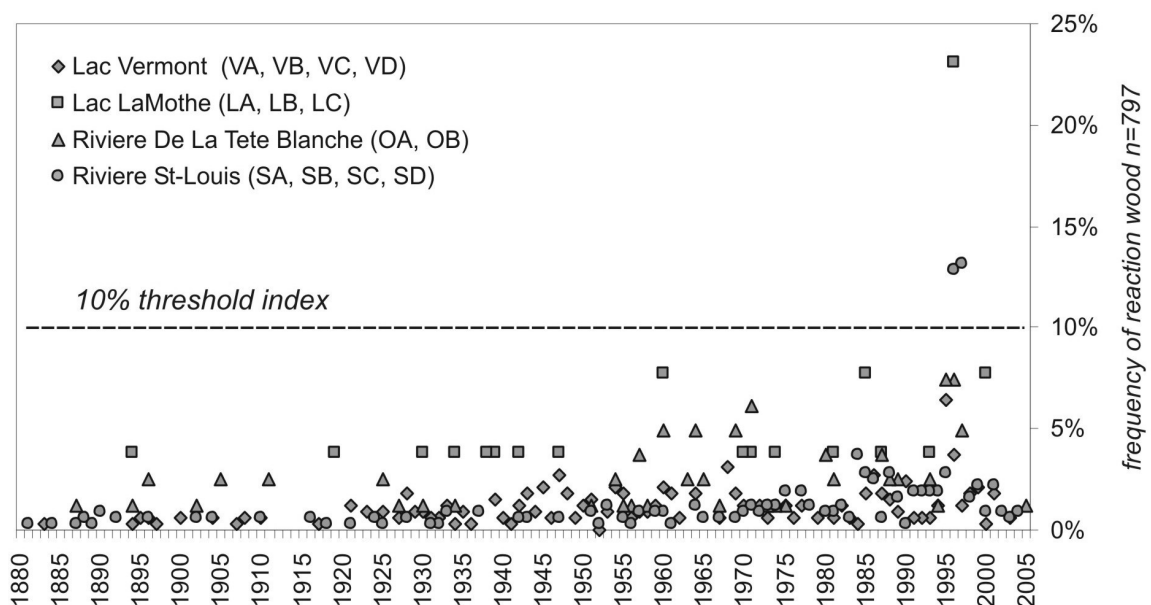Comparisons of frequencies of reaction wood revealed a period of high activity of slope related to mid 1990s: 1995-1997. Only Lac LaMothe site shows clearly two other periods of compression wood development (beginning of 1960s and mid of 80s). Trees grown adjacent to debris flows at other sites do not show such diversity of temporal distribution of reaction wood.

After passing the results of frequency of reaction wood through a 10% threshold index filter (Dubé et al. 2004), only signals from period 1995 to1997 remained significant. The homogenous character of the compression wood distribution within the examined period suggests that slopes where debris flows occurred were relatively stable before the event. Analyses of the time span of compression wood and relation between distance from debris flows and appearance of reaction wood (not shown here) support this finding.

Temporal distribution of scars was analysed using similar event-responses, calculated as frequency of scars per site for each year (Shroder 1978). Two different threshold indexes: 10% (Dubé et al. 2004) or 40% (Butler et al. 1987) were applied to define significant signals of scar abundance. That signal differs not only from site to site but also within sites (Fig. 4).
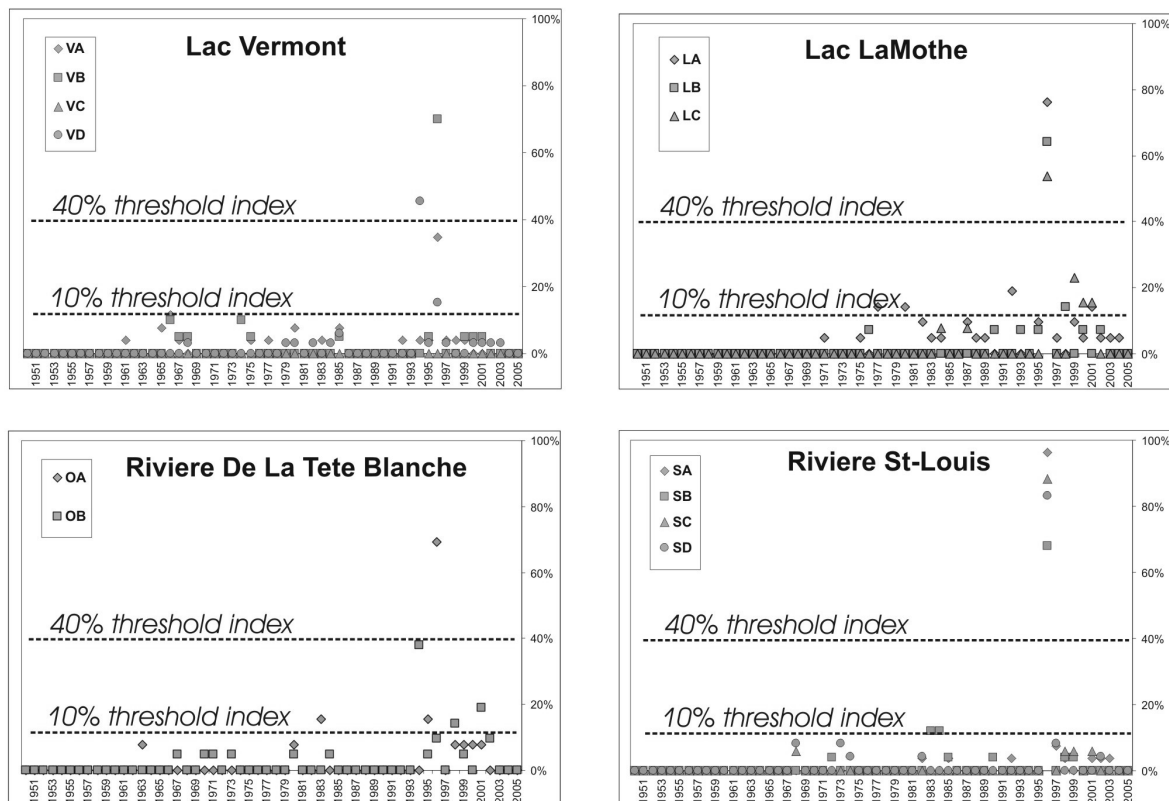
Figure 4: Summarized frequency of scar occurrence for each sampled debris flows at the four investigated sites.

Using 40% threshold index, no any debris flows activity older then 1990s was registered. For the less restrictive filter (10%), the oldest event recorded in tree-rings happened in the 1960s at Lac Vermont site. However, that period of activity is significantly registered at one out of four examined debris flows, but in two more debris flows, trees with similar dated scars were found. The date of scars and following appearance of reaction wood reveal, according to

higher levels of threshold index (40%), that main stages of debris flows activity occurred in 1994 and 1996. Due to the high intensity of the last event, records of older debris flows activity are less present. Based on lower threshold index (10%) and existing records of daily rainfall, next periods of slope instability can be established (1966, 1983). All examined debris flows at sites Riviere St-Louis and Lac LaMothe were active in 1996 and evidences of movement in 1994 were not found. In contrary to that record, the most important phase of activity of debris flows from Lac Vermont and Riviere De La Tete Blanche occurred in 1994. Though there is no clear relation between type of debris flows and date of events, field observations and results of the tree-ring analysis suggest that more channelized debris flows, characterized by relatively narrow but deep track zone, were rather active during 1994 than 1996 (most debris flows from Lac Vermont and Riviere De La Tete Blanche). Typical shallow, unchannelized debris flows (SC from Riviere St-Louis site) even with some features of landslide, reveals only one period of activity related to extremely high precipitation in July 1996.

This last and also very intense period of debris flows activity occurred in 1996, related to periods of extremely high precipitation (almost 100mm on July 19th and 50mm on September 14th). The lack of significant signal from older movement can be explained by extremely high energy of the 1996 event, which may have destroyed evidence of previous activity of debris flows. Another factor limiting records of older events in tree-ring is the ecological dynamic of boreal balsam fir forest (the average age of sampled trees did not reach 100 years).

Post-event evolution of debris flows

The type of examined debris flows differed but post-event developments are similar. Erosion of uncovered parts of debris flows has remained the main morphological post-event process during 10 years after the events. The accumulation of fine-grained mineral material stored in the lowest part of the fan is a simultaneous process. The aggradation is recorded in tree-ring widths of partially buried firs that grew on the fan (Figure 2C). The comparison of tree-ring width pattern (raw values) of the two groups of trees (cluster 1 and cluster 2) with the reference curve shows that even if trees benefited from the opening related to the event (cluster 1), they suffered from an ongoing increase of sediments burying their roots (the example of SA debris flows from Riviere St-Louis site, Figure 5).
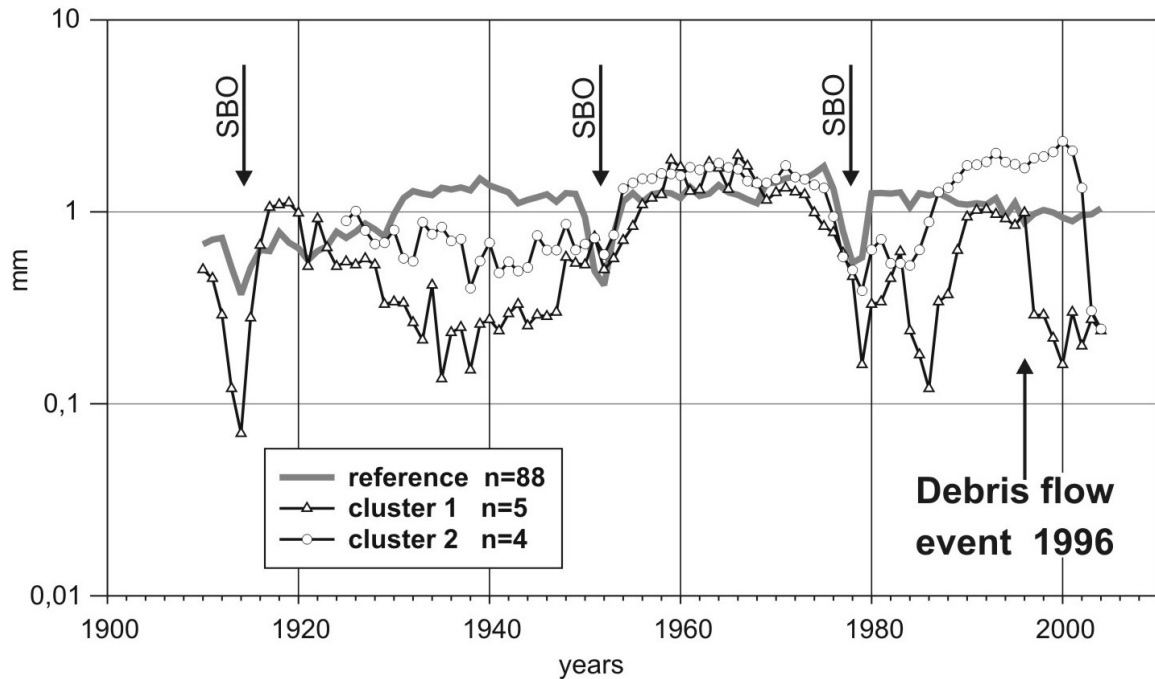
Figure 5: Tree-ring record of debris flows fan post-event development. The comparison of three growth curves (the absolute volume): reference – trees on the slope unaffected by debris flows, cluster 1: trees buried by sediments, and cluster 2: trees released by debris flows but buried as well during fan developing, SBO – sprucebudworm outbreak

References

Berti, M., Genevois, R., Simoni, A., Tecca P.R. (1999): Field observations of a debris flow event in the Dolomites. *Geomorphology* 29: 265–274.

Brooks, G. R., Lawrence, D. E. (2000): Geomorphic effects of flooding along reaches of selected rivers in Saguenay Region, Quebec, July 1996. *Géographie physique et Quaternaire* 54,3: 281-299.

Butler, D., Malanson, G.P., Oelfke, J.G. (1987): Tree-ring analysis and natural hazard: minimum sample sizes and index values. *Professional Geographer* 39,1: 41-47.

Couture, R., Evans, S.E., Locat, J., (2002): Bibliography Canadian Subaerial Cannelized Debris Flows. *Natural Hazards* 26: 1–6.

Dubé, S., Filion, L., Hétu, B. (2004): Tree-ring reconstruction of high-magnitude snow avalanches in the Northern Gaspé Peninsula, Québec, Canada. *Arctic, Antarctic, and Alpine Research*, 34, 4: 555-564.

Eisbacher, G.H. and Clague, J.J. (1984): Destructive mass movements in high mountains: hazard and management. *Geological Survey of Canada* 84-16: 230p.

Hébert, C., Cadieux, A-M., van Breemen, O. (2005): Temporal evolution and nature of Ti–Fe–P mineralization in the anorthosite–mangerite–charnockite–granite (AMCG) suites of the southcentral Grenville Province, Saguenay – Lac St. Jean area, Quebec, Canada. *Can. J. Earth Sci.* 42: 1865–1880.

Jakob, M. (1996): Debris flows - curse of the mountains. Geography Review, 9(5):34-36.

Shroder, J.F. (1978): Dendrogeomorphological analysis of mass movements on Table Cliffs Plateau Utah. *Quaternary Research* 9: 168-185.

Van Asch, Th.W.J., Van Steijn H. (1991): Temporal patterns of mass movements in The French Alps. *Catena* 18: 515-527.

Vandine, D. F., Bovis, M. (2002): History and Goals of Canadian Debris Flow Research, A Review. *Natural Hazards* 26: 69–82

Dendrochronological records of erosion and sedimentation in a mid-mountain stream (Jeseniki Mountains – Czech Republic)

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Introduction

In the longitudinal section of temperate mid-mountain fluvial systems (catchments) two zones can usually be distinguished: the sediment production zone (upper part of a catchment) and the sediment transport and deposition/ redeposition zone, which has short sections of sediment input (middle and lower part) (Schumm 1977, Owczarek 2005). The course of erosional and depositional processes in each of the zones is different. In the upper part of the fluvial system, increased activity of slope processes and sediment supply into the stream channel are observed. The most important sources of sediment in this zone are debris flows and landslides (Harvey 1991, 2001, Migon et al. 2002, Owczarek 2007). Deposition of sediment supplied from the upper parts of the catchment, takes place in the medial and lower sections of the stream channel. This deposition is frequently forced by check dams, which are a common form of hydrotechnics in mid-mountain areas in Central Europe.

Debris flow activity is very often investigated using tree ring analysis (Butler 1987). Abrupt tree ring width reduction and growth release, as well as the ages of adventitious roots are commonly used as dendrochronological markers in this type of study (Schweingruber 1996, Strunk 1997, Stoffel et al. 2005). However, no studies have investigated the erosion and accumulation processes of stream channels above and below check dams.

The aims of this study are (1) to identify debris flows on the basis of geomorphic forms; (2) to date the erosional events along the debris flow track by means of dendrochronological evidence; (3) to determine the erosional and depositional events in a river channel above and below check dams and (4) to combine dendrochronological results derived from debris flows and stream channels in order to compare the frequencies of erosional and depositional events.

Study area

The study area is located in the upper part of the Cerny Potok catchment in the Eastern Sudetes Mountains called the Jeseniki Mountains (north eastern Czech Republic) (Fig 1).

The Sudetes Mountains belong to a vast low mountain range that formed during the Hercynian Orogeny, an event which produced numerous mountain ranges and isolated massifs in Central and Western Europe. The Jeseniki Mountains are built of Proterozoic and Old Palaeozoic crystalline and metamorphic rocks, primarily gneisses. The research catchment (1.56 km^2) is located in the eastern slopes of the Cervena Hora massif (1337 m

a.s.l.). Originally, the massif was covered by beech and mixed forest, gradually giving way to spruce forests at higher elevations. This vegetation has been replaced by spruce monocultures; the highest trees being planted above the original timberline (1,250 – 1,300 m a.s.l.). The rainfall in the research area averages about 1,500 mm/year and more than 50 percent of the total precipitates during the summer months. Two high-water periods are typically observed in the streams of the Sudetes Mountains: (1) the June/July flood, caused by heavy rains, tends to be particularly high, and (2) the springtime snow-melt flood is spread over a longer period of time.

The length of the section of the Cerny Potok stream analyzed is 2.2 km. The stream channel is mainly incised within alluvial deposits, but occasionally passes short sections of bedrock. The maximal incline of the channel is 19.5 %. Two parts can be distinguished in the Cerny Potok stream catchment. The upper part forms the sediment supply zone, where erosional processes dominate. In this part, debris flows during summers and snow avalanches in winter are observed. In the lower part of the analyzed catchment, depositional processes dominate. The fluvial deposit is captured by the system of five check dams, which are spread over a 400 m section of the stream channel (Fig. 1.).
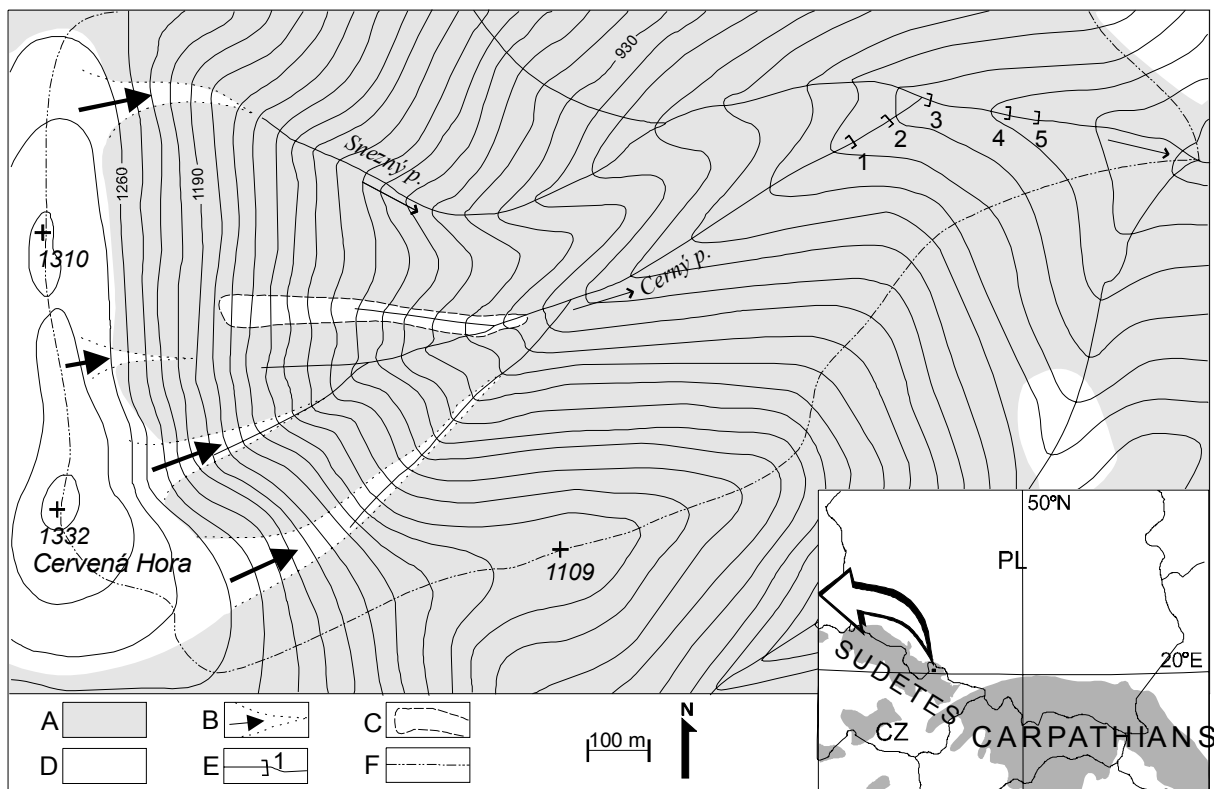
Figure 1: Location of study area and sites A – forested area, B – deforested area, C – snow avalanche tracks, D – dams (study sites), E –debris flow track, F – border of the Cerny Potok catchment.

Methods

The 350 m debris flow track of the Cerny Potok stream were surveyed by using a tape-measure, a staff and a Frieberg 59 compass. The volume of sediments deposited upstream of the check dams was estimated based on the area and depth of accumulated material.

The dendrochronological investigation was based on four methods of study. First, seven beech sprouts growing on the debris flow gully were dated. The dating of the sprouts allows an estimate of the time period of slope stability. Secondly, growth ring width reductions of 34 spruces, growing on the margin of the debris flow track and near the check dams of the Cerny Potok stream, were dated. These trees were wounded by transported material and abrupt growth reduction resulted from this process. Dating of growth reductions allows detecting changes in stream channel morphology. A local chronology was constructed from 15 living spruce trees growing on Cervena Hora massif. Then, 20 logs of spruces laying on the debris flow tongue were dated. The log ages revealed information about debris flow events. Finally, exposure of six roots were dated. Roots of spruces growing below and above dams are exposed as a result of bank erosion. Dating of root exposure allows the determination of erosion episodes.

Results and discussion

Dendrogeomorphological analyses of debris-flow activity in the Cervona Hora massif

One of the most important sources of sediment in the Cerny Potok stream channel is an active track of debris flow. The debris flow is located in the upper part of the catchment on the eastern slope of the Cervena Hora massif below the timberline (Fig. 1). The steep slopes and foliation of mica schists covered by a thick periglacial deposit contribute to debris flows. The extension of the youngest debris flow track reaches about 750 m. In its longitudinal section three distinct parts can be observed: debris flow niche, gully and tongue (Fig. 2, 3).
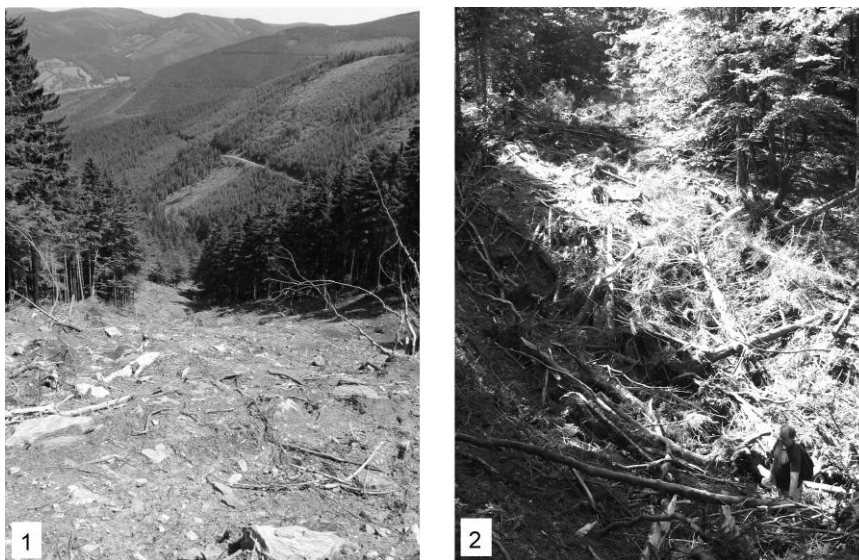
Figure 2: Pictures of debris flow track morphology located in the Cervona Hora massif: 1–debris flow gully in the upper part of the debris flow track, 2– accumulation of woody debris in the tongue of the debris flow track.
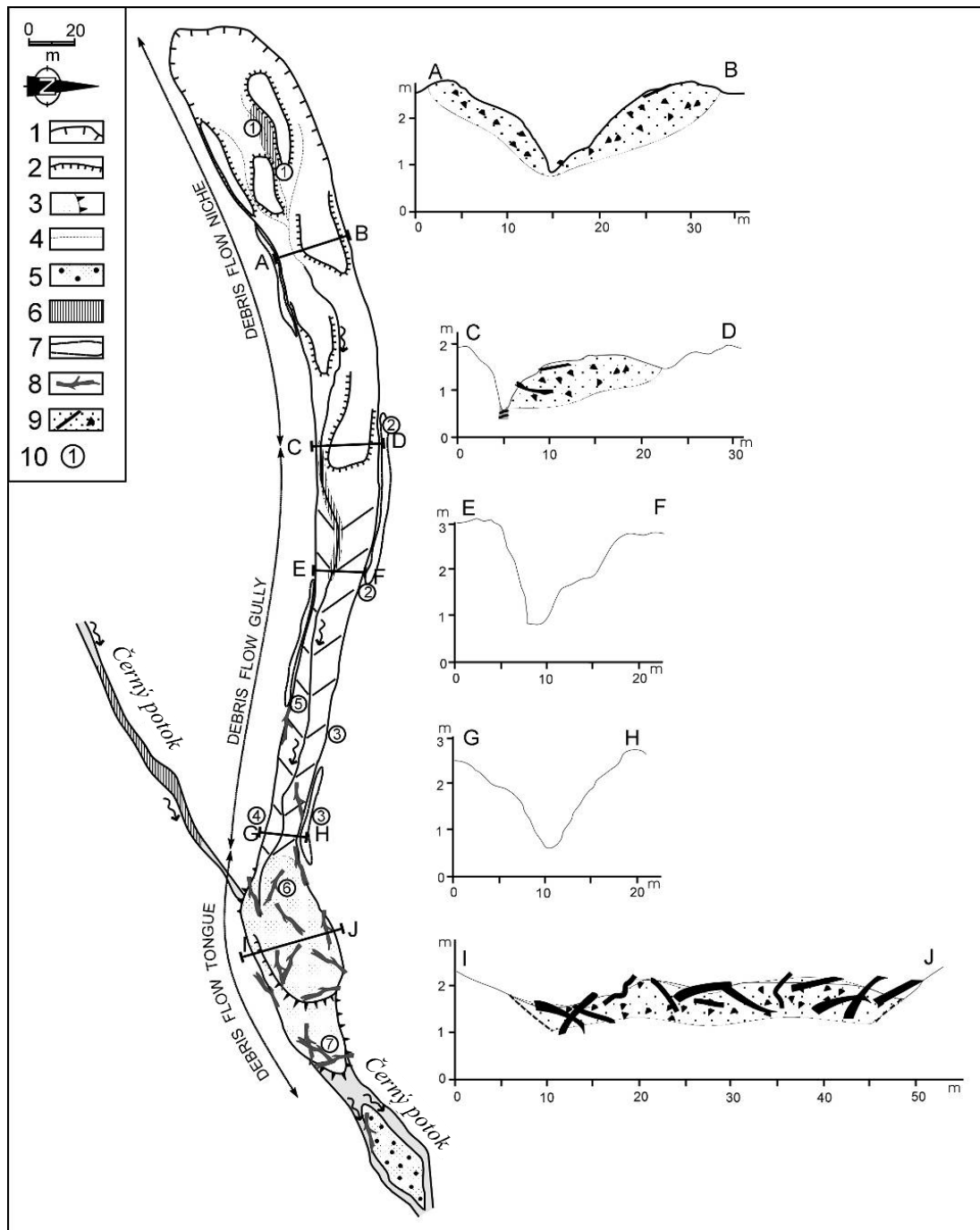
Figure 3: Morphological sketch and cross-section of the debris-flow under study
1 – edge of the niche, 2 – edge of accumulation forms, 3 – debris-flow tongue, 4 – episodically drained small gullies, 5 – depositional river channel forms, 6 – bedrock outcrops, 7 – debris-flow levee, 8 – coarse woody debris, 9 – coarse grained sediments with logs 10 – location of the dendrochronological research sites.

The upper part of the debris flow forms the shallow niche which is maximum 55 m wide and about 130 m long. The debris flow gully extends the niche downstream and forms a distinct erosional trough 4 to 5 m deep and 24 to 35 m wide (Fig. 2.1). The lower part forms the debris flow tongue, which fills the Cerny Potok stream channel over a distance of 160 m. This deposition zone accumulates mineral deposits and coarse woody debris several meters in thickness (Fig. 2.2).

The dendrochronological study shows that trees started growing at the margin of the debris flow between 1908 and 1963. On the adjacent slope, trees are about 150 years old. Hence, the studied slope was transformed by debris flows at the turn of the 19th to the 20th century. All trees collected from the tongue of the debris flow started growing between 1935 and 1964. However, the debris flows took place several years before; probably during an extraordinary rainfall event in June 1921. During this event numerous debris flow were recorded on the Cervona Hora slopes (Stekl et al. 2001). The slope was gradually reforested after the event. Most of the growth reductions observed in trees at the margin of the debris flow occurred in the years 1967/1968, 1971 to 1973 and 1975 to 78 (Fig. 6), meaning that the slope was intensively transformed during these periods. Additionally, reforestation was stopped following important debris flow events after 1965. These debris flows occurred in the existing gully, and were probably induced by snow melt.

Dendrogeomorphological analyses of Cerny Potok on both sides of check dams

Check dams, which force deposition of mineral and organic material originated from the upper part of the catchment (as observed from the deposits of the debris flow), are located in the medial and lower section of the Cerny Potok stream channel (Fig. 4). The system of 5 dams was built in the aftermath of catastrophic events, which occurred between 1920 and 1930, These events were comparable to the large floods observed at the end of the 19th and the beginning of the 20th century. The check dams (all < 6 m height) have induced the change of natural fluvial processes and the course of the Cerny Potok stream. Accumulation of sediment occurs upstream of the dams whereas intensive erosion is observed downstream (Fig. 5). The dam reservoirs are almost completely filled with 198 to 387 m^3 of fluvial deposits. Erosional terraces and deep incisions of the stream channel downstream of the dams indicate domination of erosional processes downstream. The depth of the incision running into the stream channel depends on the height of the dam and ranges from 1.0 to 2.0 m.
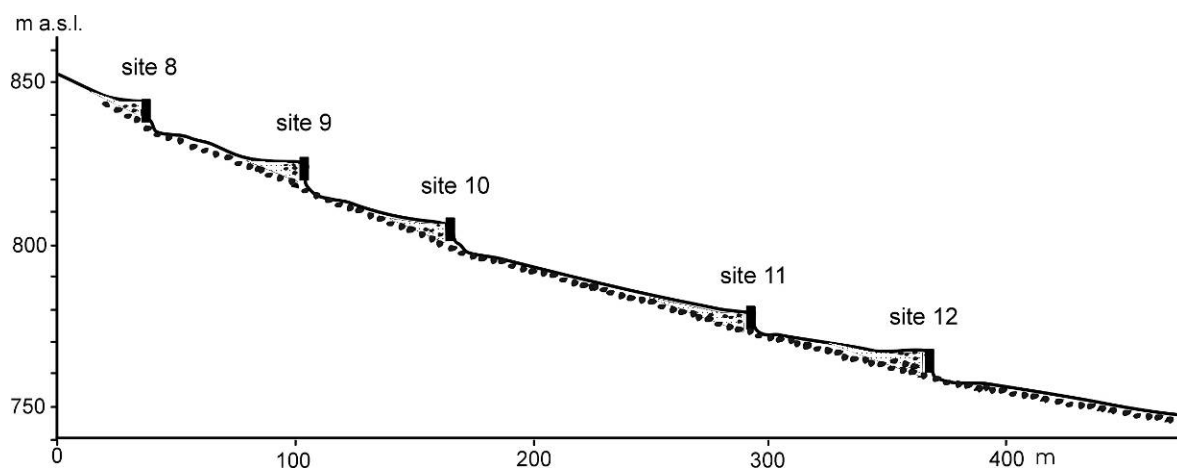

Figure 4: Longitudinal profile of Cerny Potok stream.

Figure 5: Material accumulated upstream of one of the dams in Cerny Potok stream.

Cerny Potok stream transformations were recorded as pointer years and occurred in 1948, 1957, 1962, 1967/68, 1972/73, 1979, 1983, 1985/87 and 1997 (Fig. 6). Trees growing on the upper section are about 65 years old, trees in the lower section germinated earlier, in the first decade of 20th century. The trees in the upper part of the study area were probably killed during the extraordinary event of 1921. The oldest episodes were recorded in the lower part of the Cerny Potok stream in 1921 and 1935/36 (Fig. 6). No morphological transformation episodes occurred between 1936 and 1972. Important transformations of the stream channel took place between 1972 and 1988. Dendrochronological analysis revealed that reservoirs above the check dams are filled within 50 to 60 years (Fig. 6). Erosion started downstream after the dams had been built. Intensive bank erosion occurred in the stream channel as soon as the reservoirs above the check dams were filled.

Comparison of debris flow activity and time of Cerny Potok valley floor transformation based on dendrochronological features

Our dendrochronological investigations show that the episodes transforming Cervona Hora slopes occur before events forming the Cerny Potok stream channel (Fig. 6). Intense debris flow activity occurred on the Cervona Hora slope between 1967 and 1978; whereas the Cerny Potok stream channel was extremely transformed in the period between 1972 and 1988 (Fig. 6). The results show that material transportation in the riverbed occurred after the debris flow on the Cervena Hora slope. In the Cerny Potok stream channel the tongue sediments are partially undercut by the river during floods. The material transported is partially captured by dams located downstream of Cerny Potok stream. A similar situation was observed in the 1990s when a period of increased debris flow was activity recorded by log accumulation between 1990 and 1997. The stream channel was again later transformed, between 1995 and 1999 (Fig. 6).
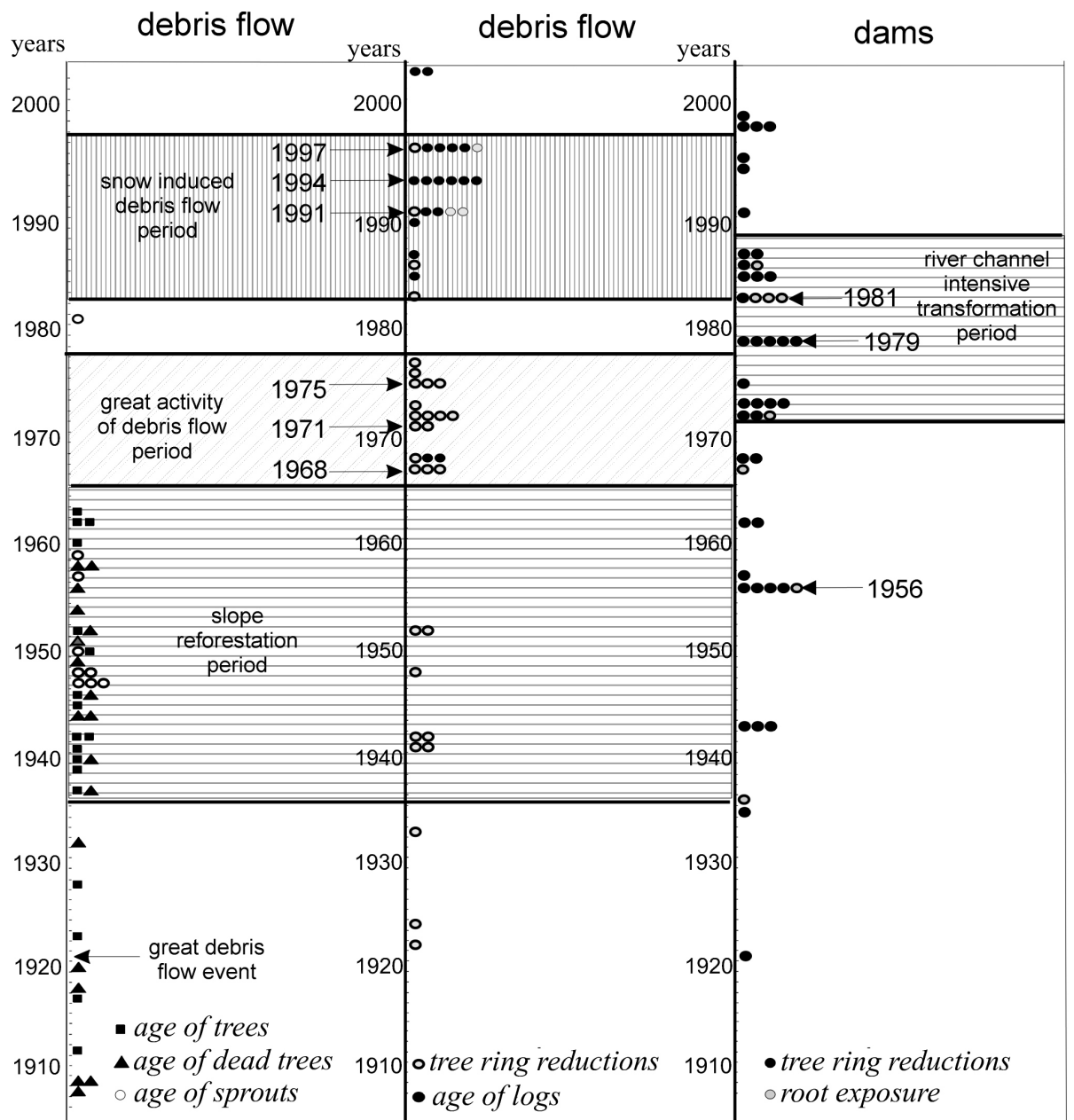
Figure 6: Comparison of dendrochronological results derived from Cervena Hora debris flow track and Cerny Potok stream.

Conclusions

1. The origin of the debris flows is connected with intense rainfall and structural conditions of the metamorphic bedrock.

- the dip of the rock layers is related to the slope gradient direction,
- metamorphic rocks (e.g. mica schists) produce a large amount of silty-debris slope sediment.

2. The oldest reconstructed episode, which influenced debris flow activity in the Cervena Hora massif, was recorded during the extraordinary precipitation event of 1921.

3. After the period of low debris flow activity between 1930 and 1965, the next intensive debris flow episodes were recorded in 1967 and 1978.

4. The third phase of the Cervena Hora slope activity (the end of 20th century) is an effect of snowmelt-induced debris flows.

5. The dam reservoirs have been filled since 1950 and about 1500 m³ of material was deposited above the dams.

6. The Cerny Potok valley floor was intensively transformed during the period between 1972 and 1988.

7. Stream channel and slope activities are not synchronous. Erosion and accumulation episodes in stream channels occur several years after debris flow events.

References

Butler, D.R. 1987: Teaching general principles and applications of dendrogeomorphology. *Journal of Geological Education* 35: 64-70.

Štekl J., Brázdil R., Kakos V., Jež J., Tolasz R. 2001: Extremal sums of rains on the area of the Czech Republic in 1879 – 2000 with their synoptic causes. Czech Hydrometeorological Institute, Prague. 140 pp.

Harvey, A.M. 1991: The influence of sediment supply on the channel morphology of upland streams: Howgill Fells, Northwest England. *Earth Surface Processes and Landforms 16*: 675–684.

Harvey, A.M. 2001: Coupling between hill slopes and channels in upland fluvial systems: implications for landscape sensitivity, illustrated from the Howgill Fells, Northwest England. *Catena 42*: 225–250.

Migon, P., Hradek, M., Parzoch, K., 2002: Extreme events in the Sudetes Mountains, their long-term geomorphic impact and possible controlling factors. *Studia Geomorphologica Carpatho-Balcanica 36*: 29–49.

Owczarek, P. 2005: The features of the mid-mountain temperate fluvial system. *Geomorphologicky sbornik 4*: 83–86.

Owczarek, P. 2007: Hillslope deposits in gravel-bed rivers and their effects on the evolution of alluvial channel forms: a case study from the Sudetes and Carpathian Mountains. *Geomorphology* (in press).

Schumm, S.A. 1977: The fluvial system. Wiley, New York, 338 pp.

Schweingruber F.H., 1996: Tree rings and environment. Dendroecology, Berne, Paul Haupt Verlag, 609 pp.

Stoffel, M., Lièvre, I., Conus, D., Grichting, M. A., Raetzo, H., Gärtner, H., Monbaron, M., 2005: 400 Years of Debris-Flow Activity and Triggering Weather Conditions: Ritigraben, Valais, Switzerland. *Arctic, Antarctic and Alpine Research* 37: 387-395.

Strunk, H. 1997: Dating of geomorphological processes using dendrogeomorphological methods. *Catena* 31: 137-151.

Dendrogeomorphological analysis of alpine trees and shrubs growing on active and inactive rockglaciers

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Introduction

The occurrence of permafrost and related landforms (e.g., rockglaciers) is a widespread phenomenon in many high mountain geosystems. In the context of changing environments, there is a need for thoroughly monitoring and analyzing the sensitivity and the complex response of these geosystems. Diverse methods like geomorphological mapping, terrestrial geodetic survey as well as photogrammetric analyses have been applied in order to assess the activity of rockglaciers and to quantify their movements (Roer et al. 2005b, Roer & Nyenhuis, in press). In general, the activity of rockglaciers is classified by their ice content and flow behaviour (Haeberli 1985, Barsch 1996). Active rockglaciers contain ice and move with at least 0.1 m/a, whereas inactive landforms still contain ice but actually do not move. Relict rockglaciers indicate former permafrost conditions; they lack the ice and definitely stopped moving (often several hundred to thousand years ago).

In addition to the mentioned techniques, a new approach has been designed assessing rockglacier activity by using dendrogeomorphological methods (Roer 2005). In permafrost science, and especially in rockglacier studies, dendrogeomorphology (Alestalo 1971) has rarely been applied. This is mainly due to the position of rockglaciers above the timberline. In addition, the vegetation cover is generally sparse, since rockglacier surfaces consist of coarse and blocky material (e.g., Giardino et al. 1984, Roer & Nyenhuis, in press). Thus, on active rockglaciers herbs and small shrubs are mostly restricted to areas with fine material (at lobe fronts and on ridges). Ring-width variations due to environmental stresses have rarely been studied in shrubs (e.g., Gers et al. 2001). However, a first monograph on growth rings in herbs and shrubs has recently been presented by Schweingruber and Poschlod (2005) and recent studies on cell structures in tree rings ascertained the great potential of wood-anatomical investigations (Gärtner et al. 2001, López et al. 2005, Heinrich et al. 2007, Eilmann et al. 2006).

Regarding dendrogeomorphological studies on periglacial processes, Zoltai (1975) was the first to report on reaction wood in different *Picea* species related to gelifluction in the Subarctic. He took stem slices from 157 trees and illustrated different phases of activity between 1847 and 1943. Additionally, he correlated the activity phases with climatic parameters. Giardino et al. (1984) studied reaction wood, tree-ring variations and tilting of 283 trees on a rockglacier complex and revealed different periods of movement since the 15th century. Jakob (1995) monitored dwarf-shrubs in the Canadian Arctic, which had been run over by gelifluction lobes. He was able to quantify movement rates of between 1.9 and

3.5 cm/a. Bachrach et al. (2004) used dendrogeomorphological methods to document the long-term development of a rockglacier in Alberta, Canada. In this case, trees (*Picea engelmannii* and *Abies lasiocarpa*) were covered by an advancing rockglacier. By comparing the death-dates of different trees, a front advance of 1.6 cm/a was estimated. Recently, Körner and Hoch (2006) investigated the dwarfing of trees growing on low elevation permafrost islands.

At the site investigated here (Turtmann Valley, Swiss Alps), different techniques have been used to quantify rockglacier movements (Roer 2005, Roer et al. 2005b). While terrestrial geodetic survey and digital photogrammetry are standard techniques for this purpose (cf., Kääb et al. 2005), the application of dendrogeomorphological methods have never been conducted in this regard but have the potential to supply additional information. Therefore, the main purpose of this feasibility study is the application of dendrogeomorphological analysis of alpine shrubs and trees in order to detect ground movements resulting from permafrost creep. The investigation focuses on wood-anatomical features in shrubs (vessel sizes), which were never examined before; neither in the given context nor for the selected species. The resulting data are interpreted and verified in relation to information on rockglacier kinematics derived from digital photogrammetric analyses (Roer et al. 2005a,b). The comparison allows for a conclusive validation of the applicability of dendrogeomorphological techniques and hence enables the implementation of this innovative approach in periglacial investigations.

Study area

The Turtmann valley is located south of the River Rhone in southern Switzerland (7° 38' E, 46° 13' N) (Fig. 1).

Figure 1: Location of the study area (Turtmann Valley) within Switzerland (black rectangle). Underlying DTM: © Swisstopo.

Due to its inner-alpine location, the area is characterised by an intramontane climate with an annual precipitation of 600-900 mm/a at c. 2000 m a.s.l. and a 0°C isotherm of the mean annual air temperature (MAAT) at c. 2300 m a.s.l. (van Tatenhove & Dikau 1990). The timberline is situated at 2200 m a.s.l., while the treeline, which is affected by grazing during the summer months, runs at 2400 m a.s.l.. The geomorphology of the Turtmann valley is dominated by several hanging valleys and two big glaciers. In addition, a multitude of

periglacial landforms such as gelifluction lobes, ploughing boulders, and rockglaciers are found above the shoulders of the glacial trough. Rockglaciers are the most striking landforms covering 4.2% of the total area of 110 km2. They occur in different states of activity and with varying degrees of vegetation cover (Roer & Nyenhuis, in press), thus making them suitable for investigations by dendroecological methods.

Most of the samples were taken from a site comprising an active and an inactive rockglacier, respectively, situated next to each other (Fig. 2). The active lobe creeps with extraordinary high velocities and indicates instability at its terminus (Roer 2005, Kääb et al. 2005, Kääb et al., in press). At the location of the sampled shrubs horizontal velocities between 0.5 and 2 m/a have been measured (Fig. 2).
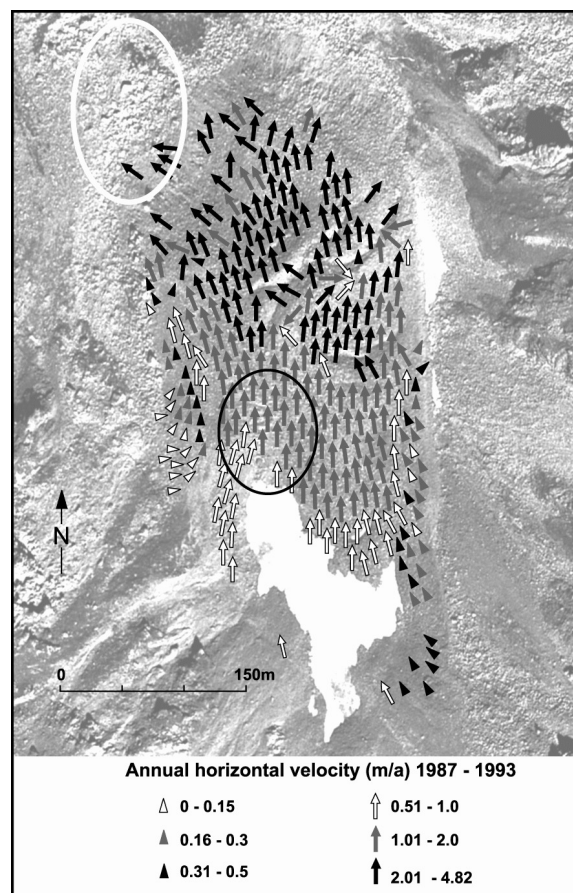
Figure 2: Location of the sample sites on the active (black circle) and on the inactive rockglacier (white circle). Note the extraordinary high horizontal velocities of the active lobe (given here for the period 1987 – 1993). Underlying orthophoto of 1993; ©Swisstopo.

Apart from the activity, other influencing factors (e.g., aspect, slope angle, etc.) are similar at the two sites. However, differences may exist in the thickness of the frozen core of the rockglacier. On the active rockglacier the upper part (several meters) – the so-called active layer - thaws in summer time, but is completely frozen during winter. On the inactive lobe, the thawed layer presumably is much thicker in summer and the freezing during winter time cannot completely penetrate through this layer; thus an unfrozen layer (talik) may exist in several meters depth.

Material and methods

During different field campaigns, some small trees (*Pinus cembra, Larix decidua*) and dwarf shrubs (*Salix helvetica*) were located on rockglaciers in the Turtmann valley (cf., Roer 2005). Several discs (at stem and roots) were taken from one tree growing at the front of an active rockglacier. Tree rings were counted, compiled and compared in skeleton-plots (Stokes & Smiley 1968, Schweingruber et al. 1990). This visual comparison allowed the identification of sudden growth changes and supplied evidence for missing tree rings in individual samples. Tree-ring widths were measured with an accuracy of 1/100 mm resulting in a tree-ring chronology which was validated by crossdating in order to guarantee exact dating (Fritts 1976, Cook & Kairiukstis 1990).

Regarding the analysis of shrubs, reaction wood is difficult to investigate due to the lack of a main stem. The single branches of shrubs often show reaction wood which might be caused by different mechanical stress factors, such as snow cover and wind exposure. In contrast, the root collar and especially the roots of shrubs growing under more stable conditions (in the soil), and hence they are best suited for the investigation of possible influences of ground movements envisaged in this study. Changes in the root environment may lead to growth stress and result in changes of the ring structures and wood anatomy (Gärtner 2003a,b).

In order to study these potential changes, entire specimens of *Salix helvetica* shrubs were taken from an active rockglacier lobe (n = 28) as well as from an adjacent inactive rockglacier (n = 20), including their entire root systems (Fig. 3). The inactive rockglacier was not affected by creep during the last 30 years and contains a frozen core (Roer 2005, Broccard 1998).

Figure 3: Salix helvetica shrub sampled from an active rockglacier. White rectangles (1 and 2) indicate the positions of the root samples collected for the analysis of anatomical variations.

In the laboratory, several discs were taken from the individual roots of the shrubs. The small size of most roots (~1.5 cm) enabled the preparation of micro-sections (thickness ~15 µ) of entire cross sections using a sledge microtome (Fig. 4).

The sections were stained with Safranin and Astrablue to distinguish between lignified (Safranin) and non-lignified (Astrablue) parts of the rings and to obtain a better contrast for the following image analysis procedure. For dehydration, the samples were rinsed with

alcohol, immersed in Xylol, embedded in Canada-Balsam and dried at 60° C in an oven for about 24 hours (Gärtner et al. 2001).
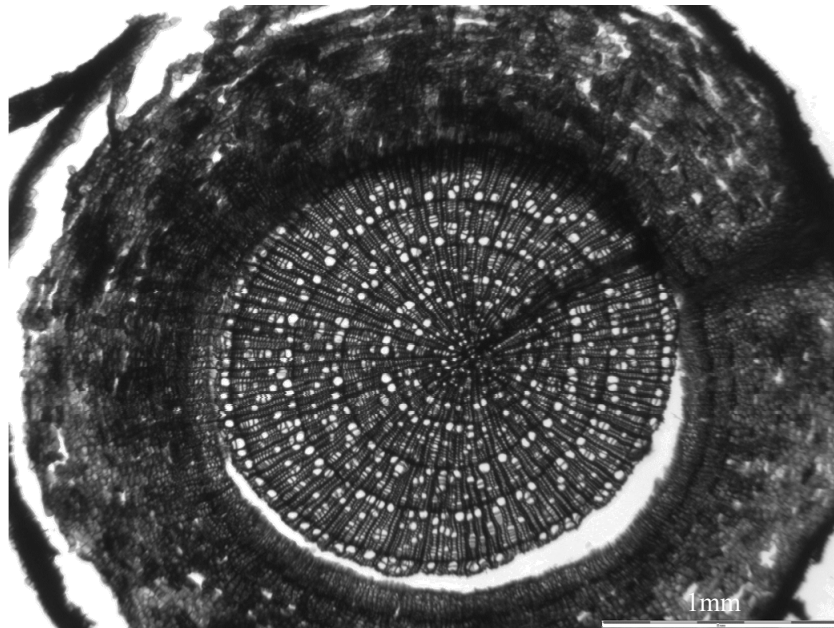

Figure 4: Digital micro photo (40x magnification) of a lateral root (Salix helvetica) which had been grown on an active rockglacier. Note the distinct annual rings and the thick surrounding bark.

The resulting micro slides were then placed under a microscope and digital photos, with 40 times magnification, were taken. In addition to the micro-sections, micro scales were photographed using the same magnification to guarantee correct scaling during digital imagery. The micro photos were then used to measure vessel sizes of stressed (active rockglacier) and unstressed (inactive rockglacier) samples using the image analysis program WinCELL (Regents Instruments, Canada). Finally, the resulting data were statistically analysed.

Results

Reaction wood in Pinus cembra stem

At the front of an active rockglacier, a *Pinus cembra* tree was sampled in 2000 (cf., Roer 2005). Even though it was the only tree (age: 34 years) growing on the rockglacier, it shows distinct compression wood phases in reaction to the tilting of the stem by ground movements (Fig. 5). After a stable growing period between 1966 and 1969, compression wood directed upslope occurs in 1970 for the first time, from 1990 it appears more distinct and in the outermost rings (1997 – 2000) it suggests major influences. In addition, the occurrence of resin ducts in the latewood of the rings 1987, 1988, 1990 as well as between 1997 and 1999 indicates strong mechanical stresses in the stem at the end of the growing season.
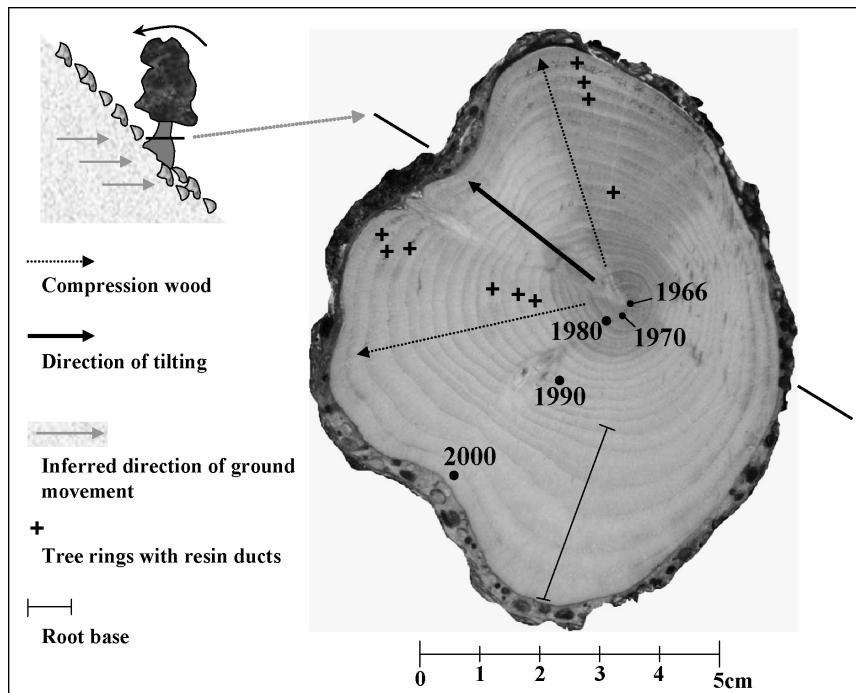
Figure 5: Compression wood in Pinus cembra stem and inferred movement of the ground (Source: Roer, 2005: 176).

Anatomical variations in Salix helvetica roots

The preliminary analysis did not show any obvious differences in ring-width variations between the unstressed and stressed samples from the inactive (Ref) and active (BG) rockglacier lobe, respectively. However, differences appear in regard to variations in the structure of tracheids and fibre cells formed mainly to stabilize the plant. More strikingly, a comparison of the vessels sizes within individual rings of the stressed and unstressed samples revealed general differences (Fig. 6). Dimensions and numbers of vessels in roots taken from the inactive rockglacier tend to be larger than those from the stressed site.
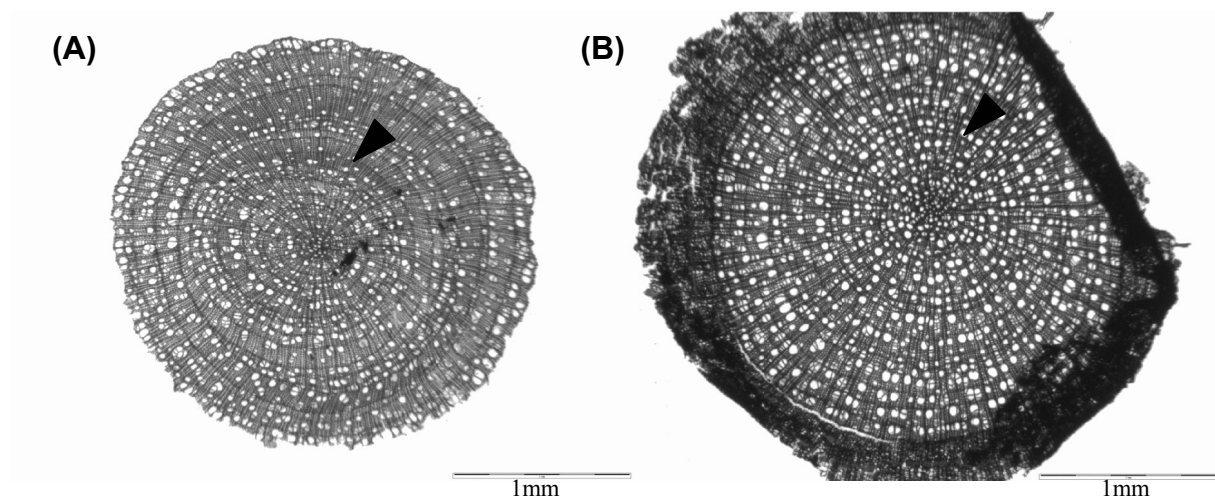

Figure 6: Micro-sections of Salix helvetica roots from an active rockglacier (BG) (A) and an inactive rockglacier (Ref) (B); Black arrows indicate vessels (magnification: 40x). The differences in number and size of the vessels of stressed (A) and unstressed (B) roots are remarkable.

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To further analyse this visual impression, vessel sizes in all micro-sections (stressed and unstressed) were quantified. First results showed that it was possible to apply an automated, comparable measurement of vessel sizes within the growth rings of the *Salix helvetica* roots. In addition, a filter which excluded all cells with an area smaller than 0.0002 mm^2 was applied. These cells were defined to be tracheids, that is, cells of the underlying tissue of the rings. All cells larger than 0.0002 mm^2 were identified as vessels. As a result, an average of 1000 vessels was measured per micro-section. Due to this filtering technique, the data do not have a normal but skewed distribution (compare figure 7). In order to analyse the data visually, box-plots are presented (Fig. 7). Within the box plot diagrams, the scale was manually adjusted to a maximum value of 0.006 mm^2 for better visualisation.
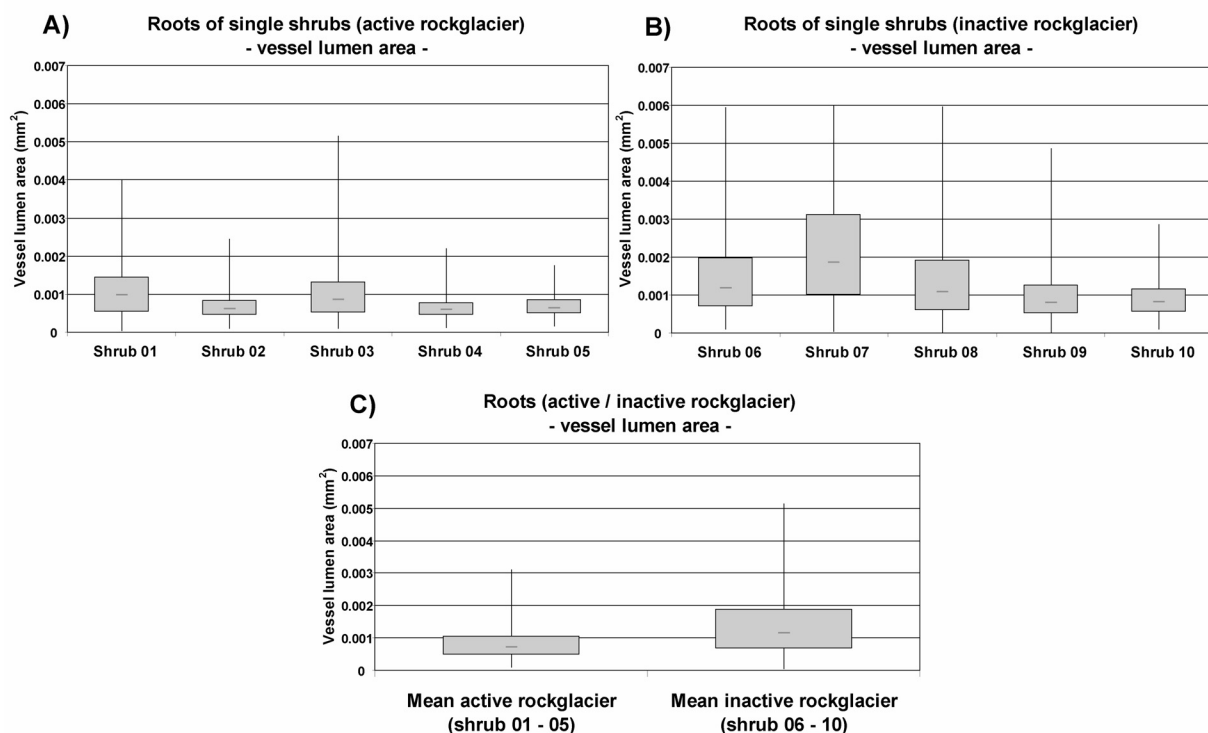

Figure 7: Boxplot visualisation of vessel size data: (A) active; (B) inactive rockglacier; (C) average values of vessel sizes (A) and (B). The skewed distribution is due to the exclusion of all cells < 0.0002 mm^2 (tracheids).

A detailed quality control of the automatic cell measurements showed, that maximum values up to 0.0098 mm^2 for single vessels were caused by errors during identification of vessel cell walls in the micro photos and thus were deleted. Nevertheless, maximum sizes of about 0.006 mm^2 for single vessels were confirmed by visual controls.

The vessel-size measurements confirm the visual impressions; although no significant differences in ring-width variation are revealed, the sizes of vessels are reduced in stressed roots on the active rockglacier compared to those from undisturbed roots on the inactive lobe. The calculated median for vessel sizes in roots of all plants taken from the active part is in average 60% lower than the value in roots of the inactive rockglacier. The statistical spread of approximately 75% to the related median values is lower in each of these plants (boxes in figure 7).

The box-plots of the averaged vessel data for stressed and unstressed roots (diagram (C) in figure 7) are partly overlapping, nevertheless the differences are statistically significant and the visual differences are obvious.

Discussion

The *Pinus cembra* stem growing on a rockglacier front revealed different information on growing conditions. On one hand, the site appears to be rather stable in the first years as the tree shows an unaffected growth. However, starting in the early 1990s, the tree-ring patterns in the form of reaction wood and resin ducts indicate mechanical stresses. These signals seem to result from the tilting of the stem due to ground movements. The findings are in good accordance with the photogrammetric results ascertaining an acceleration of the rockglacier from approximately 0.4 m/a in the period 1975-1993 to 1.5 m/a between 1993 and 2001 (Roer 2005). With the dendrogeomorphological data, it is now possible to determine the beginning of the acceleration; it started in 1990 and appeared to be very distinct between 1997 and 2000. Hence, the tree-ring pattern in the *Pinus cembra* stem at the rockglacier front clearly suggests an increase in horizontal velocities and facilitates a more complete interpretation of the movement rates measured by digital photogrammetry.

The comparison and interpretation of *Salix helvetica* shrubs growing on active and inactive permafrost bodies is more complex. Based on the present observations, the anatomical variations in the roots of *Salix helvetica* shrubs may either result from differences in ground thermal conditions or from movements of the rockglacier, since other environmental conditions (e.g., topography, climate) are comparable on both landforms. Unfortunately, suitable temperature data do not exist for the individual rockglaciers investigated here. At least it is known with certainty that the inactive rockglacier contains a frozen core, which has been documented by photographs taken during construction works at a nearby avalanche dam (Broccard 1998). As the most obvious reason for the differences in vessel size, growth stresses in the ground due to mechanical influences by rockglacier creep are assumed, which is in most cases supported by changes in the fibre tissue. Variations in the structure of tracheids and fibre cells indicating mechanical stress in single years need to be further analyzed regarding the specific conditions of the close environment of the roots. Hence, the findings are in agreement with the physiological patterns described for vessels in tree stems by Lindorf (1994) although the differences in root anatomy are not statistically significant in this dataset. Until now, this phenomenon has not been described for roots of shrubs. In general, vessels are formed to transport water and nutrients and they are known to be variable in size (at least in stems) due to environmental stresses (Kozlowski 1979). Our results indicate that one of these environmental stresses affecting vessel growth of alpine dwarf shrubs is mechanical strain experienced when growing on active rockglaciers.

Conclusion

The determination of permafrost creep using dendrogeomorphological techniques, which depend on the occurrence of trees or shrubs, was conducted on two rockglaciers. The plants sampled were between 20 and 35 years old and thus cover the same period as the data from

photogrammetrical measurements (Roer 2005). On one active permafrost body, the increase in horizontal velocity at the beginning of the 1990s is clearly reflected in the reaction wood. However, since only one tree of this rockglacier was examined the informative value is limited.

On the other rockglacier, anatomical variations were investigated in roots of several shrubs with digital imagery in order to statistically quantify them. Due to the first-time application of wood anatomy in rockglacier research and little experience in the interpretation of the new data, it was not possible to conclude with absolute certainty whether the observed growth variations result from low ground thermal conditions, from movements of the permafrost body or a combination of both factors. However, the application of this technique in rockglacier studies nevertheless appears to be feasible and the findings are promising.

The combination of the described methods provides a good opportunity to thoroughly describe and analyse rockglacier kinematics. Hence, the presented study opens a new method for a careful interpretation of the complex responses of the considered geosystem in the context of changing environments along with significant warming in mountain geosystems (cf., Kääb et al., in press).

References

Alestalo, J. (1971): Dendrochronological interpretation of geomorphic processes. Fennia 105: 140pp.

Bachrach, T., Jakobsen, K., Kinney, J., Nishimura, P., Reyes, A., Laroque, C.P., Smith, D.J. (2004): Dendrogeomorphological assessment of movement at Hilda rock glacier, Banff National Park, Canadian Rocky Mountains. Geografiska Annaler 86A (1): 1-9.

Barsch, D. (1996): Rockglaciers: Indicators for the present and former geoecology in high mountain environments. Springer: Berlin.

Broccard, A. (1998): Géomorphologie du Turtmanntal (Valais). Unpublished Diploma thesis, Department of Geography, University of Lausanne.

Cook, E.R., Kairiukstis, L.A. (1990): Methods of dendrochronology – Applications in the environmental sciences. Kluwer, London.

Eilmann, B., Weber, P., Rigling, A., Eckstein, D. (2006): Growth reactions of Pinus sylvestris L. and Quercus pubescens Willd. to drought years at a xeric site in Valais, Switzerland. Dendrochronologia 23 (3): 121-132.

Fritts, H.C. (1976): Tree rings and climate. Academic Press, London: 567pp.

Gärtner, H. (2003a): The applicability of roots in dendrogeomorphology. In Schleser, G., Winiger, M., Bräuning, A., Gärtner, H., Helle, G., Jansma, E., Neuwirth, B. and Treydte, K. (eds.) TRACE – Tree Rings in Archaeology, Climatology and Ecology 1: 120-124.

Gärtner, H. (2003b): Holzanatomische Analyse diagnostischer Merkmale einer Freilegungsreaktion in Jahrringen von Koniferenwurzeln zur Rekonstruktion geomorphologischer Prozesse. Dissertationes Botanicae 378: 118pp.

Gärtner, H., Schweingruber, F.H., Dikau, R. (2001): Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots. Dendrochronologia 19: 81-91.

Gers, E., Florin, N., Gärtner, H., Glade, T., Dikau, R., Schweingruber, F.H. (2001): Application of shrubs for dendrogeomorphological analysis to reconstruct spatial and temporal landslide movement patterns - a preliminary study. Zeitschrift für Geomorphologie N. F. Suppl.-Bd. 125: 163-175.

Giardino, J.R., Shroder, J.F., Lawson, M.P. (1984): Tree-ring analysis of movement of a rock-glacier complex on Mount Mestas, Colorado, U.S.A. Arctic and Alpine Research 16 (3): 299-309.

Haeberli, W. (1985): Creep of mountain permafrost: Internal structure and flow of alpine rock glaciers. Mitteilungen der VAW/ETH Zürich 77.

Heinrich, I., Gärtner, H., Monbaron, M. (2007): Tension wood formed in *Fagus sylvatica* and *Alnus glutinosa* after simulated mass movement events. IAWA 28 (1), 39-48.

Jakob, M. (1995): Dendrochronology to measure average movement rates of gelifluction lobes. Dendrochronologia 13: 141-146.

Kääb, A., Frauenfelder, R., Roer, I. (in press): On the response of rockglacier creep to surface temperature variations. Global and Planetary Change.

Kääb, A., Huggel, C., Fischer, L., Guex, S., Paul, F., Roer, I., Salzmann, N., Schlaefli, S., Schmutz, K., Schneider, D., Strozzi, T., Weidmann, Y. (2005): Remote Sensing of Glacier- and Permafrost-related Hazards in High Mountains: An Overview. Natural Hazards and Earth System Sciences 5: 527-554.

Körner, C., Hoch, G. (2006): A test of treeline theory on a montane permafrost island. Arctic, Antarctic and Alpine Research 38 (1): 113-119.

Kozlowski, T.T. (1979): Tree Growth and Environmental Stress. University of Washington Press, Seattle, WA: 192pp.

Lindorf, H. (1994): Eco-anatomical wood features of species from a very dry tropical forest. IAWA Journal 15: 361-376.

López, B.C., Sabaté, S., Gracia, C.A., Rodríguez, R. (2005): Wood anatomy, description of annual rings, and responses to ENSO events of Prosopis pallida H.B.K., a wide-spread woody plant of arid and semi-arid lands of Latin America. Journal of Arid Environments 61: 541-554.

Roer, I. (2005): Rockglacier kinematics in a high mountain geosystem. PhD thesis, Department of Geography, University of Bonn. http://hss.ulb.uni-bonn.de/diss_online/math_nat_fak /2005/roer_isabelle.

Roer, I., Nyenhuis, M. (in press): Rockglacier activity studies on a regional scale: comparison of geomorphological mapping and photogrammetric monitoring. Earth Surface Processes and Landforms.

Roer, I., Kääb, A., Dikau, R. (2005a): Rockglacier acceleration in the Turtmann valley (Swiss Alps): probable controls. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 59 (2): 157-163.

Roer, I., Kääb, A., Dikau, R. (2005b): Rockglacier kinematics derived from small-scale aerial photography and digital airborne pushbroom imagery. Zeitschrift für Geomorphologie N. F. 49 (1): 73-87.

Schweingruber, F.H., Poschlod, P. (2005): Growth Rings in Herbs and Shrubs: life span, age determination and stem anatomy. Forest, Snow and Landscape Research 79 (3): 195-415.

Schweingruber, F.H., Eckstein, D., Serre-Bachet, F., Bräker, O.U. (1990): Identification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia 8: 9-38.

Stokes, M.A., Smiley, T.L. (1968): An introduction to tree-ring dating. University of Chicago Press, Chicago: 73pp.

Van Tatenhove, F., Dikau, R. (1990): Past and present permafrost distribution in the Turtmanntal, Wallis, Swiss Alps. Artic and Alpine Research 22 (3): 302-316.

Zoltai, S.C. (1975): Tree ring record of soil movements on permafrost. Arctic and Alpine Research 7 (4): 331-340.

SECTION 6

WOOD ANATOMY

Anatomical description of tracheids in the compression wood of Norway spruce (*Picea abies* L. Karst.)

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Introduction

Reaction wood is formed in both hardwood and softwood species. In most gymnosperms, radial growth increases on the lower side of an inclined shoot or stem and reaction wood also develops on this side. The type of reaction wood formed in gymnosperms is referred to as *compression wood*. In the angiosperms, radial growth in a leaning stem increases on the upper side. Reaction wood is here referred to as *tension wood* (Timell 1986).

Wood is a complex, heterogeneous and anisotropic material of organic origin (Kučera 1973). The anatomical structure of softwood consists only of two anatomical cell types: tracheids and parenchyma cells (Dewitz 1969, Timell 1986, Wagenführ 1999). Tracheids are the main structural component of softwood and their percentage in the wood ranges from 90 to 94% (Sisko & Pfäfli 1995, Plomion et al. 2001). The remaining percentage is composed of parenchyma cells which form the pith rays, the axial parenchyma and resin canals.

This paper aims at describing the tracheids in the compression wood of Norway spruce (*Picea abies* L. Karst.). The objective of the paper is to describe the variability of earlywood and latewood tracheids within the ring, along a radius and at different stem heights.

Material and methods

We have collected one spruce tree (*Picea abies* L. Karst) where the presence of compression wood was anticipated. The tree was located in the Křtiny Training Forest Enterprise Masaryk Forest – Mendel University of Agriculture and Forestry Brno, Forest District Habrůvka, area 164 C 11. The tree stem axis was inclined at an angle of 21°. The tree was 110 years old and its total height was 33 m. Eight discs of 100 mm in thickness were taken from the tree at different heights along the stem (6, 8, 10, 12, 15, 18, 20 and 22 m). On each of the discs, four zones of measurement were determined: the zone of compression wood (CW), the zone opposite to the compression wood (OW) and the lateral zones to the right (SWR) and to the left of the compression wood (SWL).

To determine the variability of the tracheid diameters in relation to the position in the stem, wood samples were taken in the four zones (CW, OW, SWL and SWR) of all discs in the 5th, 15th, 30th, 45th, 60th, 75th and 85th annual ring with the first ring being closest to the cambium. These rings were selected to represent different parts along the stem radius (juvenile, mature and compression wood).

Permanent microscopic slides were made using standard methods (Ives 2001, Vavrčík & Gryc 2004). Microscopic slides of transverse sections were analysed using Lucia image

analysis software. Latewood tracheids (LWT) were defined according to Morkov's criterion (Mork 1928), where the size of the LWT lumen is smaller than the double of the cell wall thickness. The relative position (*RP*) of each tracheid within the ring was calculated as:

RP = *P* / *N*

Where: *P* : Order of the tracheid within the ring and
             N : Number of tracheids within the ring

Results

Descriptive statistics for radial diameters of EWT and LWT are given in table 1. The radial diameter of earlywood tracheids was usually smaller than 30 μm in all zones. The mean radial diameter of LWT ranged from 15 to 17 μm.

Table 1: Descriptive statistics of the radial diameters of earlywood and latewood tracheids.

Height (m)	Statistical quantity	Zone							
		CW		OW		SWL		SWR	
		EW	LW	EW	LW	EW	LW	EW	LW
22	Diameter (μm)	25.60	14.36	25.68	12.60	27.95	13.35	25.65	14.16
	Standard deviation (μm)	4.26	3.62	4.76	3.50	4.41	2.98	4.76	3.48
	Coefficient of variation (%)	16.63	25.21	18.55	27.74	15.77	22.32	18.55	24.56
20	Diameter (μm)	28.93	14.60	29.35	14.82	29.21	14.81	29.20	16.95
	Standard deviation (μm)	4.75	2.85	4.63	3.76	4.16	2.93	4.09	4.08
	Coefficient of variation (%)	16.41	19.51	15.77	25.36	14.24	19.79	13.99	24.05
18	Diameter (μm)	29.35	14.83	29.66	14.91	31.39	16.69	28.73	15.96
	Standard deviation (μm)	6.78	4.28	6.35	3.48	4.73	3.39	4.76	3.18
	Coefficient of variation (%)	23.09	28.85	21.42	23.36	15.06	20.34	16.55	19.92
15	Diameter (μm)	30.96	17.66	30.88	14.75	33.03	14.72	29.27	15.43
	Standard deviation (μm)	5.42	5.70	4.82	3.71	5.73	3.01	5.48	3.65
	Coefficient of variation (%)	17.49	32.30	15.60	25.17	17.34	20.42	18.73	23.63
12	Diameter (μm)	30.37	14.13	30.00	14.14	32.33	14.81	30.69	13.57
	Standard deviation (μm)	5.94	3.17	6.77	4.40	6.47	3.35	6.91	2.23
	Coefficient of variation (%)	19.57	22.40	22.58	31.13	20.01	22.61	22.53	16.42
10	Diameter (μm)	30.42	16.46	29.78	16.25	32.85	17.14	28.30	19.92
	Standard deviation (μm)	6.64	4.09	7.60	3.62	6.77	3.51	7.12	6.03
	Coefficient of variation (%)	21.83	24.82	25.53	22.25	20.62	20.49	25.18	30.29
8	Diameter (μm)	33.16	17.01	29.12	17.09	37.40	20.13	29.38	14.74
	Standard deviation (μm)	6.41	3.54	8.32	5.78	8.42	6.34	7.44	4.14
	Coefficient of variation (%)	19.32	20.80	28.58	33.83	22.53	31.52	25.33	28.06
6	Diameter (μm)	31.50	17.29	31.82	15.09	32.30	20.56	29.04	16.89
	Standard deviation (μm)	6.26	5.24	7.71	4.40	7.67	5.12	5.91	4.66
	Coefficient of variation (%)	19.86	30.29	24.22	29.17	23.74	24.90	20.35	27.61

Based on the data, models were constructed for particular zones describing the variability of EWT and LWT along the stem radius and height. For 3D models describing the earlywood tracheid variability only tracheids at a relative position of 0.3 in the ring (0.96 for the latewood tracheids) were considered. Those models revealed that earlywood tracheid diameters increased with increasing distance from the stem pith (Fig. 1).
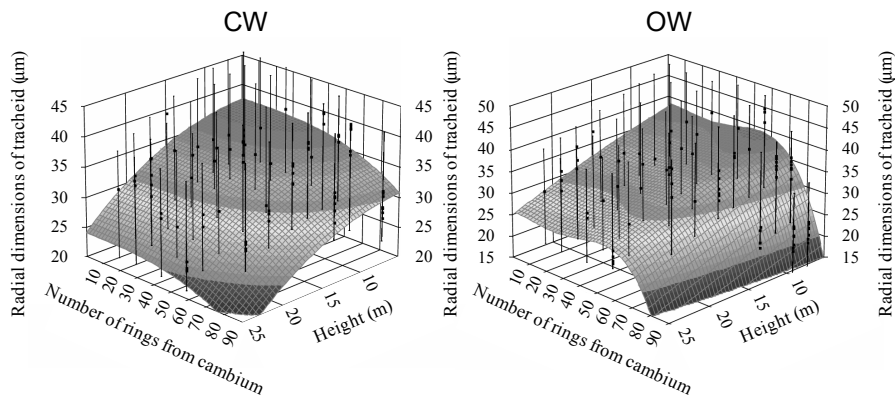
Figure 1: Radial diameter of earlywood tracheids (relative position in the ring 0.3).

The most distinct increase in the tracheid radial diameter occurred in the region of juvenile wood, while maximum values were reached in the 30th annual ring. After that, diameters remained more or less constant. In the most recently formed annual rings a negligible decrease in tracheid diameters was observed. The results were also confirmed by using ANOVA which showed that tracheid diameters were significantly affected by the distance from the stem pith (for all zones). Trends and values of tracheid diameters along the stem radius in the OW, SWL and SWR zones were very similar. As for the variability of tracheid diameters along the stem height, an inverse trend was found: tracheid diameters decreased with stem height. The models reveal that tracheid diameters decrease gradually up to 12 m, however, above this height, the diameter decreases rapidly. Results for latewood tracheids showed very low coefficients of determination. The diameters of latewood tracheids didn't change in the stem. In Table 2, functions describing the variability of the earlywood tracheid in relation to its position in the tree stem are given. The resulting models as well as particular coefficients were statistically significant.

Table 2: Resultant functions and coefficients of determination of the selective and basic sets for the radial diameters an earlywood and latewood tracheid in particular zones of a stem.

Zone	Function	R^2		Coefficients				
		sampling	basic	a	b	c	d	e
CW	$z = a+bx^{2.5}+cy^3$	0.398	0.371	37.836	–0.00439	–0.00001		
OW	$z = a+bx\ln x+cy^2\ln y+dy^{2.5}+ey^3$	0.520	0.490	39.709	–0.17322	–0.02621	0.02165	–0.00100
SWL	$z = a+bx^2+cy^2\ln y+dy^{2.5}+ey^3$	0.692	0.665	40.638	–0.02455	–0.02672	0.02225	–0.00104
SWR	$z = a+bx^2+cy^{2.5}+dy^3$	0.466	0.438	37.226	–0.02350	0.00098	–0.00013	

Figure 2 represents the tracheid variability in relation to the relative position in the ring. The diagram demonstrates that rings with compression wood show on average 1.89 more tracheids as compared to rings from the opposite side. The figure also shows that in the compression zone, diameters of compression tracheids at relative position between 0.5 and 0.9 are nearly constant (30 μm). In rings with compression wood, the tracheid diameters decreased in the last part of the ring. However, it is necessary to point out that these tracheids were not compression tracheids any more, but latewood tracheids.
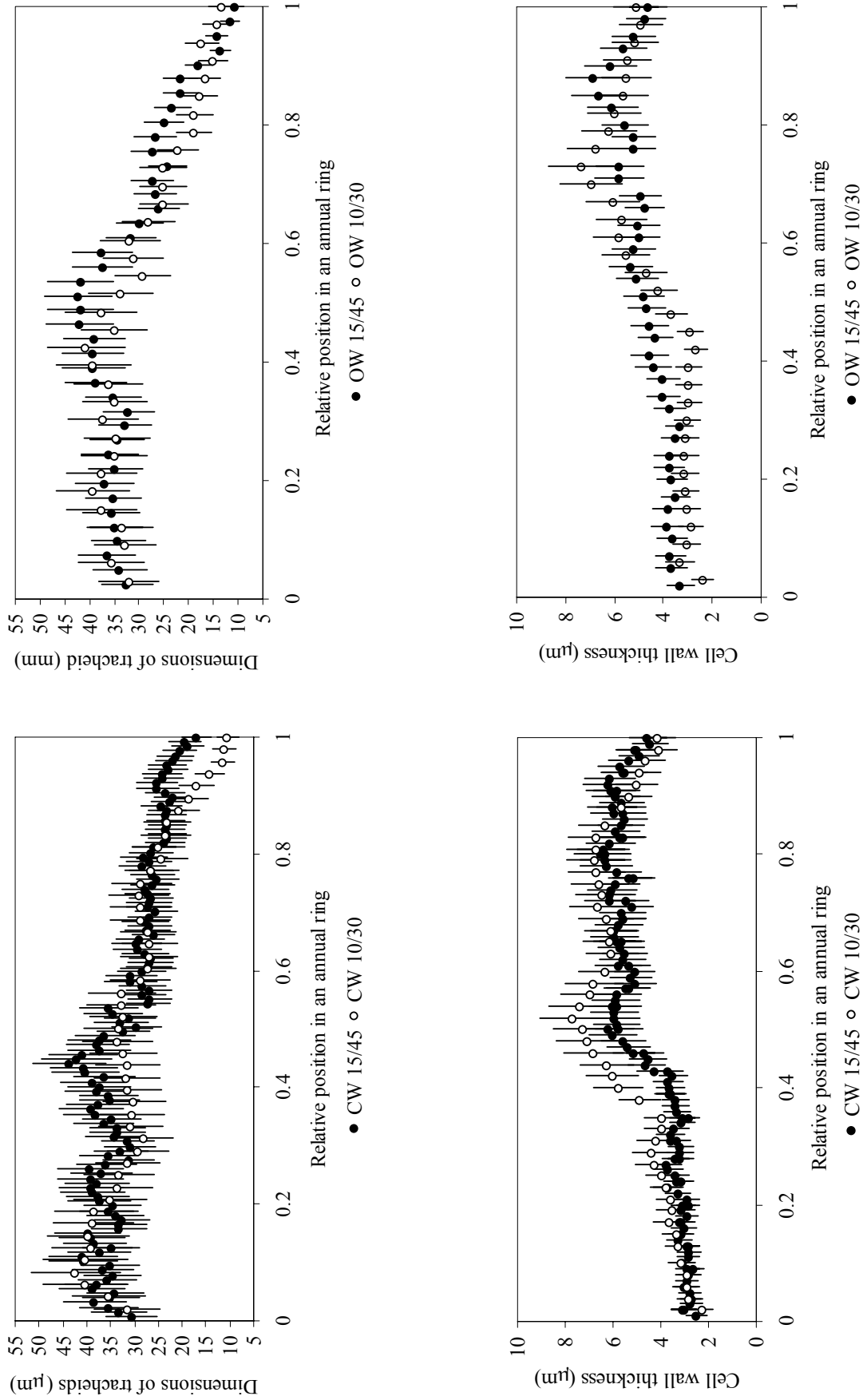
Figure 2: Comparison of tracheid diameters and cell wall thickness in relation to the relative position in the ring; height 15 meters (ring 45) and 10 meters (ring 30).

The trend of the cell wall thickness in relation to its relative position in the ring was also different between rings with and without compression wood (Fig. 3). Earlywood tracheids (relative position 0–0.45) in CW and OW zones showed no significant trend in the cell wall thickness. From a relative position of 0.45 onwards, both zones display a different trend in the cell wall thickness. In the compression wood of the CW zone, an abrupt increase in the cell wall thickness occurs. At a relative position of 0.5 to 0.9, the cell wall thickness of compression tracheids reached 5–7 µm. From the relative position of 0.9 onwards, typical latewood tracheids were usually produced and were characterized by a decrease in the cell wall thickness. In rings from the OW zone, a gradual increase occurred in the cell wall thickness of the tracheids (relative position 0.4 – 0.9) with a maximum cell wall thickness at a relative position of 0.8–0.9. At the end of the annual ring (relative position 0.8–1), the cambium produced latewood tracheids.
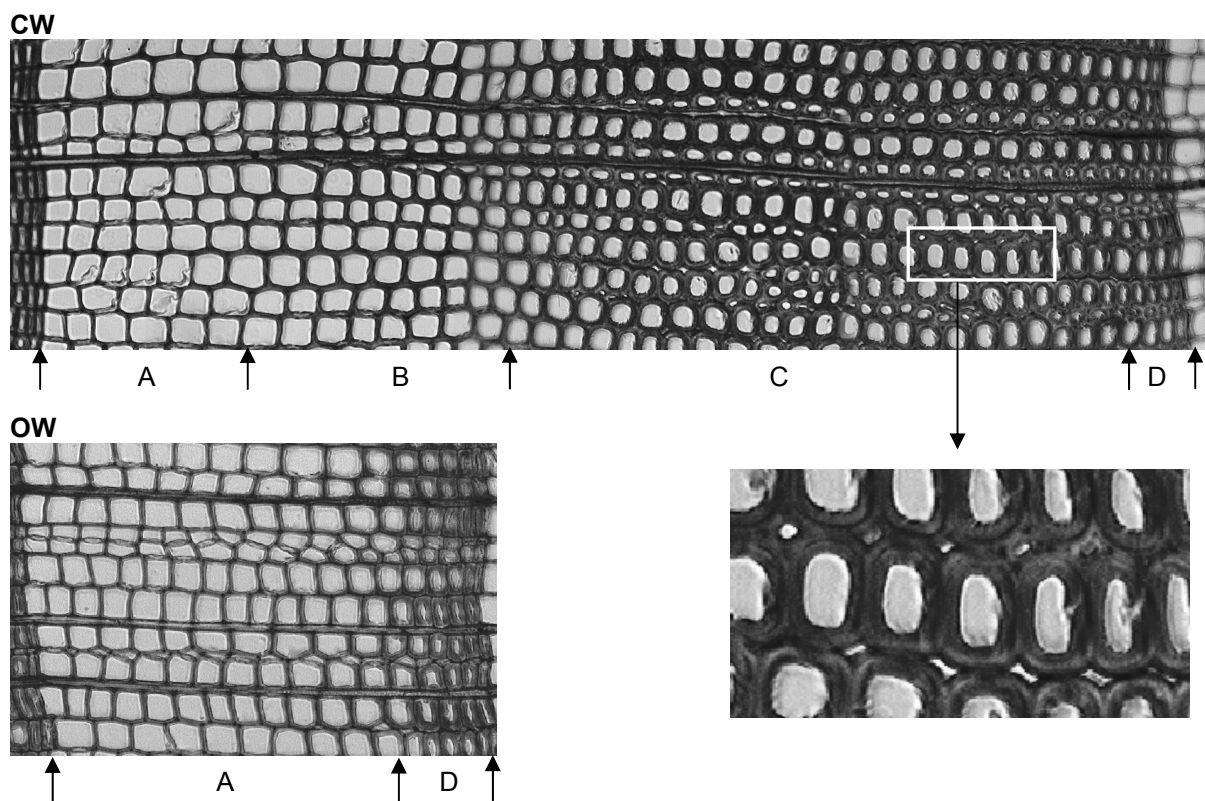
CW

Figure 3: Microscopic photograph of a ring showing the occurrence of compression wood from the CW zone (A – earlywood, B – transitional wood, C – compression wood, D – latewood) and normal wood from the OW zone (A – earlywood, D – latewood).

Figure 3 represents a ring with compression wood. At the beginning of the growing season, cambium produces earlywood tracheids, the transverse shape of which corresponded to tracheids of normal wood (tetragonal to hexagonal form). In a transitional zone, tracheids show thicker cell walls but their form is more or less x–gonal (tetragonal to hexagonal form). Intercellular spaces weren't observed among tracheids. In the compression wood zone, tracheids show a rounded shape in cross section, thick cell walls and intercellular spaces between tracheids. At the end of the ring, LWT are visible showing x–gonal form in cross section and thick cell walls, which are typical for LWT.

Discussion and conclusion

The aim of the paper was to determine the variability of tracheid radial diameters in relation to their position in the stem. The average radial diameter for earlywood tracheids was smaller than 30 μm, while the latewood tracheid radial diameters were on average 16 μm. Therefore, our values are within the range reported for coniferous wood tracheids by other authors (Trendelenburg 1939, Fengel & Stoll 1977, Gryc & Horáček 2003).

Based on the measurements, models were constructed to describe the tracheid variability in relation to its position in the stem (Fig. 1). Those models revealed that radial diameters of tracheids in juvenile wood significantly increased with increasing distance from the stem pith. Maximum tracheid diameters were reached in the 30th annual ring, after which the diameters remained more or less constant or showed a slight decrease. A trend of increasing tracheid diameters in juvenile wood was also confirmed by the models describing tracheid diameter variability in relation to height. The observed trends correspond to results reported in literature (Sarén et.al. 2001, Gryc & Horáček 2003). A decrease in the tracheid radial diameters along the stem height can be explained by the increasing proportion of juvenile wood in relation to the total area of the stem disc.

Rings with compression wood demonstrated the following structure (Fig. 3): earlywood, transition, compression tracheids and latewood tracheids. This ring structure was observed in all rings with compression wood and is similar to the structure described by Molski (1971). Tracheids of compression wood showed a circular shape, thick cell walls and intercellular spaces between the tracheids, which agrees with previous findings (Casperson & Zinßer 1965, Timell 1986, Mauer & Fengel 1991, Wagenführ 1999). When comparing the number of tracheids in rings with compression wood (the compression zone) to the rings in the wood opposite the compression zone, rings with compression wood show nearly twice number of tracheids. This results in wider annual rings in the compression zone (Timell 1986). In normal wood, tracheid diameters decreased from earlywood to latewood. These changes were related to the tracheid differentiation. At the end of the growing season, latewood tracheids remain longer in the maturing area while they remain for a shorter period in the area of radial increase (Horáček 2003).

In conclusion, this study showed that the average radial diameter of earlywood tracheids changed with the position in the stem. The compression wood has very different macroscopic and microscopic structure as compared to normal wood. The compression wood of spruce is characterized by a different colour, wider tree rings, and rounder tracheids with thicker cell walls. These results contribute to explain the different behaviour of compression wood in terms of physical (e.g. higher density with an increasing percentage of CW in the test sample) and mechanical properties of the wood.

References

Casperson, G., Zinßer, A. (1965): Zur Spaltenbilding im Druckholz von *Pinus sylvestris* L.. Holz als Roh– und Werkstoff: 49–55.

Dewitz, G. S. (1969): Variation der Strukturelemente im Nadelholz. Holztechnologie: 185–189.

Fengel, D., Stoll, M. (1973): Über die Veränderung des Zellquerschnitts, der Dicke der Zellwand und der Wandschichten von Fichtenholz – Tracheiden innerhalb eines Jahrringes. Holzforschung. 27: 1–7.

Gryc, V., Horáček, P. (2003): Vliv polohy ve kmeni na morfologii tracheid u smrku (*Picea abies* /L./ Karst.). MENDELNET 2003: Konference doktorandů LDF MZLU v Brně, Brno, 53–58.

Horáček, P. (2003): Wood structure: a tool for evaluating in growing conditions of Norway spruce. Ekológia 3: 147–162.

Ives, E. (2001): A Guide to Wood Microtomy; Making quality microslides of wood sections. Suffolk Offset Martlesham Suffolk. 114.

Kučera, B. (1973): Holzfehler und ihr Einfluß auf die mechanischen Eigenschaften der Fichte und Kiefer. Holztechnologie: 8–17.

Mauer, A., Fengel, D. (1991): Elektromikroskopische Darstellung von strukturellen Einzelheiten in Nadelholz–Zellwänden anhand sehr dünner Ultramikrotomschnitte. Holz als Roh– und Werkstoff: 53–56.

Molski, B. (1971): The significance of compression wood in the restoration of the leader in Pinus silvestris L damaged by moose (Alces alces).II. Structure of growth rings in regenerating stems in relation to juvenile wood formation. Avta Soc Bot Polon: 315–340.

Mork, E. (1928): Die Qualität des Fichtenholzes unter besonderer Rücksichtnahme auf Schleif– und Papierholz. (Auszugsweise Übersetzungen aus "Papir–Journalen" 16, Hefte 4–10, 1928.). Der Papier–Fabrikant (48): 741–747.

Plomion, CH., Leprovost, G., Stokes, A. (2001): Wood formation in trees. Plant Physiology: 1513–152.

Sarén, M., Serimaa, R., Anderson, S., Paakkari, T., Saranpaä, P., Pesonen, E. (2001): Structural variation of tracheids in Norway Spruce (*Picea abies* [L.] Karst.). Journal of Structural Biology. 101–109.

Sisko, M., Pfäfli, I. (1995): Fiber Atlas: Identifikation of papermaking fibers. Springer Verlag. Berlin. 400.

Timell, T.E. (1986): Compresion Wood in Gymnospermes. Springer Verlag, Berlin. 705.

Trendelenburg, R. (1939): Das Holz als Rohstoff. Carl Hanser Verlag., München. 541.

Vavrčík, H., Gryc, V. (2004): The methodology of making microscopical preparations of wood (in Czech). *Acta univ. agric. et silvic. Mendel. Brun. LII (4):* 169–176.

Wagenführ, R. (1999): Holz. Anatomie – Chemie – Physik. Anatomie des Holzes. DRW-Verlag Weinbrenner GmbH & Co. 188.

Analysis of root-wood in Scots pine

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Introduction

Trees are made up of three main parts: a crown, stem (branches and leaves) and root system. It has been established that in pines the branches account for 8–10 %, the stem for 65–77 % and the root system for 15–25 % of the total tree volume (Perelygin & Ugolev 1971). Until now most scientists have been concerned with the stem-wood. However, the roots in pine represent up to a quarter of the total tree volume (Manwiller 1972).

Dendrochronological analysis

So far very little research has been done on the growth rings of the root system. The aim of the dendrochronological analysis presented in this paper is, therefore, to find a relationship (possibility of synchronization) between the growth rings of the root system and the growth rings of the tree stem. Glock (1937) was very pessimistic about the possibility to obtain any ecological information from the roots. In his opinion the roots provide virtually no readable ecological record. Later however, scientists succeeded in synchronizing the growth ring widths from the large roots of two Douglas fir trees in Southern Arizona (Schulman 1945). Since then, extreme growth changes found within different sections of the same root have been discussed in other studies (Fayle 1968, Krause & Eckstein 1992).

Anatomical analysis

Due to their irregular shape and small dimensions, the roots are not of any particular value for the timber industry. The main use of the roots is likely to be found in the fibre industry. For this reason it is essential to specify the dimensions of the root-wood tracheids. Therefore, a second aim of this study is to describe the variability of the tracheid dimensions (radial diameter and cell wall thickness) in the root-wood and to examine the changes in tracheid dimensions along the root.

General differences between roots and stem

In living trees, the roots have the same functions as the stem: conduction, mechanical support and storage. The most significant differences between mature wood of the root and stem occur in plants with highly organized wood (Lebedenko 1962). Riedl (1937) argued that the difference between stem and root wood is clearer in hardwoods than softwoods. However, a pith is absent in the roots of both dicotyledonous trees and gymnosperms due to the different processes of primary tissue formation (Jeník 1964, Gebauer & Martinková 2005). While the anatomy of the root-wood is different from the structure of the stem, those parts of the root that are closer to the stem have a more similar structure to the stem

(Trendelenburg 1939). The growth rings usually contain fewer cells than those of the stem and the boundary between the successive rings is usually less clearly defined (Fayle 1968). The growth ring widths at a distance > 40 cm from the tree stem along the horizontal root are always narrow, while the growth rings at a distance of 10–35 cm are always wide (Krause & Eckstein 1992).

The variation of the tracheid dimensions in the root system of the softwoods must be considered on a threefold basis: in relation to the distance from the root collar, in relation to the radial direction, and in terms of the direction of the root orientation (Panshin & Zeeuw 1980). An increase in size of the root tracheid both in terms of its length, and the radial and tangential diameters has been observed (Göhre 1958, Panshin & Zeeuw 1980). Manwiller (1972), who was analysing the root-wood of the Southern pine (*Pinus palustris* Miller), found that the cell dimensions were determined by the root orientation (horizontal, oblique, vertical).

Material and methods

One tree of Scots pine (*Pinus sylvestris* L.) was sampled in the Forest District Utechov (49° 14′ N; 16° 36′ E), Training Forest Enterprise Krtiny. The tree was cut down and its root system was subsequently uncovered using an Air-Spade (Nadezhdina & Cermak 2003). Four horizontal roots were taken for analysis. One sample from each of the four roots was taken for dendrochronological investigation. Five discs were taken from a fifth root for anatomical investigation. Each of the five discs was taken at different distances from the stem base (0.2 m, 1.2 m, 2.2 m, 5.2 m and 7.2 m). Three discs were taken from the stem at 0.3 m, 1.3 m and 5 m from the stem base.

The growth ring width was measured on a transverse section. If the measurement could not be conducted on macroscopic samples, permanent microscopic slides were made using standard methods (see Ives 2001, Vavrčík & Gryc 2004). The growth ring curves were synchronized using the PAST32 software. The microscopic slides of the transverse sections were analysed using the Lucia image analysis software.

The radial diameters and tangential cell-wall thickness of the tracheids were measured for the purposes of the anatomical analysis. The relative position within the ring of each tracheid was calculated as $RP = P / N$; P standing for the order of the tracheid within the ring and N for the number of the tracheids within the same ring.

Results

A) Dendrochronological analysis

The measurement of the growth ring width was followed by the synchronization of the growth ring curves. We managed to synchronize four curves obtained from five main horizontal roots (Fig. 1). The average curve for the whole horizontal root system was constructed from the well synchronized curves.
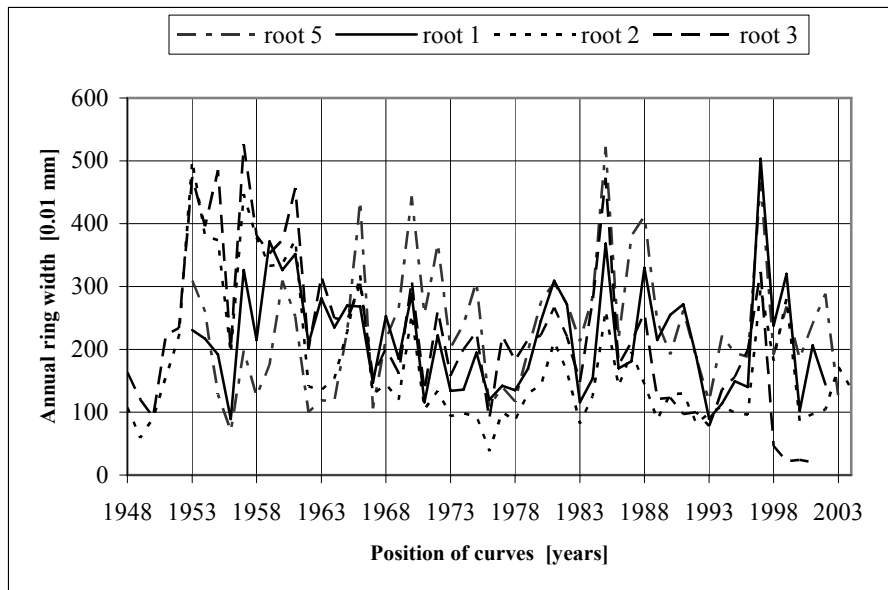
Figure 1: Synchronization of the mean growth ring curves from particular roots.

The t-test values for the synchronization of the mean curves from the different roots were the lowest for root 2 and 3 (t = 3.72, p < 0.01). This value is, however, statistically sufficient because by overlapping the curves of forty growth rings the critical value of the Student's t-distribution (p < 0.01%) rises to 3.551. By contrast, the highest synchronization (t = 8.24, p < 0.01) appeared in the mutual synchronization between the mean curves of root 1 and root 2. Furthermore, the synchronization of the mean growth ring curve of the whole root system and the mean curve of the root cross section at 1.2 m was significant (t = 6.12, p < 0.01%). The value of the *Gleichläufigkeit* of the curves was 83 %. The curves are consistent in the majority of extreme values (Fig. 2).
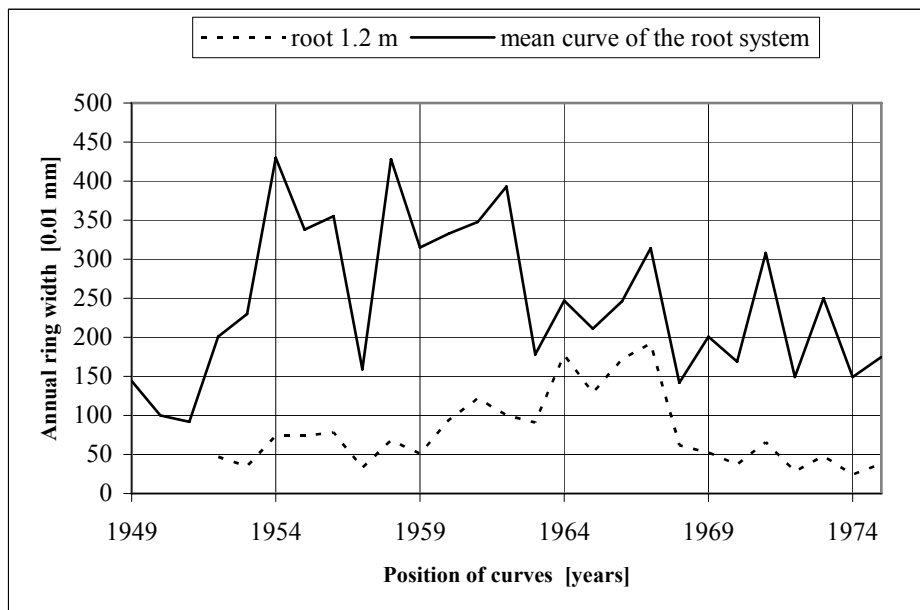

Figure 2: Synchronization of the mean growth ring curve of the whole root system with the mean curve of a root section 1.2 m from the stem.
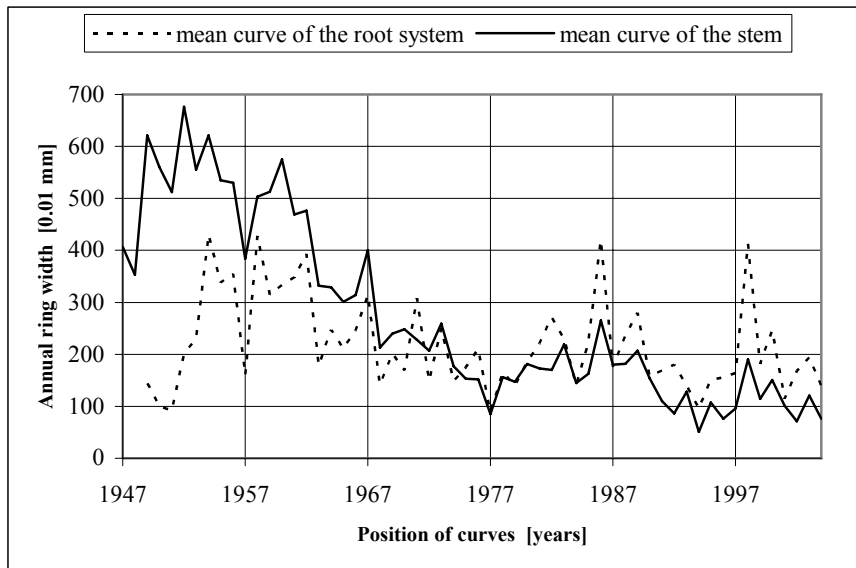
Figure 3: Synchronization of the mean growth ring curve of the whole root system with the mean growth ring curve of the stem.

The average curve of the horizontal root system as constructed above was synchronized with the average curve from the tree stem (Fig. 3). It was found that the best synchronization had been achieved between the mean curve of the stem at 5 m and the average curve of the root system (t = 7.33, p< 0.01). The value of *Gleichläufigkeit* of the curves is 70 %. The curves are consistent in the majority of the extreme values.
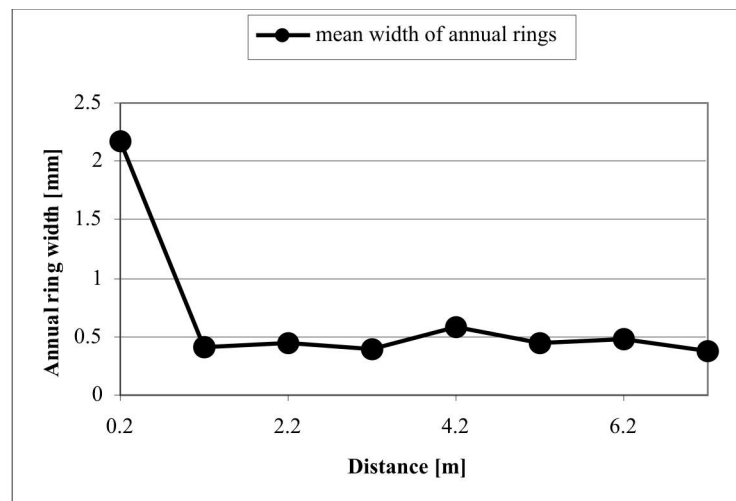

Figure 4: Growth ring width along the Scots pine horizontal root (root 5).

The diameter of the fifth root at 0.2 m from the tree stem was 251 mm and 61 mm at 1.2 m from the stem. The diameter of the root was more than four times smaller at the father distance. The mean width of the growth rings in the stem at a height of 1.3 m above the ground was 2.05 mm. The mean width of the growth rings in root five at 0.2 m from the stem was 2.18 mm and was 0.4 mm at 1.2 m from the stem. Moreover, the growth ring width was roughly constant at about 0.5 mm for most of the root (Fig. 4).

B) Anatomical analysis
The variability of the tracheid radial diameter along the root radius

Analysis at 0.2 m from the stem base
Differences in the tracheid dimensions were found between the inner and the outer rings (Fig. 5A). In the outer rings, the radial diameter of the tracheids increased in the first part of the first ring (the ring closest to the cambium). A maximum value was observed at a relative position 0.1 in the ring, after which the radial diameter decreased. The diameter decreased further from the earlywood to the latewood. The earlywood tracheid diameters ranged from 40 to 60 μm, whereas the latewood tracheid remained between 10 and 15 μm. A different trend was observed in the inner rings. The tracheid diameters increased up to a relative position of 0.4, after which the diameter remained more or less constant. The maximum tracheid radial diameter (60–80 μm) was observed at a relative position of 0.8 to 0.9 of the in the ring. The diameters decreased dramatically at the end of each of those rings. Only one or two latewood tracheids were observed within each ring per one radial row. Their mean diameter was 10–15 μm. In comparison with the inner rings, the outer rings contained a higher number of tracheids.

Analysis at 2.2 m from the stem base
The radial diameters of the tracheids differed from the trends observed at 0.2 m distance from the stem base. A large variation in tracheid diameter (50–80 μm) was observed in the first half of the ring (Fig. 5B). In the second half of the ring, the diameters decreased almost linearly. The diameter varied from 10 to 30 μm at the end of each ring.

Analysis at 7.2 m from the stem base
The trends of the tracheid radial diameters were very different at 7.2 m from the stem base as compared to closer to the stem base. We found that the radial dimension of the tracheids reached the maximum value at a relative position 0.55 (outer rings), respectively 0.9 (inner rings) (Fig. 5C). The tracheid diameter ranged between 45–80 μm for the earlywood and between 20–35 μm for the latewood. The latewood was composed of maximum two tracheid rows.

The variability of the tracheid radial diameter along the stem radius
The radial diameters of stem tracheids were steadily decreasing throughout the growing season in all analysed rings (Fig. 5D). In comparison with inner rings, the outer rings manifested an earlier transition from the earlywood to the latewood.
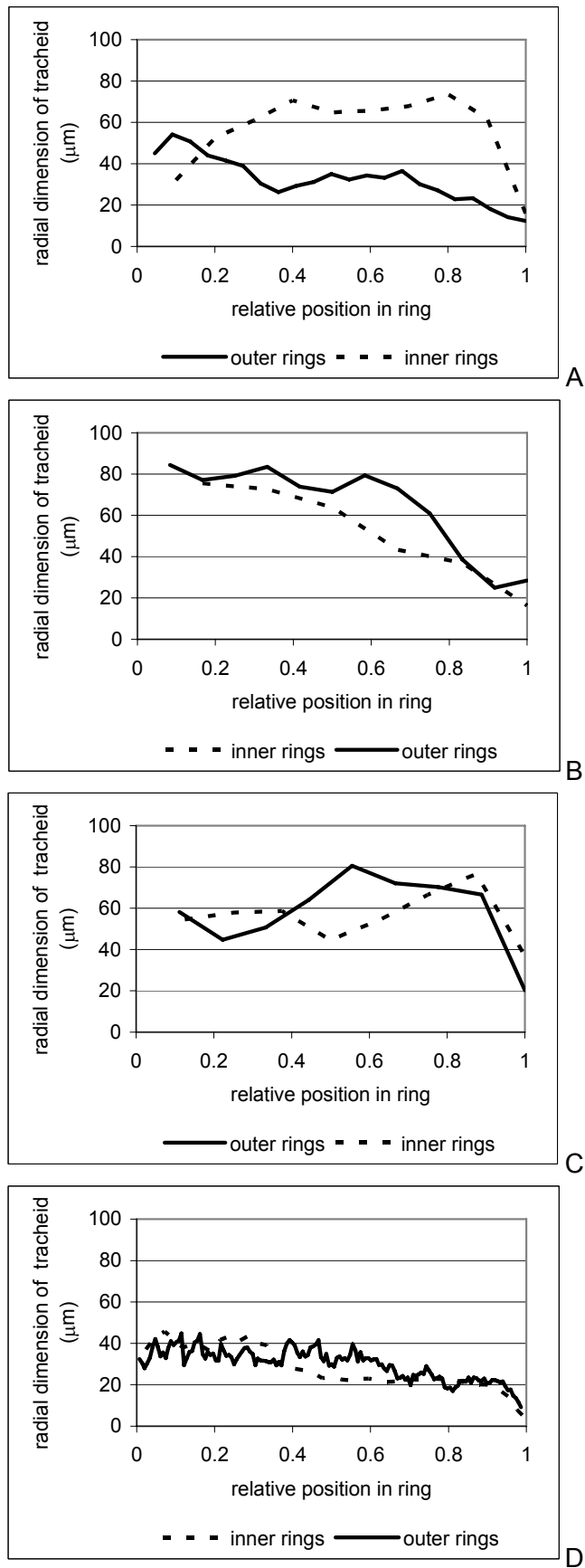
Figure 5: Radial diameters of the tracheid in relation to the relative position in a growth ring. A – root 0.2 m from the stem base, B – root 2.2 m from the stem base, C – root 7.2 m from the stem base, D – stem.

The variability of the tracheid radial diameters along the root

The comparative analysis of the tracheid radial diameters at various distances from the stem base was performed only on the ring adjacent to the cambium. While the number of tracheids decreased, their radial diameters increased with increasing distance from the stem base (Fig. 6).

The variability of the tracheid cell-wall thickness

The cell-wall thickness at 0.2 m distance did not vary as much as the radial diameters of the tracheids. The cell-wall thickness ranged between 2–3 µm at the beginning of each ring, and between 2–6 µm in their remaining parts. There were only negligible changes in the cell-wall thickness within each ring in samples taken at 7.2 m from the stem base. The variability of the tracheid cell-wall thickness is shown in Fig. 7.
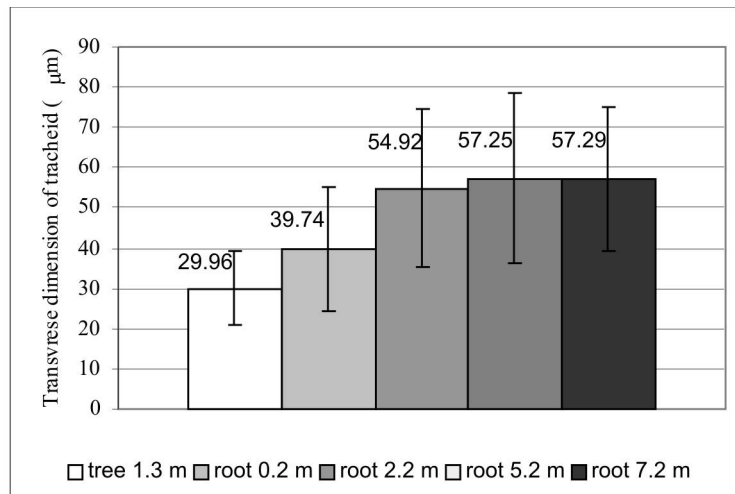

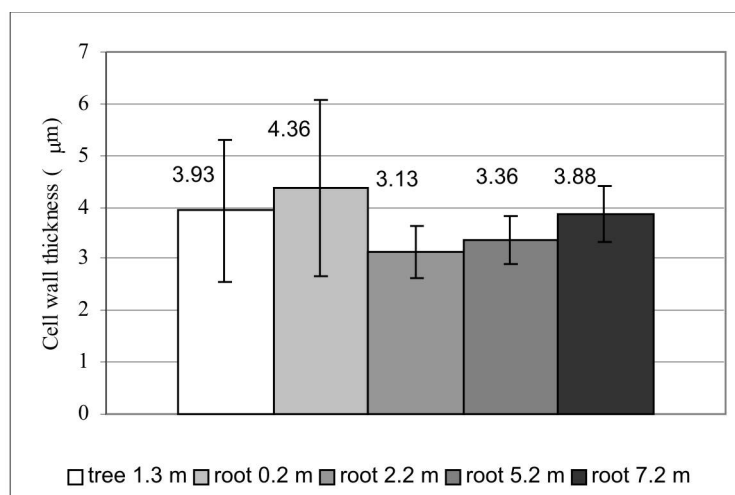Figure 6: Mean radial diameters of the tracheids at different distances from the stem base.

Figure 7: Mean cell wall thickness of the tracheids at different distances from the stem base.

Discussion and Conclusion

Dendrochronological analysis

We have succeeded in synchronizing four of the five main horizontal roots studied. The mean growth ring curve of these four horizontal roots has been reliably synchronized with the mean growth ring curve from the tree stem. It has been demonstrated that the sharply decreasing root diameter is determined by the growing distance from the tree stem (Krause & Eckstein 1992). The diameter of a root at the stem base was more than four times bigger than the diameter of a root taken at 1.2 m from the stem base.

The mean growth ring width in the stem at a height of 1.3 m above the ground was 2.05 mm, whereas the mean growth ring width in a root 0.2 m from the stem base was 2.18 mm. This striking similarity between the mean growth ring widths is explained by the fact that the growth ring widths of the roots were measured in a compression zone that gave rise to abnormally wide growth rings. The mean width of growth rings in a root 1.2 m from the stem base was 0.4 mm. From that point towards the root tip, the growth ring width remained virtually constant (about 0.5 mm). These values support the theory that the root diameter (as well as the growth ring width) is falling rapidly at a distance > 40 cm from the tree stem (Krause & Eckstein 1992).

This study has shown that the horizontal roots of Scots pine (*Pinus sylvestris* L.), and its roots up to 40 cm from the tree stem in particular, could be a very suitable source of ecological information. It has been illustrated that the growth ring curves from different roots are synchronizable. Moreover, it has been found that a partial synchronization is also possible between the growth ring curves from different cross sections of one root at various distances from the stem base. Finally, this showed that growth ring width curves from a root system can be reliably synchronized with growth ring curves from the tree stem.

Anatomical analysis

As expected, the wood structure in the horizontal root was different from the stem-wood. It was found that the relative amount of latewood along the horizontal root decreases from the stem base to the root tip, which corresponds to the findings made by Riedl (1937) and Bannan (1941). Similarly, it was observed that the percentage of the mechanical supporting cells declines in proportion to the distance from the stem base - the narrow roots near the root tips performing mostly conductive functions. For better xylem permeability, most tracheid cell-walls exhibited paired bordered pits. In pine stems uniseriate bordered pits have been reported (Wagenführ 1999, Schweingruber 1990). Due to the smaller proportion of the latewood in the rings, the ring boundaries of the horizontal root wood were not clearly visible (Fig. 8).
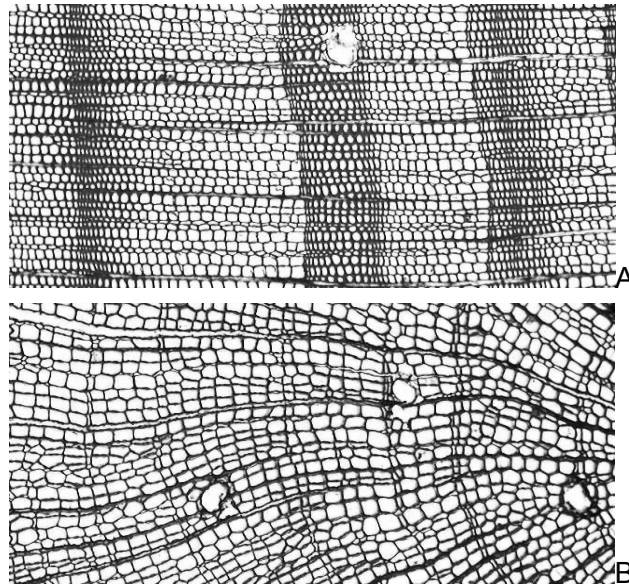
Figure 8: Transverse section of a root 0.2 m (A) and 7.2 m (B) from the stem base.

Manwiller (1972) found that the cell diameter tends to increase along the growth layer in horizontal roots. The same trend was observed in a root with a smaller diameter (7.2 m) and in the inner part of a root with a bigger diameter. The average radial diameter of the horizontal root tracheids increased proportionally to the increasing distance from the stem base. This confirms the findings reported for other species by Göhre (1958) for Douglas fir, by Bannan (1941) for Larch and Spruce and Manwiller (1972) for Southern pine. Futhermore, it has been shown that those parts of the root closer to the stem have a more similar structure to the stem itself (Trendelenburg 1939), which was also observed in our study

References

Bannan, M.W. (1941): Variability in wood structure in roots of native Ontario conifers. *Bull. Torrey Bot. Club 68*: 173–194.

Fayle, D.C.F. (1968): Radial Growth in Tree Roots – distribution, timing, anatomy. Faculty of forestry, University of Toronto. 183.

Gebauer, R., Martinková, M. (2005): Structure of the types of Norway spruce (*Picea abies* L. Karst.) roots. *Journal of forest science 51(7)*: 305–311.

Glock, W., (1937): Principles and Methods of Tree-Ring Analysis. Carnegie Institution of Washington. 100.

Göhre, K. (1958): Die Douglasie und ihr Holz. Akademie-Verlag. Berlin, 595.

Ives, E. (2001): A Guide to Wood Microtomy; Making quality microslides of wood sections. Suffolk Offset Martlesham Suffolk. 114.

Jeník, J. (1964): Morphology of root system in trees: a proposal for terminology. In: Sen D. N. (ed.). Tenth International Botanical Congress, Edinburg: 393–394

Krause, C., Eckstein, D. (1992): Holzzuwachs an Ästen, Stamm und Wurzeln bei normaler und extremer Witterung. In: Michaelis, W.: Bauch, J. (eds): Luftverunreinigungen und Waldschäden am Standort Postturm, Forstam Farchau/Ratzeburg. GKSS-ForshcungszentrumGeesthacht, 100: 215–242.

Lebedenko, L. A. (1962): Comparative anatomical analysis of the mature wood of roots and stems of some woody plants. Trud. Inst. Les. Akad. Nauk SSSR (Sib. Otdel).

Manwiller, F.G. (1972): Tracheid dimensions in rootwood of Southern Pine. *Wood science 5:* 122–124.

Nadezhdina, N., Čermák, J. (2003): Instrumental methods for studies of structure and function of root systems in large trees. *Journal of Experimental Botany 54:* 1511–1521.

Panshin, A. J., Zeeuw, C., 1980: Textbook of wood technology. McGraw-Hill, New York. 722.

Perelygin, L. M., Ugolev, B. N. (1971): Wood Science (in Russian). Lesnaja Promischlenost. Moscow. 288.

Riedel, H. (1937): Bau und Leistungen des Wurzelholzes. *Jahrb. wiss. Bot. 85:* 1–75.

Schulman, E. (1945): Root growth-rings and chronology. *Tree-ring bull. 12:* 2–5.

Schweingruber, F. H. (1990): Anatomie europäischer Hölzer. – Anatomy of European woods. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf, Bern und Stuttgart. 800.

Trendelenburg, R. (1939): Das Holz als Rohstoff. Carl Hanser Verlag., München. 541.

Vavrčík, H., Gryc, V. (2004): The methodology of making microscopical preparations of wood (in Czech). *Acta univ. agric. et silvic. Mendel. Brun. LII (4):* 169–176.

Wagenführ, R. (1999): Holz. Anatomie – Chemie – Physik. Anatomie des Holzes. DRW-Verlag Weinbrenner GmbH & Co. 188.

Reconstructing the flow of the River Nile from *Juniperus procera* and *Prunus africana* tree rings (Ethiopia) – an explorative study on cross-dating and climate signal

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Introduction

The people of Egypt and the Northern Sudan strongly depend on the waters of the River Nile for irrigation and electric power. Therefore, to fight poverty in this region, an adequate water resources management is essential. This requires longer reliable discharge records (Sutcliffe & Lazenby 1994).

The amount and variability in Main Nile River discharge at Aswân is mainly controlled by water availability in Northwest Ethiopia through its most important tributary the Blue Nile River (Said 1993). On a smaller spatial scale this water availability controls tree growth. Although seasonality in temperature is negligible in Ethiopia, certain tree species produce yearly rings, such as *Juniperus procera* Endl. and *Prunus africana* (Hook f.) Kalkman. Besides tree growth, ring definition and isotopic signature strongly depend on moisture availability and seasonality therein (Conway et al. 1998, Couralet et al. 2005, Krishnamurthy & Epstein 1985). These observations suggest the possibility to reconstruct River Nile discharge from growth rings of trees growing in Ethiopia.

This paper presents a preliminary study to cross-date *Juniperus procera* and *Prunus africana* trees from Northwest Ethiopia and to explore the water stress signal contained in them as a proxy for river discharge. Weak ring definition, asymmetrical growth, scarceness of previous research in this area and scarceness of the trees themselves – and hence the ethics of sampling many trees – provide a challenge for dendroclimatology that cannot be dealt with in standard ways. What is presented is *not* intended as a hard conclusion, but rather as a soft discussion to explore opportunities to divert from the standard method of cross-dating, chronology building and environmental signal interpretation as described by Fritts (1976) and Cook and Kairiukstis (1990).

Materials

Stem discs from three young trees, two *Juniperus procera* and one *Prunus africana*, growing at different sites near Mekane Selame (10°35'N, 38°45'E), 30 km east of the Blue Nile River, Ethiopia, were studied. Completely concentric rings were scarce on both *Juniperus* samples, but more dominant on the *Prunus* sample. However, most rings could be measured along one carefully selected radius. Cross-dating of these trees was difficult due to weak ring

definition (see *e.g.* figure 1), the lack of a chronology from the Blue Nile basin and the small number of samples available.
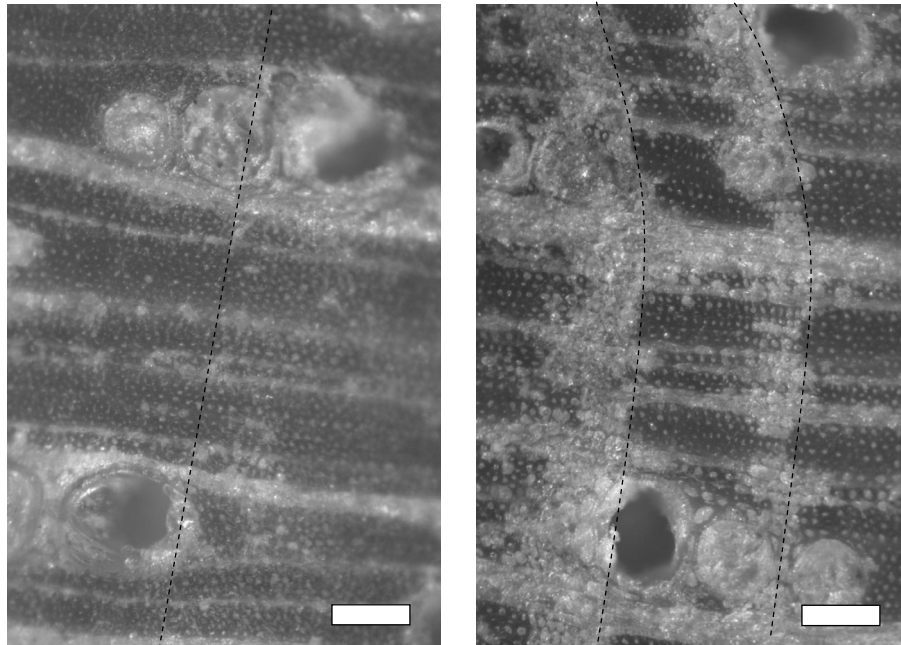

Figure 1: Weak (left) and relatively strong (right) ring definition in Prunus africana. *Growth is from left to right. Ring boundaries are indicated. Magnification is 10x and scale bars are 100 µm.*

Methods

Evaluation of conventional cross-dating and dendroclimatology

Fritts (1976:21) stated that 'cross-dating is possible because the same or similar environmental conditions have limited the ring widths in large numbers of trees, and the year-to-year fluctuations in limiting environmental factors that are similar throughout a region produce synchronous variations in ring structure.' In other words, cross-dating is based on the assumption that there is a large-scale external factor which controls the high-frequency variability in tree-ring width. Hence, it is not only possible on ring widths, but on all time series which can be assumed to be controlled by such a factor.

By convention, cross-dating is conducted without explicitly using information about the nature of the external factor. The ring width series are just matched up, but determining the best match is quite subjective (Baillie 1995, Grissino-Mayer 2001, Pilcher 1990, Wigley et al. 1987). After cross-dating, the ring width series are detrended and standardized and a chronology is calculated expressing some kind of central tendency thought to represent the common signal (Cook et al. 1990). In dendroclimatology attempts are made to interpret the common signal in terms of climatic variables and, if possible, ring widths are calibrated against those (Fritts 1976, Fritts et al. 1990).

In science-philosophical terms, the *assumption* underlying cross-dating is not tested, though there are numerous cases that samples are not cross-datable, but those are just 'laid aside as unsuitable for dendrochronological work' (Fritts 1976:21). Combined with the subjectivity

of judging a match, cross-dating cannot be regarded as an objective practice. However, although it clearly does not comply to Popper's falsificationism (Popper 1980), cross-dating has proven to be a very valuable tool in dendrochronology. Besides, after all the underlying assumption is tested by *applying* instead of falsifying it, otherwise Fritts (1976) would not lay samples aside. Feyerabend's critic to the 'Popperian Church' and the abstract concept of objectivity (Feyerabend 1993) seems to make sense in dendrochronology.

Nevertheless, inferences about the nature of the common signal are generally treated as *hypothesises* to be tested independently against climate data. In fact, this independence is an illusion, as cross-dating is based on the assumption that there is a common signal and enhances it. So, if the assumption is right, there is as a matter of course a correlation between the chronology and some climate data or another large-scale external factor, whereas if the assumption is not right, the cross-date is definitely wrong. Yet, this pseudo-independent hypothesis testing has also proven valuable and strongly diverging from it may enlarge circular reasoning beyond the limit of touching the empirical reality. However, some aspects of the process can be changed.

A new approach

This study changes the order within the procedure of cross-dating, chronology building and environmental signal interpretation, to improve cross-dating and to avoid comparing a chronology distorted by misdated series to climate data. The process can be described as a multi-proxy approach to cross-dating.

Five sources of information are used or proposed to use: ring width series, wood anatomy, historical and modern river discharge records, historical (written documentary and oral legendary) accounts on famines and stable isotopes. Initially an attempt is made to match up the ring width series on the basis of mutual synchrony and wood anatomical properties. Wood anatomy is an important feature, as it contains information about potentially missing or false rings.

The ring width series are then compared *individually* to Blue Nile River discharge to test independently the hypothesis that ring width and discharge are associated. If this hypothesis is rejected, it is hypothesised that the causality that leads to association between ring width and discharge exists, but is obscured by misdating of the ring width series. This improved hypothesis is tested by searching for a cross-date which is confirmed by mutual synchrony, wood anatomy, river discharge and historical accounts on famines. If such a non-contradicted cross-date can be found, the improved hypothesis is accepted and the ring width series is adjusted accordingly. If not, the improved hypothesis is rejected and the sample is in a Frittsian (1976) way 'laid aside'.

The final stage would be checking and if necessary adjusting the cross-date by synchronising stable isotope series, which theoretically contain a stronger common signal and should therefore cross-date better. However, stable isotope series are not yet available.

After this combined cross-dating and environmental signal interpretation a chronology can be calculated from the different ring width series, which as a matter of course correlates with Blue Nile River discharge.

This multi-proxy approach to cross-dating diverges from the conventional method in a number of aspects. Wood anatomical properties are highly used during matching-up. Ring width series are individually tested against climate data. Rejected hypothesises are interpreted as possibly caused by misdating, which is tested using mutual synchrony of the ring width series, wood anatomy and historical accounts on famines. Finally, stable isotopes are proposed to be used as a cross-datable proxy to improve the original cross-date. Thus, inferences about the nature of the common signal are still treated as hypothesises tested independently against climate data, but this testing takes place earlier and misdating is explicitly treated as a potential cause of hypothesis rejection.

Results

Initial matching-up of the ring width series using wood anatomical properties was relatively straightforward. The first *Juniperus procera* series (JP1) needed no adjustments at all. The *Prunus africana* (PA) series needed re-measurement of the period 2003-2005 to include two partial rings (see figure 2A and table 1). The second *Juniperus procera* (JP2) series needed merging of four rings in 2004 as density variations were assumed intra-annual and re-measurement of the period 1970-1971 to include a ring which seemed an intra-annual density variation at first measurement (see figure 2A and table 1).

Table 1: Wood anatomical features supporting the adjustments made to the original ring width series and correlations (r) between the series and annual Blue Nile River discharge for the initial and final cross-date. The master series is a weighted mean after log-transforming and equalising mean and standard deviation of the raw ring width series, the weights being the correlation coefficients between the standardized series and Blue Nile River discharge.

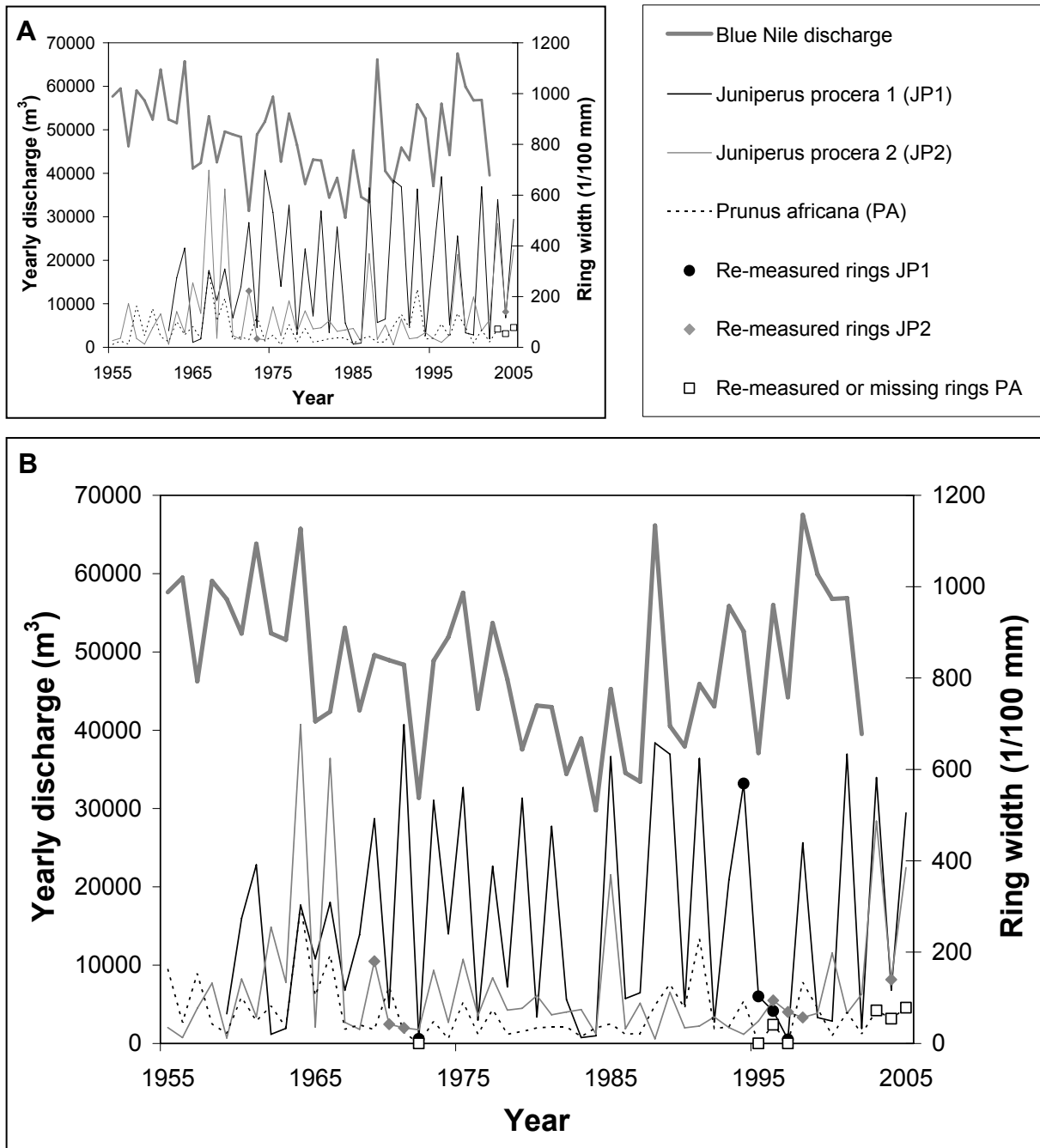| Tree	Year(s)	Wood anatomical feature	r (initial)	r (final)
JP1	1994-1997	Density variations	0.13	0.33
	1972	Very small partial ring		
JP2	2004	Density variations	0.01	0.16
	1996-1998	Density variations		
	1969-1971	Density variations		
PA	2003-2005	Partial rings	0.24	0.34
	1995-1997	Unclear ring boundaries		
	1972	Unclear ring boundaries		
Master series			0.27	0.47

Figure 2: Graphs showing the ring width series of the initial (A) and final (B) cross-date and annual Blue Nile River discharge (measured at Roseires and, after construction of the Roseires Dam, at El Deim, Ethiopian-Sudanese border). Re-measured and inserted missing rings are indicated. The wood anatomical evidence supporting these adjustments is summarized in table 1.

Comparison of the initially cross-dated series with Blue Nile River discharge suggested that there were some shifts in the ring width series (see figure 2A). Therefore, the original hypothesis – ring width and discharge are associated – was rejected, and the improved hypothesis – the association is obscured by misdating of the ring width series – was examined.

Two rings seemed to be missing in the 1990s. The anatomical properties of the samples suggested in all three cases that these rings could exist but were originally not measured due

to weak ring definition (see table 1). Further, one ring seemed to be missing in the extremely dry year 1972. According to historical accounts, this was a year of extreme drought and famine in Ethiopia, known as Wollo drought, which was one of the causes of the communist revolution and subsequent fall of the monarchy in 1974. On JP1 this ring was found as a very small partial ring, whereas on PA it could be masked by unclear ring boundaries (see table 1). JP2 did not contain any evidence to justify inserting a missing ring in 1972, but a density variation was present in 1970 (see table 1). Hence, the improved hypothesis could not be rejected: probably the tree rings contain a water stress signal which is however obscured by errors in the initial cross-date.

Therefore, the initial cross-date was adjusted to comply with all available evidence. The final cross-date is presented in figure 2B. Correlation coefficients between each series and the initial and final cross-date are given in table 1.

Discussion

The ease with which the ring width series were matched-up without referring to river discharge clearly suggests the existence of a common signal. The wood anatomical and historical support for the final cross-date and the *high* degree of synchrony between the final cross-date and Blue Nile River discharge support the idea that this common signal is water-stress related. Therefore, the original hypothesis of this paper and the cross-dating strategy seem to hold.

An important question to ask is however to what degree this approach is circular. Does this approach really *test* the existence of a water-stress signal in the ring widths?

The moment of testing is as described in the methods section shifted to before chronology building. Hence, it is not the common signal that is compared with climate data, but the individual signals. Those are heavily influenced by other factors than climate alone. However, the practice of initial cross-dating *assumes* a common signal and *enhances* it, so by effect the initially cross-dated individual series do already represent a *common* signal, especially in the high-frequency domain.

After rejecting the original hypothesis, the improved hypothesis is tested by partly using the same data. This is a practice which is very common in dendroclimatology (and science in general), *e.g.* during cross-dating and interpretation of the common signal, as in both cases hypotheses are constantly being tested and rewritten *within* a certain dataset. It reflects the ambiguity of the data, in this study especially of the wood anatomy, and hence supports the generalization as representing the empirical reality rather than as fitting to a certain approach in hypothesis testing.

Further, no claims are made about the synchrony between ring width and discharge alone. Only the *high* degree of it after *justifiable* adjustments is treated as a *justification* to adjust the ring width series and to express the *conjecture*, not the claim, that probably the tree rings contain a water stress signal which is however obscured by errors in the initial cross-date. In other words, although there are some testing stages, the approach as a whole does not *test* the existence of a climate signal in the ring width series, but rather pieces together bits of evidence to express a conjecture. In that sense, the approach is weakly circular, however not

to such a degree that the results are complete nonsense. In fact, it is close to the way archaeologists and historians tend to work. Besides, conventional dendroclimatology itself is not completely free from circular reasoning (see evaluation of it above). Using common sense, when three samples do cross-date, but on comparison with climate data seem to be shifted exactly in years which either show problematic ring definition or experienced extreme drought, claiming to have found no climate signal would be nonsensical.

The essential weakness of the approach is that in testing the improved hypothesis other potential causes for rejection of the original hypothesis are ignored. Acceptation of the improved hypothesis – such as in this study – does not necessarily imply that it is right. Therefore, it is better to say the study *failed to reject* the improved hypothesis.

In standard dendroclimatology cross-dating is treated as a technique, whereas environmental signal interpretation is treated as a test of hypothesises. This is a justifiable approach if trees are easily cross-datable and environmental signal interpretation is not straightforward, *i.e.,* in the temperate regions. In the case of Northwest Ethiopia the opposite appears to occur. Cross-dating is excessively difficult, whereas environmental signal interpretation is relatively straightforward (Conway et al. 1998, Couralet et al. 2005, Krishnamurthy and Epstein 1985). Therefore the presented approach, which treats the initial cross-date as more hypothetical and the environmental signal as more probable than the conventional approach, fits this specific case.

The most important benefits of the approach are that it prevents comparing an internally misdated chronology with climate data and helps identifying weakly defined ring boundaries. This is especially important in the (sub)tropics. Nevertheless, adjustments *after* comparison of ring width series and climate data should be made with great caution and preferably in explorative studies only. It is strongly recommended that final studies rely on enough replication to make such adjustments unnecessary.

Conclusion

From the acquired evidence and following an unorthodox approach there appears to be a basis for reconstructing River Nile discharge from *Juniperus procera* and *Prunus africana* tree rings from the Ethiopian section of the Blue Nile basin. This paper discusses 'standard dendroclimatology' in an attempt to create new opportunities for tree species which are difficult to cross-date. Regarding the discussing nature, this paper does not have any higher claims than the ambiguity that is presented.

Acknowledgements

References

Baillie, M.G.L. (1995): A slice through time: dendrochronology and precision dating. The Bath Press, Bath. 176 p.

Conway, D., Brooks, N., Briffa, K.R., Merrin, P.D. (1998): Historical climatology and dendroclimatology in the Blue Nile River basin, Northern Ethiopia. Water resources variability in Africa during the XXth century, Proceedings of the Abidjan '98 Conference, November 1998, Abidjan, Côte d'Ivoire. IAHS Publications no. 252: 243-251.

Cook, E.R., Kairiukstis, L.A. (eds.) (1990): Methods of Dendrochronology, Applications in the Environmental Sciences. Kluwer Academic Publishers, Dordrecht, The Netherlands. 394p.

Cook, E.R., Shiyatov, S.G., Mapeza, V.S. (1990): Estimation of the Mean Chronology. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht, The Netherlands: 123-132.

Couralet, C., Sass-Klaassen, U., Sterck, F., Bekele, T., Zuidema, P.A. (2005): Combining dendrochronology and matrix modelling in demographic studies: an evaluation for *Juniperus procera* in Ethiopia. *Forest ecology and management 216:* 317-330.

Feyerabend, P.K. (1993): Against Method. Verso, London. 279 p.

Fritts, H.C. (1976): Tree rings and climate. Academic Press, London. 567 p.

Fritts, H.C., Guiot, J., Gordon, G.A., Schweingruber, F.H. (1990): Methods of Calibration, Verification, and Reconstruction. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kluwer Academic Publishers, Dordrecht, The Netherlands: 163-217.

Grissino-Mayer, H.D. (2001): Evaluating crossdating accuracy: a manual and tutorial for the computer program Cofecha. *Tree-ring research 57(2):* 205-221.

Krishnamurthy, R.V., Epstein, S. (1985): Tree ring D/H ratio from Kenya, East Africa, and its palaeoclimatic significance. *Nature 317:* 160-162.

Pilcher, J.R. (1990): Sample preparation, Cross-dating and Measurement. In: Cook, E.R., Kairiukstis, L.A. (eds.): Methods of Dendrochronology, Applications in the Environmental Sciences, Kuwer Academic Publishers, Dordrecht, The Netherlands: 40-51.

Popper, K.R. (1980): The logic of scientific discovery. Hutchinson, London. 479 p.

Said, R. (1993): The river Nile: geology, hydrology and utilization. Pergamon Press, Oxford. 320 p.

Sutcliffe, J., Lazenby, J. (1994): Hydrological data requirements for planning Nile management. In: Howell, P.P., Allan, J.A. (eds.): The Nile, sharing a scarce resource, Cambridge University Press, Cambridge: 163-192.

Wigley, T.M.L., Jones, P.D., Briffa, K.R. (1987): Cross-dating methods in dendrochronology. *Journal of Archaeological Science 14:* 51-64.

A comparison of extreme conditions at the southern and polar Ural, using frost rings in wood of Siberian spruce

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Introduction

The Ural Mountains, located at about 60° E longitude and extending over 2000 km north-south is the geologic division between Europe and Asia. The Ural has characteristic climatic zoning which is defined by orographic features and geographic location. Climatic distinctions of the Polar and Southern Ural Mountains are great enough that interactions of air masses, seasonal movement of Arctic and Polar fronts, and an oceanic-continental gradient are all characteristic features.

The most important climatic factors in determining the distinction of ecosystems of the Polar and South Urals are the relative distributions of warmth and moisture. Distinction in thermal balance of the Polar and South Ural Mountains is relatively small in the winter, but a strong radiation gradient during the spring and autumn in the South Ural in comparison with the Polar Ural plays a large-role in the length of the growing season. The duration of snow cover on the Polar Ural is greater than that for the Southern Urals. Intensive thawing of snow during spring leads to over wetting and poor aeration of the soil and further reduces the short vegetative season, typical for high latitudes. Additionally, melting of snow in the Polar Ural is slowed down by frequent snowfalls and frosts. In summer, the radiation balance is approximately identical, as the long day-length in the Polar Ural compensates for the lower radiation intensity. Frosts stop in June in the high-mountain areas of the South Ural, but in the Polar Ural frosts are possible during all months and may occur even towards the middle of the growing season. Summer is colder in the Polar Ural, than in the Southern with average summer temperatures being +11.2°C and +17.8°C, respectively.

The role of solar energy in the Polar and the South Ural Mountains can be broadly differentiated. In the southern Urals, up to 60 % of the radiating energy is used in turbulent exchange. The total amount of heat energy for evaporation doesn't exceed 40 %, because of a small amount of precipitation. In the Polar Ural, on the contrary, humidity is great and up to 70 % of heat is spent on evaporation, and for a turbulent exchange up to 30 %. (Ural & Priurale, 1968).

These distinctions broadly define the climatic features of research areas, including influence on the spatial and temporal occurrences of climatic extremes and on distribution of trees. For example, the upper tree line in the Polar Ural occurs at 300 m elevation above sea level, and in the Southern Urals spruce ascends up to 1360 m elevation. (Shiyatov 1986).

Pathological structures in wood of coniferous trees are formed under influence of climatic extreme events. Low-temperature extremes during a vegetative period lead to formation light and frost rings. Light rings represent a disturbance in formation xylem issue because of long influence of low, yet above freezing, temperatures during second half of vegetation period.

Usually such long cold snaps are observed over a wide spatial range. Frost damages, on the contrary, represent damages of xylem cells under influence of short-term decrease of temperature below 0°C during the period of tree ring formation.

Frosts during the vegetative period damage xylem cells of coniferous trees and as result of this influence we can observe formation so-called frost rings within a tree ring (Kaennel & Schweingruber 1995). Frequencies of frost damages, and their position within the limits of the tree ring, characterize the severity of climatic conditions on tree growth (Gurskaya 2002).

The study's aim was to compare extreme climate conditions of the South and the Polar Ural Mountains using frost rings in spruce wood. The following tasks were conducted to understand the spatial and temporal occurrences of frost damage and to quantify the climatic and weather conditions leading to this damage.

1. To determine and record the occurrence of frost rings in spruce trees growing at upper tree line of the Polar and Southern Ural.
2. To compare the tree age when frost rings form, the position of frost injury within tree rings, and the fraction of damaged annual rings for each year.
3. To compare frost rings and daily meteorological data from the nearest meteorological stations to determine conditions when frost rings form.
4. To build and compare chronologies of frosts, based on the share of frost rings, in the Polar and the South Ural during last 100 years.

Material and methods

Research Area

The study was carried out on forest-tundra ecotone at the upper tree line of Ural Mountains (Fig.1). Two transects were made on upper tree line on south-west slopes of the Polar Ural (66° 55′N, 65° 45′E) and the South Ural (54°32′N, 58° 52′E).

Methods

There are three the altitudinal levels on every profile (Fig.2). The uppermost altitude (1), were single trees grow , was located at 1360 m a.s.l. at the South Ural (SUR) and at 300 m a.s.l. at the Polar Ural (PUR). Here 10 samples of Siberian spruce (*Picea obovata*, Ledeb.) were collected on PUR, and 13 spruces were gathered on SUR. The middle elevational level (2), with generally scattered trees was located at 250 m a.s.l. on PUR and 1300 m a.s.l. on SUR. This elevation has enough trees and here 100 samples at PUR and 92 trees at SUR were collected. The third altitude level (3) represents continuous spruce forest. It is located at 90 m a.s.l. on PUR and 1200 m a.s.l. on SUR. This lowermost level corresponds to the bottom of mountain valley on the PUR. At PUR 100 spruce cores were gathered and 139 samples were chosen at SUR. In total, 210 trees from PUR and 244 trees from SUR were selected for this study.

All sampled trees were growing in forest-tundra ecotone on generally moist sites on south-western slope. Cores were collected 0.2 m above the base of the tree, where the pith was hit for 70 % of the samples. In the cases of a missing pith, the amount of absent rings were

estimated by overlaying a circular grid to more precisely determine the cambial age of all rings. Samples have from 20 up to 110 annual rings with the oldest trees generally found at the uppermost level. The mean age of trees was 80 years.
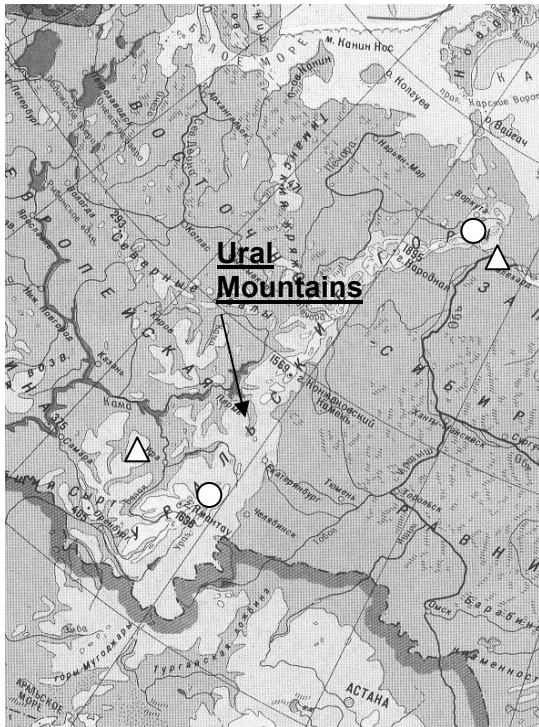

Figure 1: Research area.   O: studied sites;
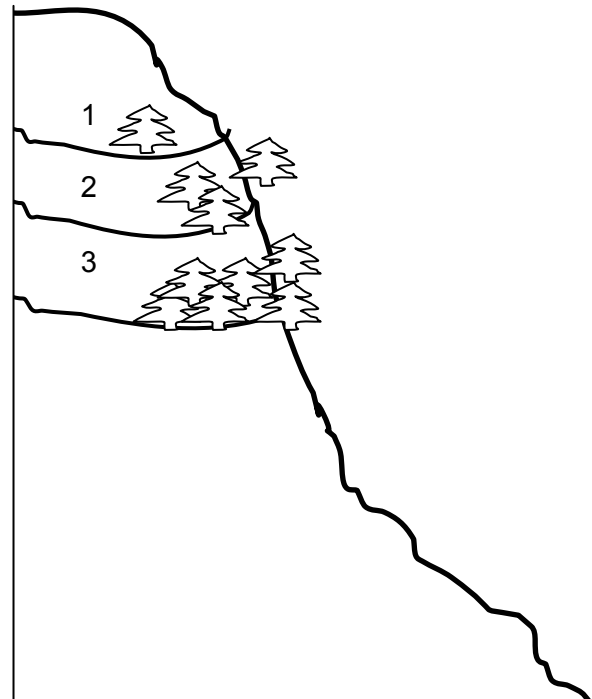 - Δ: the nearest meteorological stations

Figure 2: Scheme of transects.

Frost rings were identified on the surface of well polished cores. It is known that frost rings form under the influence of spring and summer frosts. To make the analysis more detailed and accurate, tree rings were divided into three parts: the beginning of earlywood (first 1-2 rows of tracheids, EW0), the remaining portion of the earlywood (EW1), and the latewood (LW). Usually, frost damage, located in the beginning of earlywood, indicate late spring frosts, in the "late" earlywood they reflect early summer frosts, and frost damages in latewood reflect summer frosts (Gurskaya 2002).

Analysis

All wood samples were measured and cross-dated using TSAP. Missing rings were found in some of the older trees. The occurrence and position of frost rings were visually determined. Meteorological data from the nearest weather stations were used (Fig. 1). In the Polar Ural Salekhard's weather station (66°32'N 66°32'E, 16 m above sea level) is located 60 km from the study site and has observations between1883 to 2006. Ufa's weather station (54.7° N 55.8° E, 136 m above sea level, with data between1900-1995) is located in 160 km from the South Ural site. Average June, July and August temperatures (mean summer temperature) were used to compare conditions of research areas. Days with minimal air temperature during June-July were identified for each year since 1900 to 1995. Minimum, mean and maximum daily temperatures of these days were analyzed.

In this article, we refer to the duration of frosts as the number of continuous days for which the minimal temperature was below 5°C. This temperature corresponds to that when many physiological processes are strongly reduced or cease in trees. It is know, that temperature data were collected in weather stations fixed 2 m above the grounds surface, whereas ground temperatures are generally lower by 2-7°C. The temperature data were not corrected to the altitude of the investigated sites.

Years between 1900 and 2000 were divided into four groups based on the different amounts of frost damage. The first group represents years without frost rings (0 %). Years when less than 10 % of the trees were injured formed the second group, from 10 – 40% were in the third group, and years with injuries in more than 40% of the trees were classified in group four. The following parameters of frosts were analyzed using Student's T-test in the STATISTICA program to test for significant differences between means: minimal, average, and maximal daily temperatures at 2 m height, diurnal daily temperature range per day with frosts, duration of frost (in days), date of beginning of frosts, and average monthly temperatures of June, July and August.

Results

Many researchers mention that frost rings are commonly formed in the xylem of trees during their first 20-30 years (Glerum & Farrar 1966, Stoeckli & Schweingruber 1996, Knufinke 1998, Block & Treter 2001, Gurskaya & Shiyatov 2006). Comparison of tree age, when frost damages stop to form in wood of studied spruces, has shown that this age is characteristic at different elevations along the transect. The longest sensitivity period to frosts is shown for the uppermost level where single trees grow. Frosts damages 70-80 year-old trees on PUR at the first level, and at the third level 35 year-old trees are already capable of resisting frost damage (Fig.3). On SUR differences in the ages of the trees damaged by frosts are not as big as at PUR, but tree age decreases down the slope as well.
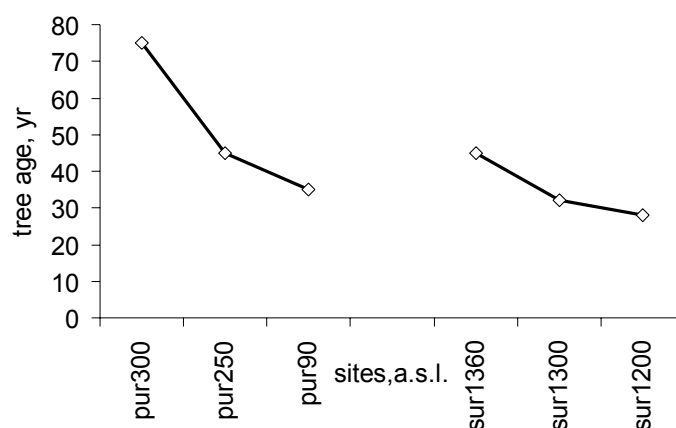

Figure 3: Tree age, after which frost rings in the xylem are no longer found.

Despite the fact that in the Polar Ural trees have a longer period of frost sensitivity than those in the Southern Ural, the total amount of damaged rings for this period of tree life is less. On PUR the share of the damaged rings varies from 2 –7%, and on SUR between 8 – 10 % of

the total amount of the rings during the tree's period of sensitivity to frost. The total share of frost damages on every elevation level is greater in the South Ural in comparison to the Polar Ural (Fig.4).
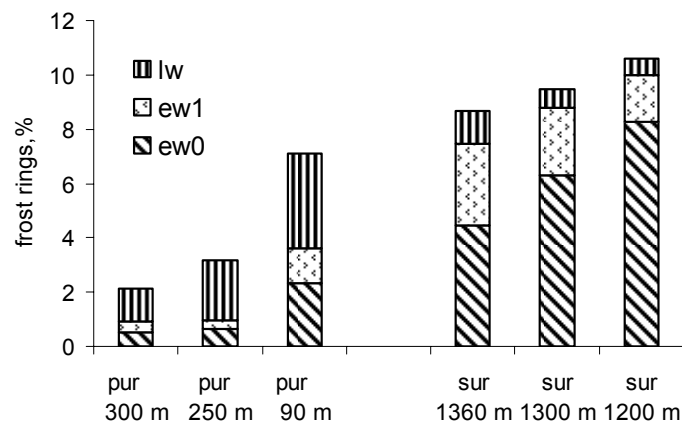

Figure 4: Percentage of frost damage on study's two profiles.

The frequency of damaged tree rings increases down slope at both locations. With the greatest quantity of frost damages found at the lowest site on SUR. On PUR maximum frost damages are also found on the lowest altitude. Here, the total amount of damages is about 2 times greater in comparison with the uppermost and middle elevations. These trends in quantity are systematic for all ring sub-divisions (EW0, EW1, LW). In spruce on PUR, frost damages in LW are more prevalent in comparison to those in EW0 or in EW1. The sum of frost damages in EW0 and EW1 is comparable to the quantity in LW alone. PUR's two top levels have a few years when frost rings are obtained but not found in the lowermost site.

On the contrary, in tree rings of spruce from the South Ural frost damages are most prevalent in the EW0 zone. The greatest contribution to the increase in quantity of damages downhill on SUR is reflected in EW0 damage. Frost injuries in EW1 zone of tree ring are much more rare in comparison to the EW0 frost rings. In SUR's LW the amount of such damages is lower in comparison with frost damages in EW1 zones and frost damages in LW in wood of trees from the Polar Ural.

Considering the highest frequency of frost rings, only the third altitudinal levels of the studied profiles were taken to develop subsequent frost ring chronologies. Frost ring chronologies are constructed in the following way. The maximal tree age, when frost damages are no longer found, has been determined for each profile at the lowermost (third) level. This age is 35 years on PUR, on SUR it is 30 years old. The amount of rings in these age-classes is known and is then considered as the sample size for each year. The number of such tree ages for every year was 20-30. Finally, the percentage of damaged tree rings from the total amount of "juvenile" rings for every year has been calculated.

A comparison of the resulting PUR and SUR frost-ring chronologies is shown in figure 5. There are periods when frost damages occur often and synchronously both on PUR and on SUR, but also periods when frost damages form only on one of the two profiles. Furthermore there are also periods with a very low incidence of frost damage.
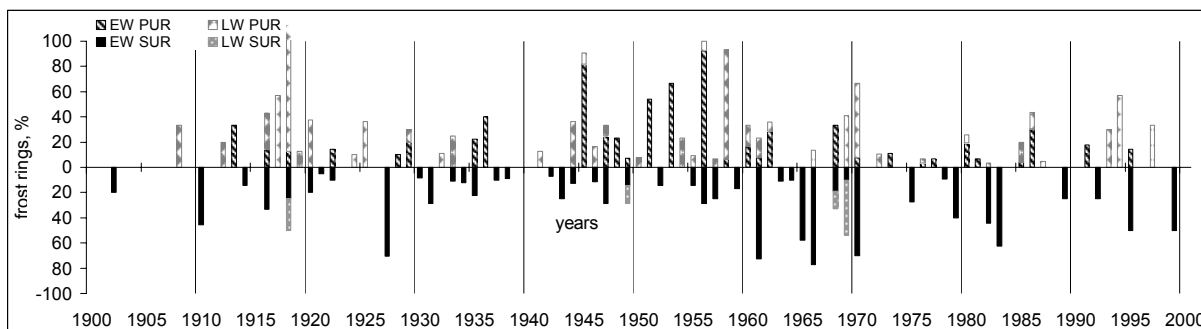
Figure 5: Comparison of frost damages between PUR and SUR chronologies.

Overall, in the Polar Ural frost damages occur more often than in the Southern Ural. On third level of PUR, 70% of the years for the last 100 years are characterized by conditions severe enough to lead to frost ring formation. In the Southern Ural, 40 % of years are characterized by such extreme conditions. Thus, years with extremely strong frosts (when frost damaged more than 40 % of trees) are more often observed on the Polar Ural. Frost damage was most frequent and intense in both chronologies during the following decades: 1910-1920, 1940-1950, 1960-1970. In each of these periods, frost rings were observed synchronously at the Polar and Southern Urals in at least three years. However, in the 1950s many frost rings were formed on the Polar Ural, but not on the South Ural.

There are 18 years with synchronous formation of frost rings: 1916, 1918, 1920, 1922, 1933, 1935, 1946, 1947, 1949, 1955, 1956, 1957, 1961, 1968, 1969, 1970, 1982 and 1995. Most of these years occur during the periods with a high frequency of damages. During other periods, namely in 1900-1910, 1920-1940, 1970-1980, frost damages were seldom formed in spruce wood. In these periods, synchronous frost damage are seldom observed at PUR and SUR. During the last 20 years (1980-2000) there are many frost rings, but few of these are common to PUR and SUR.

These data were compared with average summer temperature data received from Salekhard and Ufa meteorological stations. The variations in average summer temperature for the Polar and the South Ural is shown in figure 6. Cold periods are: 1910-1920, 1940-1950, 1960-1980, warm periods are 1900-1910, 1920-1940, 1950-1960, and 1980-1990 for SUR and 1990-2000 for PUR. These periods coincide with the decades showing the greatest intensity and frequency of frost damage. Thus, frost rings form frequently and synchronous for two study's sites in cold periods and rarely in warm periods.

The 1950s were a warm period for both sites, but only for the Polar Ural many frost rings were observed. The period between 1960 and 1970 was one of the coldest times of the 20th century. In this period frost rings were not as abundant on PUR, as on SUR. In the Polar Ural tree rings tend to be very narrow; frost rings rarely form in narrow tree rings (Gurskaya, 2002). However, during this period three common years with frost rings exist.

In 1980s and in 1990s, the thermal conditions during the summer months on PUR and SUR became somewhat anti-phased. Therefore, in these two periods, despite the frequent observations of frost damage at the investigated profiles, the amount of common frost years is not as great as during other times.
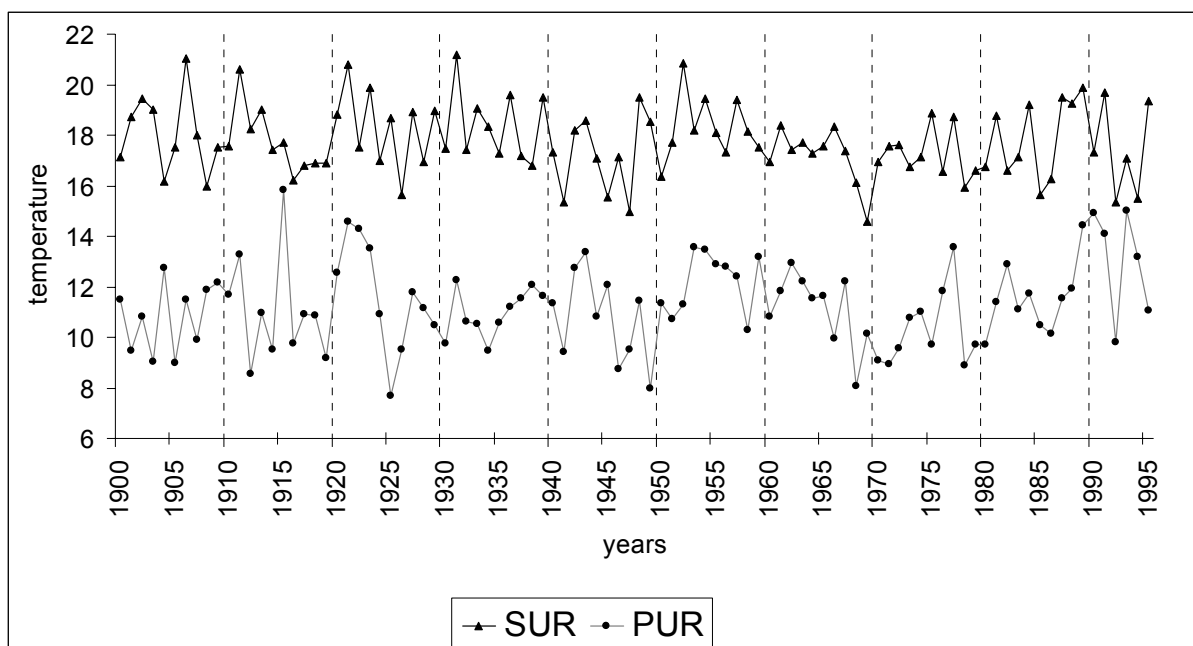
Figure 6: Mean summer temperature on Salekhard (for PUR) and Ufa (for SUR) weather stations, from 1900 to 1995.

Analyzing the 18 years which have common frost rings, shows that in only 6 years the frosts are classified as having the same position within the three differentiated zones. These six years (1916, 1935, 1951, 1956, 1969 and 1995) had strong frosts, as confirmed by the high percentage of trees having frost damage over a large territory. These years were characterized by a cold growing season, when mean summer temperature was lower than the long-term temperature mean. Only 1956 was characterized as a warm summer.

Despite the synchronism of frost damages during some decades, the similarity of two profiles shows that the formation of frost injuries occurs under influence of the different independent factors (i.e. spring or summer frosts). Climate extreme conditions on PUR are not necessarily found on SUR's climate and vice versa.

Furthermore, various instrumental parameters were analyzed to determine which of them most directly triggers frost damage, their threshold values, and which of them can be used for reconstruction of extreme climatic phenomena. The most obvious relations are found for 'minimal temperature' and the 'duration of frost' (Fig.7).

Other relationships, such as correlation between frost rings and mean monthly temperature, mean summer temperature, maximum daily temperature, diurnal temperature range, precipitation, date of frost beginning, and beginning of the tree growing season were not evident. For example, a diagram showing the relationship between maximum daily temperature on frost ring formation in figure 7 shows no clear statistically significant relationship.
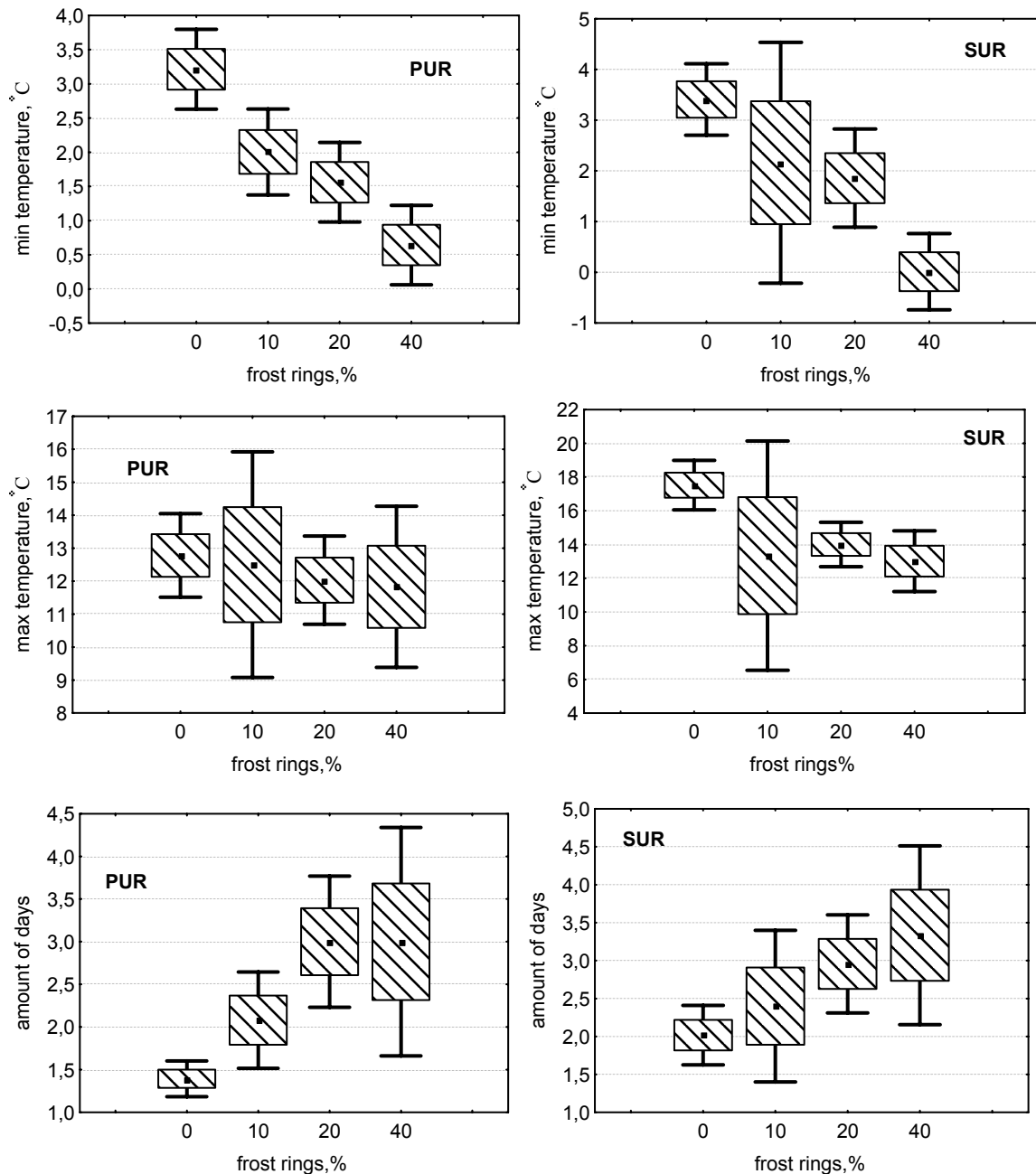
Figure 7: Some meteorological characteristics in relation to the percentage of frost damage.

The minimal air temperature at 2 m height, when in tree rings some frost damage (less than 10 % of total tree rings) is observed approaches +1.5°C. Further decrease of this temperature leads to an increase in severity of the damage. However, this dependence is not linear in character. It has been observed that maximal temperatures during frost days don't reflect the formation of frost damages. However, even the maximal temperatures during this period may be around +1-2°C. The duration of frosts when a minimum quantity of damages is formed in xylem appears to be 2 days. A one-day frost, when minimal temperature falls below +5°C, doesn't lead to the formation of frost damage in coniferous wood. Prolonged frosts of 3-4 days lead to substantial frost damage.

Thus, the formation of frost damage is most closely related to two factors: minimal daily temperature and duration of frost. This pattern is observed both on the Polar and on the

Southern Ural. The differences in minimal temperature means are caused by differences in the elevation of meteorological stations and also by the elevation of sites along the transect. By analyzing such data, it is possible to reconstruct frost events and various intensities of frost and related synoptic conditions (minimal temperature and duration of frosts).

Discussion

Frost damage occurs in wood of coniferous trees under influence of cold climatic extremes during the growing season. In high mountains of Urals these extremes are often observed. Despite the fact that the studied territories represent the upper tree-line of spruce and that the sampled trees grew in similar habitats, the frequency and intensity of the extreme climatic phenomena on the Polar and South Ural are different.

A decrease in the cambial age for which trees are susceptible to frost damage downhill is connected with a general increase of width of tree rings and as a consequence also with an increase spruce trunk diameters. Larger trunks are characterized by higher thermal capacity which allows larger trees to become more resistant to spring and summer frosts. In addition, climate conditions at the upper tree-line of the Polar Ural are harsher, than on the Southern Ural. This greater severity of conditions in higher latitudes results in more damage to older trees on the PUR in comparison with lower levels and with SUR.

The increasing quantity of frost damage downhill is a result of the influence of cold air which flows down slope and remains caught in the lower elevations. This is reflected by the greatest percentage of frost rings at the lowest site of both transects (the third level).

Intrusion of cold air masses that cause damage to tree rings is characteristic for the Polar and South Ural Mountains. However, years with frost damages both the Polar and the South Ural under influence of the same cold air mass is seldom observed (up to 20% of cases). More local frosts seem to more often influence the trees in the study region rather than vast cold air masses.

A greater incidence of frosts in the beginning of the vegetation season is more characteristic for the South Ural in comparison with the Polar Ural. Frost damage to the EW0 zone, reflecting late spring frosts, are largely responsible for the greater percentage of frosts at SUR. Frosts during summertime rarely injure trees on the upper tree line of the South Ural, as demonstrated by the low frequency of frost damage in the LW zone. On the Polar Ural, in contrast, most frost damage is observed in the latewood (zone LW), indicative of strong frosts during the growing season in the summer.

Detection of instrumental records that are related to frost damage on PUR and SUR was not always possible. The most important factors are decreases in minimal air temperatures and the duration of minimum temperatures, being two or more days. These comparisons are complicated by differences in location and elevation between the instrumental stations and the tree sites.

In conclusion, the upper tree-line of the forest tundra ecotone on the Southern Ural, where very few trees grow (the first level), is characterized by extreme climatic events such as strong late spring frosts. But on the Polar Ural, the cold vegetation season passes without any strong frost. Strong summer frosts, which limit the vegetation season to only several

weeks at the Polar Ural, can be most readily observed on the bottom of the mountain valley (the third level). Overall, Polar Ural Mountains frosts occur more often in comparison to the Southern Ural. However, on the South Ural frosts have more catastrophic consequences for trees.

Frost rings allow determining extreme climate conditions for similar ecosystems (for example, spruce growing on the upper tree-line on the forest-tundra ecotone) across different geographic zones. The frost rings can be used to show periods of common climate forcing and also to illustrate differences in the location, timing, and local nature of cold air masses.

Acknowledgments

Reference

Block J., Treter U. (2001): The limiting factors at the upper and lower forest limits in the mountain-woodland steppe of Northwest Mongolia. Tree rings and people: An International Conference on the Future of Dendrochronology, 22-26 September 2001, Davos, Switzerland, 2001. P. 250-251.

Glerum C. Farrar J.L. (1966): Frost ring formation in the stem of some coniferous species: *Canad. J. Bot. 1966. Vol.44, №7:* P. 879-886.

Gurskaya M.A. Shiyatov S.G (2006). Distribution of frost rings in coniferous wood. *Russian Journal of Ecology, 2006 №1:* P. 9-15.

Gurskaya M.A. (2002): Morozoboynye povrezhdenia ksilemy hvoynih derev'ev v lesotundre Zapadnoy Sibiri i Polyarnogo Urala. Avtoreferat dissertatsii na soiskanie uchenoy stepeni kandidata biologicheskikh nauk. Ekaterinburg, 2002. 24 p.

Kaennel M. Schweingruber F.H. (1995): Multilingual glossary of dendrochronology: Terms and definition in English, German, French, Spanish, Italian, Portuguese and Russian. Bern, Stuttgart, Vienna: Haupt. 467 p.

Knufinke A. (1998): Frostringe in Lärchen (Larix decidua Mill.) und deren Beziehung zu Wetter und Standort. Dargestellt an Material aus der Waldgrenz-Aufforstung Stillberg, Davos, Schweiz. Diplomarbeit an der Universität Bielefeld, Fakultät für Biologie. 112 p.

Shiyatov S.G. (1986): Dendrochronologiya verchney granicy lesa na Urale. M. Nauka. 136 p.

Stoeckli V.B., Schweingruber F.H. (1996): Tree rings as indicators of ecological processes: the influence of competition, frost and water stress on tree growth, size, and survival. Basel. 90 p.

Ural i Priurale: Prirodnye uslovija I estestvennye resursy SSSR (1968): M., Nauka, 460 p.

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