A question of time: extension of the Eastern Alpine Conifer Chronology back to 10 071 b2k

K. Nicolussi, G. Weber, G. Patzelt & A. Thurner

Institute of Geography, University of Innsbruck, Innsbruck, Austria
E-mail: kurt.nicolussi@uibk.ac.at

Introduction

The Eastern Alpine Conifer Chronology (EACC) was established from samples originating at treeline or treeline-near sites, i.e. ca. 2000 to 2400 m a.s.l., mainly in the eastern Alps (Nicolussi et al., 2009). The exploited sites are peat bogs, small lakes and glacier forefields where samples of the typical central-Alpine tree species stone pine (*Pinus cembra*), larch (*Larix decidua*) and occasionally also spruce (*Picea abies*) were collected. The EACC continuously spans the last ca. 9100 years up to the present day. The chronology has served as the basis to analyse the Holocene environmental history, i.e. glacier and treeline variability as well as snow avalanche activity in the Alps (e.g. Nicolussi et al. 2005, Nicolussi et al 2007, Joerin et al. 2008, Nicolussi and Schlüchter 2012) but also for dating of archaeological material (e.g. Pichler et al. 2009, Steiner et al. 2009, Stöllner et al. 2012). The tree-ring data itself were utilized for millennial to multi-millennial summer temperature reconstructions for central Europe (Büntgen et al. 2011, Nicolussi et al. 2013).

With a length of some 9000 years the EACC is one of the longest continuous chronologies worldwide. However, additional tree-ring data from sites with the same environmental settings that date from the earliest part of the Holocene have also been obtained. Two multi-centennial but only radiocarbon-dated chronologies that fall into the 10th and 11th millennium b2k were established using these early-Holocene data (Nicolussi et al. 2004).

Recently discovered and analysed samples from the Schlatenkees site in the Austrian Alps now allow closing the chronology gap around 9200 b2k and linking the more recent floating chronology with the calendar-dated EACC.

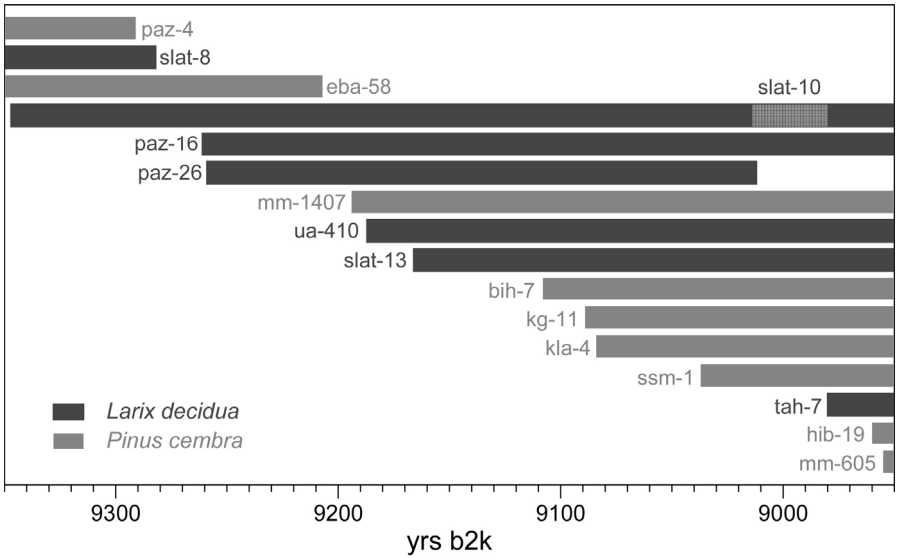

Figure 1. Coverage of tree-ring series around the former end of the EACC (9108 yrs b2k). The extension of the EACC is mainly based on samples from the site Schlatenkees but also on previously not calendar-dated samples.

Site, material and results

The Schlatenkees site (E 12°25'30'' N 47°6'50'') is located in the valley Innergschlöss just south of the main Alpine ridge at an altitude of 2160 m a.s.l. within the local timberline ecotone and near early-Holocene moraines of the Schlatenkees glacier. There are small lakes and peat bogs scattered over a north-facing slope. We collected several sections of logs preserved in these peat bogs.

The most important results were obtained from three larch samples (slat-8, slat-10 and slat-13) for which tree-ring measurement series of 355, 471 and 319 years in length were established. These larch tree-ring series could be crossdated both with the earliest part of the EACC and the end of the floating 10th millennium b2k chronology. Additional crossdating of other, formerly only floating, i.e. radiocarbon-dated, tree-ring series from different sites subsequently improved the sample depth around the chronology gap at ca. 9200 b2k (Fig. 1). However, there are only two tree-ring series that span the period around 9270 b2k. These two samples are from two different sites and of two species.

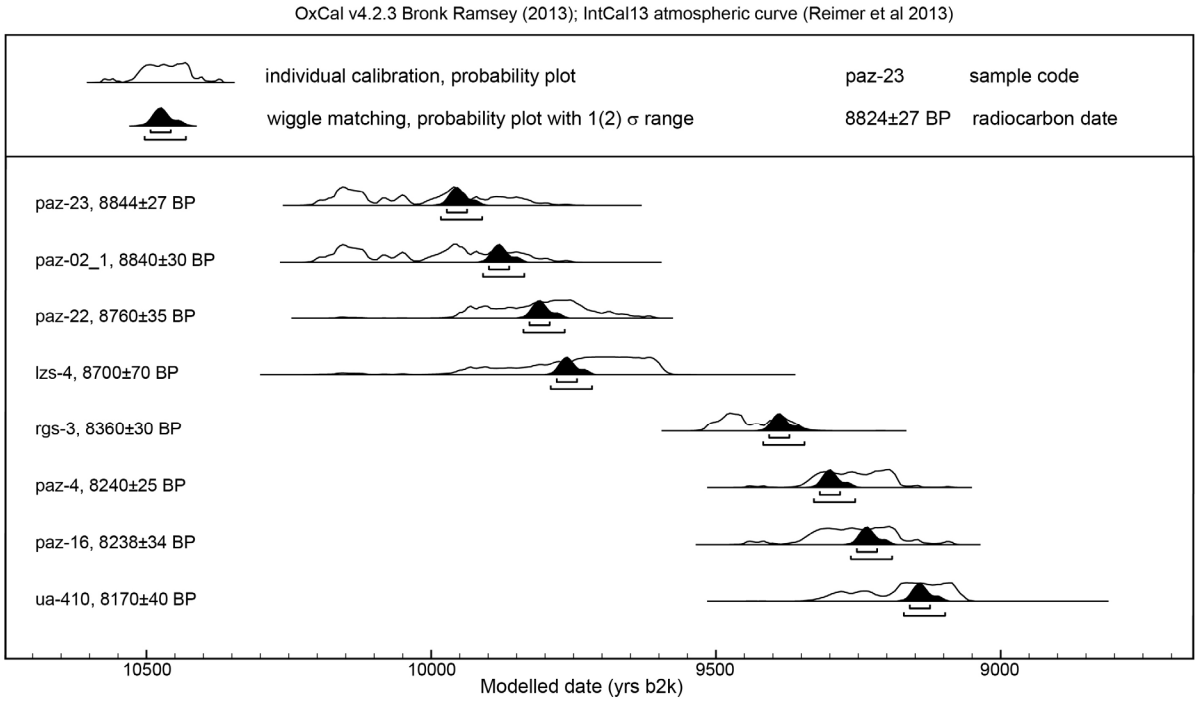

Figure 2. Wiggle matching of ^{14}C-dates from the 10th millennium b2k supports the correct extension of the EACC: the dendro-dates of the radiocarbon-dated samples fall into the 2 sigma wiggle matching range.

The tree-ring crossdating of the EACC is also backed by radiocarbon analysis. Wiggle matching was carried out with eight radiocarbon dates of initially not calendar-dated samples by using the D-Sequence procedure of OxCal 4.2.3 and the IntCal13 calibration curve (Bronk Ramsey 2001, Reimer et al. 2013). The material for radiocarbon dating was always taken with an assigned position at the tree-ring series. The obtained wiggle matching result supports the correct extension of the EACC: i.e., the calendar position of the 16 radiocarbon-dated tree-rings of the sample paz-23 is 9975-9960 b2k and the corresponding wiggle matching result gives 9973-9938 (68.2% probability) and 9984-9911 b2k (95.4% probability) (Fig. 2).

The bridging of the data gap around 9200 b2k enables to establish calendar dates for the tree-ring series of the former floating chronology from the 10th millennium b2k and with that the extension of the continuous EACC back to 10 071 b2k (8072 BC).

Discussion

With the new extension and by adding data from living trees, the EACC covers 10 085 years (8072 BC to AD 2013). The chronology is mainly based on two typical Alpine tree species, stone pine and larch (Fig. 3). Interestingly, the first millennium of the now extended EACC shows a distinct different tree-species composition related to the younger EACC section; it is dominated by larch samples (74%), whereas the following nine millennia are mainly covered by stone pine (81%). Tinner and Kaltenrieder (2005) also found a dominance of larch before 9600 BP at a treeline site in the Swiss Central Alps. These results suggest different (drier) climatic conditions during the Boreal in relation to the following millennia.

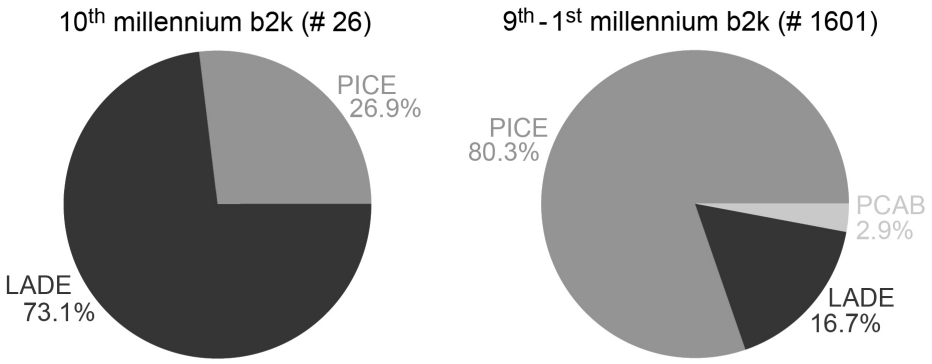

Figure 3. The first ca. 1000 years of the extended EACC show a distinct different tree-species composition related to the remaining EACC section: it is dominated by larch (Larix decidua, LADE) samples whereas the following nine millennia are mainly covered by stone pine (Pinus cembra, PICE).The number of spruce samples (Picea abies, PCAB) is limited, however, this is caused by the selection of the sampling sites.

Even if the EACC covers the last some 10 000 years continuously, the individual species comprising the full chronology still contain a few gaps: the stone-pine data has a small single gap around 9200 b2k, whereas the larch data possess three gaps, around 8150, 6350 and 5350 b2k. These species-related gaps correspond with periods of reduced sample depth of the EACC (Fig. 4) and are, moreover, known, as periods of disturbed and cooler climate. I.e., the larch data gap around 8150 b2k corresponds with the 8.2 ka event. The time periods around 9200 and 10 100 b2k - the latter period overlaps with the actual onset of the EACC - are also proven as periods of cooler climate in the Atlantic sector shown by Greenland ice-core data (Björck et al. 2001, Rasmussen et al. 2007).

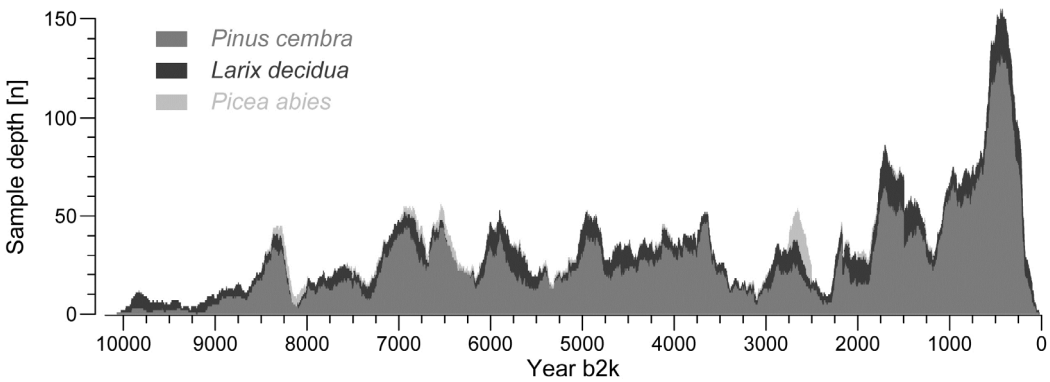

Figure 4. Sample-depth record of the continuous Eastern Alpine Conifer Chronology (EACC). The data (sample) distribution is a consequence of sampling strategy, sample access, climate variability and human impact on high Alpine landscape. The latter factor can be restricted to the last ca. 4000 years.

The synchronicity between sample depth minima / gaps and episodes of cool climate suggests that the ability to find tree remnants preserved at sites in the timberline ecotone of the Alps is related to climate conditions that determined the former tree distribution, i.e the position of the treeline but also the stand density in the timberline ecotone (Nicolussi et al. 2009).

Conclusions

Recently analysed and crossdated samples from the site Schlatenkees allows the closure a former tree-ring chronology gap around 9200 b2k and to extend the continuous Eastern Alpine Conifer Chronology back to 10 071 b2k (8072 BC). This will improve the framework of accurately dated results on past glacier and treeline variability in the Alps as well as enable extended climate reconstructions.

Acknowledgements

This research has been supported by the Austrian Science Fund (Project I 1183-N19). We thank an anonymous reviewer for his helpful comments and suggestions.

References

Björck, S., Muscheler, R., Kromer, B., Andresen, C.S., Heinemeier, J., Johnsen, S., Conley, D., Koç, N., Spurk, M., Veski, S. (2001): High resolution analyses of an early Holocene climate event may imply decreased solar forcing as an important climate trigger. *Geology* 29: 1107–1110.

Bronk Ramsey, C. (2001): Development of the radiocarbon calibration program OxCal. *Radiocarbon* 43: 355-363.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J. (2011): 2500 Years of European Climate Variability and Human Susceptibility. *Science* 331: 578-582.

Joerin U.E., Nicolussi K., Fischer A., Stocker T.F., Schlüchter C. (2008): Holocene optimum events inferred from subglacial sediments at Tschierva Glacier, Eastern Swiss Alps. *Quaternary Science Reviews* 27: 337-350.

Nicolussi, K., Lumassegger, G., Patzelt, G., Pindur, P., Schießling, P. (2004): Aufbau einer holozänen Hochlagen-Jahrring-Chronologie für die zentralen Ostalpen: Möglichkeiten und erste Ergebnisse. In: Innsbrucker Geographische Gesellschaft (Ed.): *Innsbrucker Jahresbericht* 2001/2002, 16: 114-136.

Nicolussi, K., Kaufmann, M., Patzelt, G., van der Plicht,J., Thurner, A. (2005): Holocene tree-line variability in the Kauner Valley, Central Eastern Alps, indicated by dendrochronological analysis of living trees and subfossil logs. *Vegetation History and Archaeobotany* 14: 221-234.

Nicolussi, K., Pindur, P., Schießling, P., Kaufmann, M., Thurner, A., Luzian, R. (2007): Waldzerstörende Lawinenereignisse während der letzten 9000 Jahre im oberen Zemmgrund, Zillertaler Alpen, Tirol. In: Luzian R., Pindur P. (Eds.): Prähistorische Lawinen - Nachweis und Analyse holozäner Lawinenereignisse in den Zillertaler Alpen, Österreich. BFW-Berichte 141 / Mitt. d. Kommission für Quartärforschung d. Österr. Akademie der Wissenschaften, Wien, 16: 157-176.

Nicolussi, K., Kaufmann, M., Melvin, T.M., van der Plicht, J., Schießling, P., Thurner, A. (2009): A 9111 year long conifer tree-ring chronology for the European Alps - a base for environmental and climatic investigations. *The Holocene* 19, 909-920.

Nicolussi, K., Schlüchter, C. (2012): The 8.2 ka event - Calendar-dated glacier response in the Alps. *Geology* 40: 819-822.

Nicolussi, K., Matuschik, I., Tegel, W. (2013): Klimavariabilität und Siedlungsdynamik am Beispiel der Feuchtbodensiedlungen im Raum Oberschwaben, Bodensee und Nordostschweiz 4400–3400 BC. In: Bleicher N, Schlichtherle H, Gassmann P, Martinelli N (Eds.). Dendro -

Chronologie -Typologie -Ökologie. Festschrift für André Billamboz zum 65. Geburtstag. Freiburg i. Br., 61–77.

Pichler, T., Nicolussi, K., Goldenberg, G. (2009): Dendrochronological analysis and dating of wooden artefacts from the prehistoric copper mine Kelchalm/Kitzbühel (Austria). *Dendrochronologia* 27: 87-94.

Rasmussen, S.O., Vinther, B.M., Clausen, H.B., Andersen, K.K. (2007). Early Holocene climate oscillations recorded in three Greenland ice cores. *Quaternary Science Reviews* 26: 1907-1914.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., van der Plicht, J. (2013): IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years cal BP. *Radiocarbon* 55: 1869–1887.

Steiner, H., Putzer, A., Oberrauch, H., Thurner, A., Nicolussi, K. (2009): Vorgeschichtliche Moorfunde auf der Schöllberg-Göge in Weissenbach (Gde. Ahrntal/Südtirol). *Archäologisches Korrespondenzblatt* 39: 489-508.

Stöllner, T., Breitenlechner, E., Fritzsch, D., Gontscharov, A., Hanke, K., Kirchner, D., Kovács, K., Moser, M., Nicolussi, K., Oeggl, K., Pichler, T., Pils, R., Prange, M., Thiemeyer, H., Thomas, P. (2012): Ein Nassaufbereitungskastens vom Troiboden. Interdisziplinäre Erforschung des bronzezeitlichen Montanwesens am Mitterberg, Land Salzburg. *Jahrbuch des Römisch-Germanischen Zentralmuseums* 57 (2010): 1-32.

Tinner, W., Kaltenrieder, P. (2005): Rapid responses of high-mountain vegetation to early Holocene environmental changes in the Swiss Alps. *Journal of Ecology* 93, 936–947.