Quaternary Science Reviews 36 (2012) 78–90

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Challenging process to make the Lateglacial tree-ring chronologies from Europe absolute – an inventory

Klaus Felix Kaiser[a,b,*], Michael Friedrich[c], Cécile Miramont[d], Bernd Kromer[e], Mario Sgier[a,b], Matthias Schaub[f], Ilse Boeren[c], Sabine Remmele[c], Sahra Talamo[g], Frédéric Guibal[c], Olivier Sivan[h]

[a] Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland
[b] Department of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland
[c] Institute of Botany (210), University of Stuttgart-Hohenheim, D-70593 Stuttgart, Germany
[d] CNRS, Institut Méditerranéen d'Ecologie et de Paléoécologie (IMEP), Europôle méditerranéen de l'Arbois, Batiment Villement, BP 80, 13545 Aix-en-Provence cedex 04, France
[e] Heidelberg Academy of Sciences, INF 229, 69120 Heidelberg, Germany
[f] Risk Management Solutions (RMS), Stampfenbachstr. 85, CH-8006 Zurich, Switzerland
[g] Max Planck Institute for Evolutionary Anthropology, Department of Human Evolution, D-04103 Leipzig, Germany
[h] Institut National de Recherches Archéologiques Préventives / CEPAM UMR 6130-CNRS, 24 avenue de la Grande Bégude Immeuble le Mozart, F 13770 Venelles, France

ARTICLE INFO

Article history:
Received 4 February 2010
Received in revised form
5 July 2010
Accepted 7 July 2010
Available online 23 August 2010

ABSTRACT

Here we present the entire range of Lateglacial tree-ring chronologies from Switzerland, Germany, France, covering the Lateglacial north and west of the Alps without interruption as well as finds from northern Italy, complemented by a ^{14}C data set of the Swiss chronologies. Geographical expansion of cross-matched European Lateglacial chronologies, limits and prospects of teleconnection between remote sites and extension of the absolute tree-ring chronology are discussed. High frequency signals and long-term fluctuations are revealed by the ring-width data sets of the newly constructed Swiss Late-glacial Master Chronology (SWILM) as well as the Central European Lateglacial Master Chronology (CELM) spanning 1606 years. They agree well with the characteristics of Boelling/Alleroed (GI-1) and the transition into Younger Dryas (GS-1). The regional chronologies of Central Europe may provide improved interconnection to other terrestrial or marine high-resolution archives. Nevertheless the breakthrough to a continuous absolute chronology back to Boelling (GI-1e) has not yet been achieved. A gap remains, even though it is covered by several floating chronologies from France and Switzerland.

1. Introduction

The Last Glacial–Interglacial transition (LGIT; Boelling/Alleroed [GI-1] and Younger Dryas [GS-1], between 14 700 and 11 700 ice-core years BP (Rasmussen, 2006), reveals a rapid warming by 14 500 cal BP and several abrupt climatic breaks from warm to cold and back thereafter (Björck et al., 1998). The most dominant is the YD stadial (GS-1). These abrupt climatic shifts have been documented in high resolution archives such as Greenland ice cores, including GRIP (Johnsen et al., 1992; Dansgaard et al., 1993), GISP2 (Taylor et al., 1993; Stuiver et al., 1995) and NorthGRIP (NorthGRIP Members, 2004) as well as lacustrine and marine varves during Lateglacial (Hughen et al., 1998a, b, 2000; Kitagawa and Van Der Plicht, 1998a, b). Tree finds document the LGIT as well, starting at Revine South of the Alps in the Oldest Dryas (ODD/GS-2a) between 15 200 and 14 300 ^{14}C BP (Kromer et al., 1997; Friedrich et al., 1999). Reforestation in the northern Alpine foreland starts with a certain delay ca. 14 300 cal BP (Kaiser, 1993).

Also first promising steps combining different high-resolution archives have been carried out by Friedrich et al. (2001a, b) and Schaub et al. (2008b). These studies comprised correlation of tree-ring sequences, marine varves and ice accumulation rates or temperature information from GISP2 rendering tree-ring chronologies a very important tool. It strengthens our efforts to extend, combine and complete our series.

Tree-ring chronologies are of special importance for an accurate calendar of the past. Absolutely dated tree-ring chronologies provide the most accurate and annual, absolute time frame, which can be rigorously tested by internal replication of many overlapping sections and by cross-checking to independently established chronologies of adjacent regions. Decadal ^{14}C analyses from tree-rings are very important for a precise, global time frame of

---

[*] Corresponding author. Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland. Tel.: +41 44 739 23 86; fax: +41 44 739 22 15.
E-mail address: kf.kaiser@access.uzh.ch (K.F. Kaiser).

0277-3791/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.quascirev.2010.07.009

Holocene and Lateglacial and have been used to establish a high--precision radiocarbon data set. This serves as a backbone for the absolute calibration of the radiocarbon time scale, as well as to anchor other annual, yet floating chronologies like varves, to an absolute time frame.

Becker (1986) and co-workers from Hohenheim tree-ring laboratory had assembled long chronologies mainly from logs recovered from gravel deposits in alluvial flood plains of Southern Germany combined with timber and living trees. The Holocene part is based on oak trees (*Quercus* sp.) whereas the oldest part is built up by pine trees (*Pinus sylvestris* L.) covering Preboreal and parts of Younger Dryas (Becker, 1986, 1993). Spurk et al. (1998) and Friedrich et al. (1999) cross-dated this Preboreal Pine Chronology (PPC) to the absolute oak chronology starting at 10 340 cal BP by both precise decadal ^{14}C wiggle matching and dendrochronological cross dating. PPC has been extended into the Lateglacial thereafter with trees from East Germany (Cottbus) and German Pre-Alpine forelands (Breitenthal) as well as a larch tree found in the Rhone Valley of the Swiss Canton of Valais (Strasser et al., 1999). Finally it was supplemented by a chronology from Zurich-Wiedikon (KW1)(Kaiser unpubl.), which provided the earliest part of PPC and extended the absolutely dated part to 12 410 cal BP used in radiocarbon calibration dataset IntCal04 (Friedrich et al., 2004).

Recently Schaub et al. (2008a) based on chronology KW1 extended the absolute tree-ring chronology back to 12 594 cal BP. The resulting chronology YDB spans 399 years (Hua et al., 2009) and represents now the onset of the tree-ring based terrestrial radiocarbon calibration –INTCAL09 – as presented in Reimer et al. (2009).

For the earlier part of the Lateglacial in Central Europe several find sites have provided sub fossil pines dating into LGIT all of them floating chronologies (Fig. 1): Schaub et al. (2008a) collected a cohort of more than 100 pines from the Zurich sites Gänziloh and Landikon. The rich yield of trees resulted in another Swiss chronology dating into of early YD and chronology ZHLG1 covering 1420 yrs of entire Alleroed (GI-1c-a) and the transition into YD (GS-1). Kaiser (1993) had developed four floating chronologies including pines from the

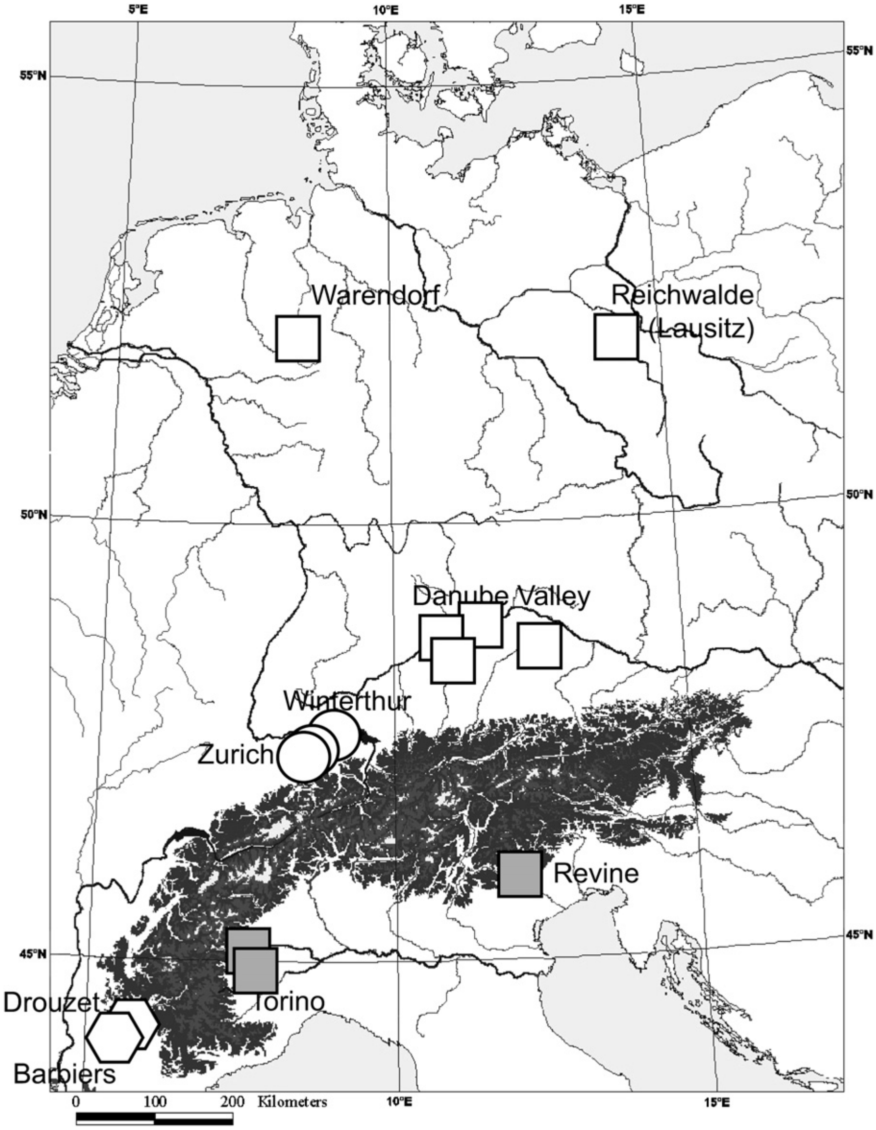

Fig. 1. Map of the different site areas and sites in Southern and Central Europe: In Switzerland we differ two areas: Winterthur with the Dättnau site, while Zurich area comprehends various find sites: Birmensdorf, Wiedikon, Landikon Dorf (Kaiser, 1993) as well as Gänziloh and Landikon of the construction sites of Uetliberg tunnel (Schaub, 2007, Schaub et al.,2008a, b).In Germany all sites of Danube and tributaries as well as the sites in Eastern Germany are pooled (Friedrich et al., 2001a, 2004).In France: Only the main sites Drouzet and Barbiers are displayed, while scattered finds in the Durance River valley and tributaries are neglected (Sivan and Miramont, 2008; Miramont et al., 2000a,b).In Northern Italy both areas as of Turin (Avigliana, Carmagnola, Palughetto) and Revine appear (Friedrich et al., 1999, 2001a,b, 2004).

Dättnau site, near Winterthur. The oldest chronology covers the younger part of Boelling, Older Dryas, and the onset of Alleroed (GI-1e-c) reflecting the earliest reforestation North of the Alps. Three additional floating chronologies date from early Alleroed (GI-1c) through Alleroed/YD transition (GI-1a/GS-1) (Kaiser, 1993; Friedrich et al., 1999). Friedrich et al. (1999, 2001a, b) used floating Lateglacial sections of trees from sites in Southern Germany (Kromer et al., 1997) and combined them with new finds from various sites in South-, North-, and East Germany.

The valleys of Durance River and tributaries hold different find sites. Most promising ones are Drouzet and Barbiers in the vicinity of Sisteron (France), where Sivan (2002), Miramont et al. (2000a, b) and Sivan and Miramont (2008) built several floating chronologies. Two chronologies from Drouzet date into early Alleroed (GI-1c), while a chronology from Barbiers covers the Alleroed/YD transition (GI-1/GS-1). At both sites and in other tributaries of Durance River as well, further 9 floating chronologies have been developed devoid of any synchronisation with other sites.

On top of that Friedrich et al. (1999, 2001a, b) extended the focus even to Northern Italy by creating different regional pine chronologies of Oldest Dryas (GS-2a), Boelling and Alleroed (GI-1).

In this paper we focus on the following questions and problems:

What potential for development exhibit the different sites?

What regional chronologies may be cross-dated with each other?

Which environmental events are recorded within the sequence?

2. Regional Lateglacial tree-ring chronologies from Europe

A generalised view of the European find sites is shown in Fig. 1 and comprises those from all four countries Germany, Switzerland, France and Italy.

2.1. Lateglacial in Switzerland

2.1.1. Find sites, site characteristics, growth pattern, wood preservation

The sites are mainly located in glacial outlets formed around 14 500 cal BP during melt water pulse MWP 1a (Fairbanks, 1989), when the climatic shift at the onset of Boelling (GI-1e) occurred. These channels such as Reppisch and Sihl valleys near Zurich and Dättnau Valley West of Winterthur were carved into the Upper Freshwater Molasse by melt water and then filled with unstable debris, glacial till from both slopes by solifluidal processes. Loamy alluvia of clay, silt, and sand were washed into the valleys after the high geomorphic activity had ended. Parallel to this gentle sedimentation scattered pioneer forest stands consisting of Scots pines (P. sylvestris), birches (*Betula* sp.), willows (*Salix* sp.), Buckthorn (*Hippophaë* sp.) and Juniper in the under wood started to establish themselves (Kaiser, 1993; Schaub, 2007, Schaub et al.2008a, b). The trees while growing were gradually buried by fine-grained material at the foot slope. Hence these site characteristics effectuate particular growth patterns and damages within the first 50 heartwood rings near the pith and affect the preservation of the sapwood in the last 50 rings. The water-bearing sapwood cells are decomposed and squeezed (Fig. 2). With mean segment lengths of 150 rings at end of late Alleroed into Younger Dryas (YD) (GI-1/GS-1) cross dating becomes difficult (Schaub, 2007, Schaub et al.2008a, b). This fact still inhibits to cross match overlapping series by dendrochronology.

All find sites contain mainly stumps of Scots Pine (*P. sylvestris*), which are applied in dendrochronology. Complementary tree species are scattered birches (*Betula* sp.) and willows (*Salix* sp.) of no dendrochronological use, since the pores of leaf trees are supportive to cell compression the tree rings of these species are obliterated.

The rising number of tree finds near Zurich has resulted in the development of high replicated long sequences in the Alleroed (LG-1c-a). The Dättnau site reveals higher replication in Boelling (GI-1e) and scattered finds during Alleroed time, while the Zurich sites with one exception did not provide trees in Boelling (GI-1e), but show high allocation during the whole Alleroed (GI-1c-a), and scattered finds in YD (GS-1).

All chronologies were built by applying both programs dos- and win-tsap (Rinn, 1996, 2003) and several sequences checked with the program COFECHA (Grissino-Mayer, 2001). The high replication provided by the rich finds at both sites Gänziloh and Landikon ended in the construction of chronology ZHLG_1 (Schaub, 2007, Schaub et al.2008a, b). This enabled the cross dating of floating trees and evidenced floating chronologies we had refrained from building previously, mainly due to weak correlation coefficients in

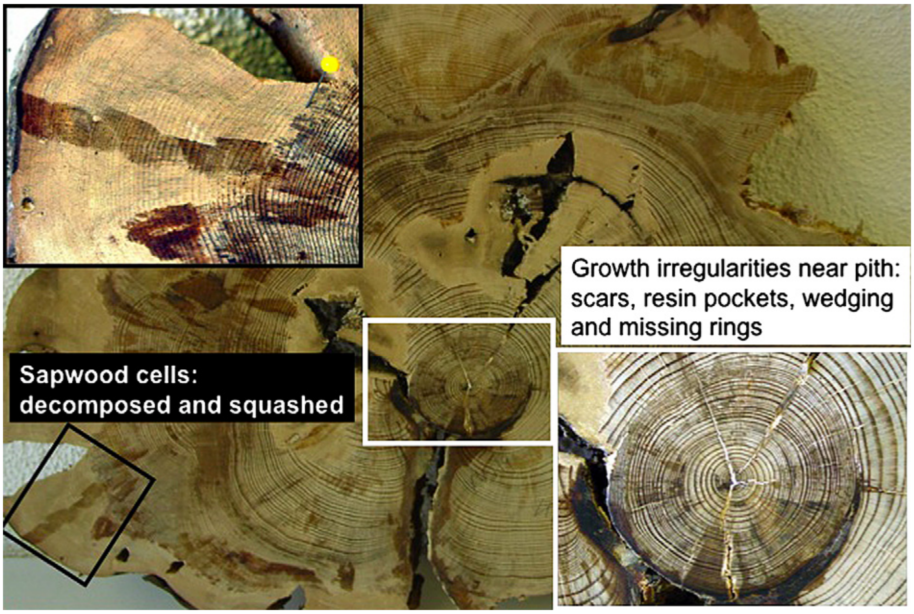

Fig. 2. Tree-ring characteristics that impede cross dating triggered by the local geomorphic influences of the Swiss Lateglacial sites.

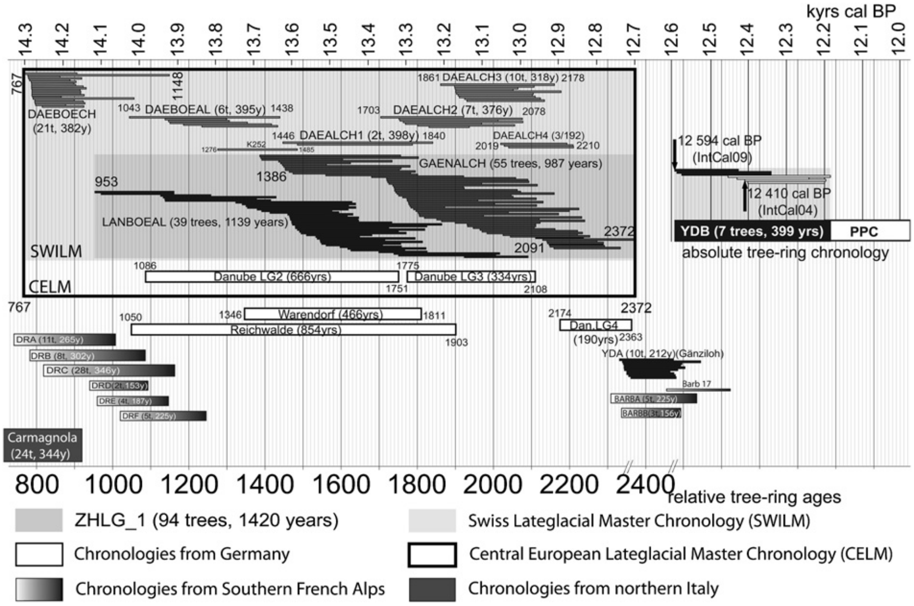

Fig. 3. Entire scope of Lateglacial chronologies such as all site chronologies from Switzerland, important series from Germany, France, and Italy are displayed as well as Swiss and Central European Lateglacial Master Chronologies. Both timescales, for the floating chronologies relative tree-ring years and cal BP years are added. a: Chronology DAEBOECH from Dättnau of Boelling age (GI-1e), (Gleichlaeufigkeit and *t*-values are displayed in Table 1)b: Chronology LANDBOEAL from Landikon of late Boelling (GI-1e) through mid Alleroed age (GI-1e-c), early part of ZHLF_1 chronology (Schaub, 2007) (Glk and *t*-values see Table 1). c: Chronology DAEBOEAL from Dättnau of early Alleroed age (GI-1c) (Glk and *t*-values see Table 1). d: Chronology DAEALCH1 from Dättnau of mid Alleroed age (GI-1c) (Glk and *t*-values see Table 1). e: Chronology DAEALCH2 from Dättnau of late mid Alleroed age (GI-1c) (Glk and *t*-values see Table 1). f: Chronology DAEALCH3 from Dättnau of late Alleroed age (GI-1b) (Glk and *t*-values see Table 1). g: Chronology DAEALCH4 from Dättnau of end of Alleroed (GI-1a) (Glk and *t*-values see Table 1). h: Chronology GAENALCH from Gänziloh mid Alleroed (GI-1c) through early Younger Dryas (GS-1) (Gleichlaeufigkeit and *t*-values are displayed in Table 1). i: Chronology YD_A (Schaub, 2007) of early YD (GS-1), in Table 1 Gleichlaeufigkeit and *t*-values are displayed. k: Swiss Lateglacial Master Chronology built of the chronologies from Dättnau, Landikon, and Gänziloh.

mid Alleroed (Gleichlaeufigkeit [Glk] $\geq$55%, *t*-values [*t*] $\geq$ 3.0) (Baillie and Pilcher, 1973). Additionally some chronologies were regrouped, since there was evidence for better cross match mainly in the early Alleroed (Gi-1c). Additional trees have supplemented some of the chronologies.

2.1.2. Advances in developing chronologies

The following procedure was selected to present the results: The entire scope of the chronologies is displayed in Fig. 3 positioned in relation to the relative Zurich tree-ring scale for the floating chronologies, which are wiggle-matched to the absolute cal BP scale IntCal09 to obtain an information about the approximate absolute position. Chronologies that have been newly built or changed or expanded are presented in Fig. 3a–k. For each chronology the statistical values of the ring-width correlation are listed in Table 1 of the appendix: Gleichlaeufigkeit-% [Glk:] and the *t*-value [*t*:] (Baillie and Pilcher, 1973; Rinn, 1996, 2003). The overlap may bee seen in Fig. 3.

2.1.2.1. Boelling (GI-1e). The existing chronology DAEBOECH (Fig. 3a) was supplemented by two more trees from Dättnau and Landikon and extended. The chronology forms the first cohort of 21 trees reflecting the earliest reforestation North of the Alps after LGM, where forest vegetation had been completely erased. It initiates the whole tree-ring sequence on the Swiss Plateau. The stand of 21 pines at Dättnau is established within 32 years. The relative position coincides with Friedrich et al. (2001a). The chronology spans the last few centuries of Boelling (GI-1e) and stretches out over approx. the first century of Alleroed. In analogy to Friedrich et al. (2001a) OD likely appears in a growth disturbance in the interval of years 930–952 Zurich scale.

Newly formed chronology LANBOEAL (Fig. 3b) presented here is part of the ZHLG_1 (Schaub, 2007, Schaub et al.2008a, b). It consists of 39 trees from Landikon exclusively and its onset strikes just the Boelling/Alleroed (GI1d) transition. The formation of such local chronologies may provide better teleconnection to remote sites.

DAEBOECH and LANBOEAL are cross-dated based on 4 trees, 2 in each chronology: In DAEBOECH ovl: 266 yrs, Glk: 69%, *t*: 8.6 and in LANBOEAL ovl: 192yrs, Glk: 67%, *t*: 5.7. The individuals come up with the following values: ovl: 206 yrs, Glk: 59%, *t*: 3.4; ovl: 179 yrs, Glk: 59% and *t*: 3.1; ovl: 103 yrs, Glk: 55%, *t*: 2.6 and ovl: 87 yrs, Glk: 58%, *t*: 2.5. The cross match between both pairs of trees DAEBOECH with LANBOAL nevertheless is satisfactory (ovl: 196 yrs, Glk: 57%, *t*: 4.0). We cross date different individuals each one definitely fixed in its own chronology and are able to exclude incoherent positions. The match is the only option provided by the programs win-tsap and COFECHA.

DAEBOECH is integrated into the master chronology. The remaining interval of the 28 years at the Boelling/OD/Alleroed transition (GI-1d) only covered with 2 trees before the onset of LANBOEAL is indeed a handicap and hence this part not be used for any statistical purposes e.g. applying splines for detrending and RCS. On the other hand the cross match is confirmed and the low replication reveals additional evidence for the OD (GI-1d).

2.1.2.2 Alleroed (GI-1c-a). Chronology LANBOEAL (ZHLG_1 respectively) from sites Landikon and Gänziloh initiate the Alleroed (LG-1c) (Fig. 3b). New chronology DAEBOEAL (Fig. 3c) enabled Schaub (2007) to extend chronology ZHLG_1 represented here by chronology LANBOEAL back to year 953 on our relative scale (approximately end of Boelling).

The match of DAEBOAL to LANBOEAL (and ZHLG_1 respectively) is excellent (ovl: 396 yrs, Glk: 61% *t*: 6.5). It implies a 106 yrs overlap between DAEBOECH and DAEBOEAL which reveals the following statistical values: ovl: 106 yrs, Glk: 57% *t*: 2.1).

The position of chronology DAEALCH1 (Fig. 3d) into the Alleroed context is strongly evidenced by the matches to either ZHLG_1 or

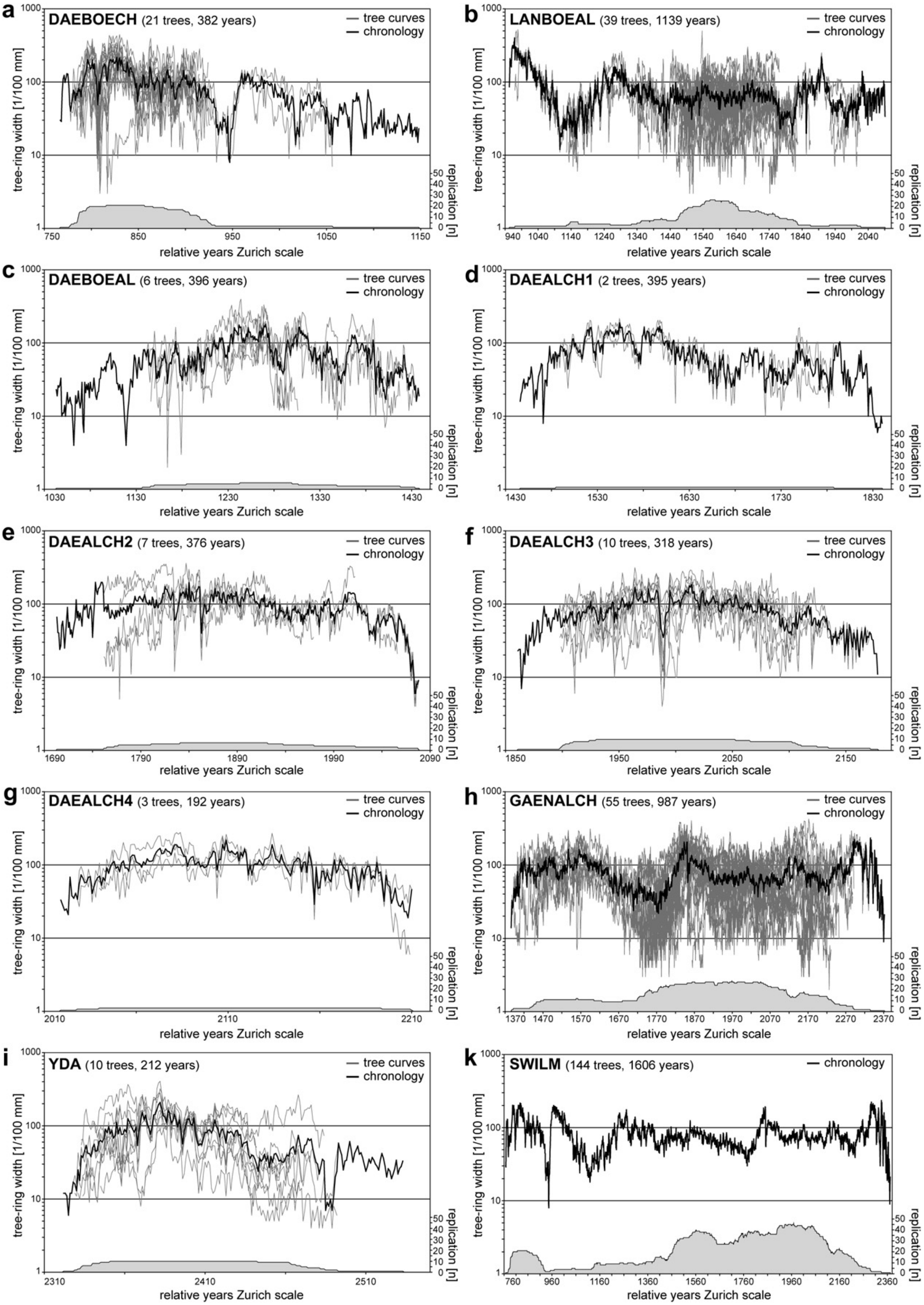

Fig. 3. (*continued*).

LANBOEAL or GAENALCH (Glk >60%, *t*: >5.4). The intra-site overlap with adjacent chronology DAEALCH2 is not seen in any dendromatches.

New chronology DAEALCH2 (Fig. 3e) expanded to 376 yrs is cross-dated to ZHLG_1, LANBOEAL as well as GAENALCH. The spectrum of correlation to the chronologies from Zurich ranges between ovl: 326 yrs, Glk: 57%, *t*: 5.8, and ovl: 203 yrs, Glk: 66%, *t*: 7.3.

Chronology DAEALCH3 (Fig. 3f) (Kaiser, 1993; Friedrich et al., 1999) newly consists of 10 trees. The interval spanned remains 318 years. Two trees (ovl: 210 yrs, Glk: 62%, *t*: 5.2; ovl: 209 yrs, Glk: 61%, *t*: 3.1) determine the relative position on ZHLG_1 (GAENALCH resp.) at the end of Alleroed (LG-1a). It attested previously the end of the forested period at the Dättnau site just before the onset of YD.

By now, three shorter-lived pines only up to 180 years form chronology DAEALCH4 (Fig. 3g). These trees extend the forested period at site Dättnau by 32 more years to position 2210 on the relative time scale and across the Alleroed/YD (GI1/GS1) transition.

Finally, associated to Landikon site chronology LANBOEAL also the Gänziloh, site chronology GAENALCH, is presented (Fig. 3h). It covers the younger part of chronology ZHLG_1 (Schaub, 2007), consists of 55 pines, and overlaps LANDBOEAL by 706 yrs and spans 987 yrs from mid Alleroed (LG-1c) about 150–190 years into YD (GS-1).

In contrast to the Dättnau site where further wood finds are missing, the forested period seems to continue in the Zurich area. Fossil wood finds do not end, but become less abundant and more scattered. Schaub et al. (2008b) showed how the mean segment length (MSL) of the pines drops in two steps at the Alleroed/Younger Dryas (GI-1/GS-1) transition. The first occurs approximately at year 2200 when the MSL drops to 150 yrs, the second after a short recovery at 2300 with MSL of only 140 years. While tree-ring widths remain in the same range.

2.1.2.3. Younger Dryas (YD, GS-1). The final approx. 150–190 yrs of ZHLG_1 (GAENALCH resp.) stretch into early YD. Estimating the Alleroed/YD (GI-1/GS-1) transition at 12 850 cal BP the forested period ends temporarily in Dättnau as well as at some sites in Germany in contrast to the Zurich area. The last century of Alleroed and the first of YD are characterised by pronounced shorter life spans of the trees (150, resp. 140 rings) but comparable tree-ring widths (Schaub et al., 2008a).

As described above the absolute chronology was stretched backwards from the end of YD to 12 594 cal BP (Spurk et al., 1998; Friedrich et al., 2004; Schaub et al., 2008a; Hua et al., 2009) (Fig. 3). This recent extension encroaches on IntCal09 (Reimers et al., 2010).

The remaining hiatus is estimated to comprise 100–110 years maximum. Exactly within this gap Schaub et al. (2008b) has built chronology YDA with 10 trees from Gänziloh comprising 212 rings (Fig. 3i). The series ought to fill the remaining gap with even some overlap of 40–50 years on both sides. We see similarities in the tree-ring pattern, but we have been unable hitherto to find cross matches that score both *t*-values and Gleichlaeufigkeit according to our preconditions. The approximate position is in agreement with typical wiggles and ^{14}C plateaus of 10 700 BP and 10 600 BP (Hua et al., 2009) by decadal radiocarbon samples.

2.1.2.4 Lateglacial Master Chronology from Switzerland (SWILM). - Chronologies LANBOEAL and GAENALCH (ZHLG_1 respectively) form the backbone of the master chronology (Schaub, 2007; Schaub et al., 2008a,b). The incorporation of the five relevant floating chronologies from Dättnau into the Swiss Lateglacial Master Chronology (SWILM) has been executed in three steps: Firstly those 13 trees were added matching with an overlap of 100 yrs minimum, Glk: ≥60% and *t*-values: ≥4.0 to either ZHLG_1 or LANBOEAL or GAENALCH (Fig. 3k). For trees with *t*-values exceeding 6.0 we accepted Glk of ≥58%. After the integration of these 13 trees a second group of 6 trees met the above limits. This is standard procedure when building chronologies. Herewith 19 of 28 relevant trees had been integrated. In the next step the remaining 9 trees were incorporated. Comparisons of the 3 chronologies resulting revealed such marginal differences, that all trees from Dättnau were incorporated. This guarantees a better anchoring of the Dättnau site characteristics in the Swiss Lateglacial Master Chronology (SWILM) (Fig. 3k). According to Section 2.1.2.1 also chronology DAEBOECH has been incorporated to the Swiss master chronology.

2.2. German find sites and chronologies

2.2.1. Danube and tributaries, South Germany

Since the 1970s Becker (1986) and co-workers from the Hohenheim laboratory have sampled sub fossil oaks as well as pines in gravel pits of the river Danube and its tributaries Iller, Günz and Isar (Becker, 1993). The vast majority of the pines dated to the Preboreal and the Younger Dryas and have been used to construct the Preboreal Pine Chronology (Spurk et al., 1998; Friedrich et al., 2004).

Only few gravel pits provide Lateglacial wood sporadically. In this respect sites Breitenthal at Günz River, Woerth and Freising at Isar River, and Burlafingen, Pfuhl, Altisheim, Tapfheim, and Dillingen at Danube River are of special interest. The trees at those sites were not found in situ as the trees were eroded from the riverbanks and buried by the fluvial sediments. So there is little information about original tree stands.

However sub fossil trees of these particular sites provide a strong and coherent tree-ring signal, since individual or local growth disturbances of trees are most likely minor in those river habitats. This fact creates strong connections of the Danube pine chronology to pines at remote sites i.e. the Swiss sites Landikon, Dättnau, and Avenches, the North German site Warendorf and the East German sites Reichwalde and Lohsa.

46 trees from those sites have been synchronized and combined into a chronology of 666 years (Danube-LG2), which cover the first half of the Alleroed (GI-1c) from ca. 14.000 BP to 13.300 cal BP. Another chronology (Danube-LG3) of 13 trees covers 334 years of second part of the Alleroed (GI-1c). Both series show outstanding correlations to the chronologies from Landikon and they could be synchronized with the Alleroed chronologies from Dättnau, Switzerland as well as both N-German chronologies Reichwalde (NE-Germany) and Warendorf (NW-Germany). A third series of 3 trees at the ultimate end of the Alleroed (GI-1a) does not show any correlation to the Swiss chronologies of that period and is therefore still floating.

2.2.2. Reichwalde, East Germany

In the open cast mining area of Reichwalde along the southern rim of the Lausitz glacial drainage channel prospected in 1997 revealed an in situ Lateglacial forest, a relict of well preserved pine trees, forming a comprehensive palaeoecological archive in Central Europe (Friedrich et al., 2001b). Below lake deposits up to 5 m thick 1565 trunks and stumps of an ‘in-situ’ forest were excavated (Friedrich et al., 2001b). The forest mainly consists of pines (*P. sylvestris*) and birches (*Betula* sp.), with pines of a maximum age of 250 years. The trees were rooting either in a thin fossil soil underneath the bog or in different layers of the peat overlying it. Accompanied palaeobiological analyses reveal a detailed reconstruction of composition, structure and history of a specific Lateglacial forest (Figs. 1 and 3).

The pines in Reichwalde exhibit remarkable signs of forest fires in the tree rings. Investigations on the fire scars prove that intense forest fires affected the forest episodically. Fire scars were established every 10–15 years over several centuries of early Alleroed (GI-1c), indicating a very high fire frequency in the Lateglacial pine forest of Reichwalde (Friedrich et al., 2001b). So far 509 trees have been compiled to a highly replicated chronology of 854 years starting at the onset of the Alleroed. Teleconnection to South Germany and NW-Germany proofs the superregional tree-ring signal of those trees.

2.2.3. Warendorf, North Germany

In a sand pit in Warendorf near Muenster in Westphalia in Northern Germany numerous pine trunks as a Lateglacial forest relict were recovered, embedded in an organic layer below the groundwater table. The trunks were up to 5 m long, had diameters of 1 m, and were well preserved. According to complementary palaeoecological analyses on macro remains the forest mainly consisted of pines (*P. sylvestris*), willow (*Salix* sp.), and birches (*Betula* sp.). 21 trees of that forest relict could be combined forming a 466-year chronology of the mid-Alleroed (GI-1c), which highly correlates to the NE-German site Reichwalde and to S-Germany (Figs. 1 and 3).

2.3. French find sites and chronologies

In small lateral catchment basins of river Durance (Southern Alps, France) Lateglacial and Holocene alluvial deposits contain hundreds of sub fossil trunks of Scots Pines (*P. sylvestris*) (Miramont et al., 2000a,b) (Figs. 1 and 3). The area ranges in altitudes from 500 to 2000 m, and the climate is forced by both Mediterranean and Alpine influences. Outcrops of calcareous Jurassic marls, which are subject of intense erosion processes, dominate the landscape. Large embankments were formed (some up to 20 m thick) and alluvial fans were deposited from Alleroed to Atlanticum (14 500 through 7000 cal BP) (Miramont et al., 2000a,b). Under these specific environmental conditions numerous pines were fossilised in flood deposits. These sedimentation trends stopped after 7000 cal BP, and conditions for burial and preservation of wood became unfavourable. These well preserved trunks found in situ are exposed by recent vertical incision of the river since the mid 20th century. Hence sub fossil pines have been discovered at more than 30 sites of the Durance basin. We present here the results obtained from two important Lateglacial sites, Drouzet and the Barbiers Rivers. The program win-tsap (Rinn, 1996, 2003) is used to build the chronologies. Lateglacial pines were frequently stressed by aggradations and often have similar growth patterns and damages as the pines found in Switzerland. Individual chronologies are characterised by frequent abrupt growth changes, wedging, and missing rings. Therefore, weak correlation coefficients make cross dating difficult.

2.3.1. Progress and prospects

Lateglacial Drouzet River deposits have revealed more than 150 sub fossil Scots pines (*P. sylvestris*). The in situ trunks buried by three loamy alluvial layers of 2 m in thickness, which include a high number of vegetable remains. Radiocarbon age determinations open a time frame from 12 500 to 11 800 BP (^{14}C). The sub fossil Scots pines in the Drouzet River, as well as several trunks of the same species discovered at different places in the Durance basin, point out the onset of alluvial sedimentation trends and attest the earliest reforestation at LGIT in the valleys of the Southern French Alps. Tree finds become scarce later due to lower sedimentation rates during Alleroed (GI-1c). 72 individual trees have been measured and 6 new chronologies (DRA, DRB, DRC, DRD, DRE, DRF) have been built (Figs. 3 and 4a and Table 2 [Glk/*t*]). In the future, further tree finds may replenish existing chronologies.

Several cross datings with satisfactory coefficients exist between single trees of Drouzet as well as from Dättnau (DAEBOECH). The replication of trees showing these positions remains too small for a cross match. Comparing decadal ^{14}C datings of the Drouzet site chronologies and the Dättnau data set, there appears the same wiggle between 850 and 1000 of the relative scale. This position coincides with the preliminary tree-ring correlations above.

In the Barbier riverbed, subfossil pines are scarcely spread (18 trees). Some date into the Alleroed (GI-1)/YD (GS-1) transition and into early YD. As observed by Schaub et al. (2008a) at the Zurich sites, trees of Barbier have significantly shorter life spans at the Alleroed (GI-1)/YD (GS-1) transition than trees in mid Alleroed (GI-1c).

2 chronologies BARBA and BARBB have been built (Fig. 4b). Between both exists a correlation based on the synchronisation of 2 individual trees (ovl: 131 yrs, Glk: 51%, *t*: 4.7). Both chronologies date between 11 050 and 10 600 ^{14}C BP and reflect the rapid decrease of ^{14}C ages at the onset of Younger Dryas (Kromer et al., 2004)(Fig. 7b). The individual pine Barb17 has been cross-dated with pine Barb12 at the end of BARBA (ovl: 79 yrs, Glk: 64, *t*: 3.4). The dendromatches are sustained by decadal ^{14}C age determinations.

These trees may hold the potential to fill existing gaps between the absolute and the floating chronologies from Switzerland. Tree Barb17 of chronology BARBA and the absolute chronology YDB matches with values of ovl: 117 yrs, GLK: 61%, *t*: 4.2. Nevertheless the cross match of the French tree is not coherent to the different trees forming the onset of the absolute chronology. The overlap of almost 120 yrs particularly within the Alleroed/YD transition (GI-1/GS-1) is characterised by growth disturbances described in Section 2.1.1. Similar to that, no satisfactory correlation position exists between G5 (last tree ^{14}C dated of ZHLG_1) and the older side of the two chronologies from Barbier. At least both reflect the rapid decrease of the ^{14}C ages at the onset of YD (GS-1). For the positions to YDA- and YDB-chronologies the correlations (*t*-values and GLK%) do not meet our preconditions.

2.4. Italian find sites and chronologies (Fig. 1)

2.4.1. Revine, Veneto

The quarry near the lakes of Revine (Treviso, Italy) was studied in an interdisciplinary project by Casadoro et al. (1976) between 1972 and 1976. At this site more than 70 Larch trees (*Larix decidua*) were found of which 13 were of dendrochronological use to construct a 304-year chronology (Corona, 1984). Supplemented with additional samples Friedrich et al. (1999) built two additional chronologies of 317 and 259 years from 14 larch trees (*Larix* sp.) found in the clay pit near the small town of Revine in NE-Italy. Problems in chronology building arose from the presence of the Larch bud moth (*Zeiraphera diniana*) causing strong growth depression and missing rings every 7–10 years (Weber and Schweingruber, 1995). ^{14}C age determinations place the forest of the Revine site between 15 200 and 14 300 BP (^{14}C) contemporaneous with ODD and Heinrich 1 (GS-2a).

2.4.2. Avigliana, Dora Riparia

In the fluvial sediments of the Dora Riparia River near Avigliana north of Torino 32 logs have been collected by Bernd Becker in the 1980’s and supplemented by new samples from nearby sites. A group of 8 pines was synchronized into a 253-year chronology dated to Boelling (GI-1e) by radiocarbon. Another group of 5 trees can be placed to the end of Alleroed. Up to now no statistically valid cross match to the other Boelling chronologies of this study could yet be found.

2.4.3. Carmagnola, Po valley

A large number of sub fossil trees of Lateglacial and Holocene age was found in gravel pits in the alluvial plain of the Po River

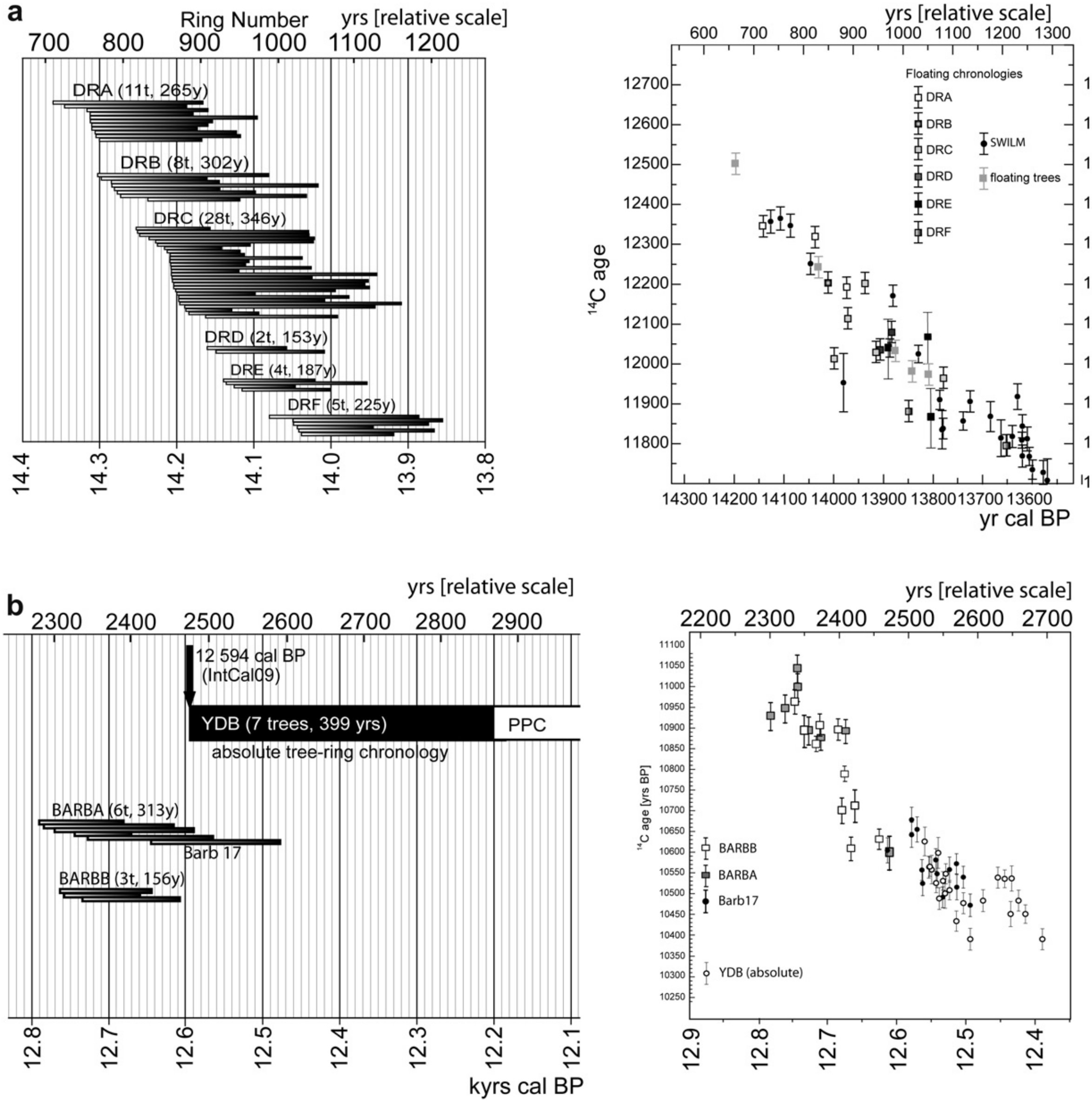

Fig. 4. Scope of French chronologies. On the left, composition of chronologies, on the right, decadal ^{14}C age determinations versus tree-ring ages. Both timescales, for the floating chronologies relative tree-ring years and cal BP years are added. As for the French trees Gleichlaeufigkeit and *t*-values are displayed in Table 1. a: Chronologies of late Boelling (GI-1e) from Drouzet. b: Chronologies of the end of Alleroed and Younger Dryas (GS-1) from Barbiers.

south of Torino. So far a group of 24 pines of this collection from Carmagnola could be combined to a chronology of 344 years dated between 14 500 and 14 150 cal BP (Boelling/GI-1e).

2.4.4. Palughetto, Belluno

Geo-archaeological investigations at the Cansiglio Plateau in the Venetian Pre-Alps Northeast of Revine revealed finds of Lateglacial trunks in a bog at Palughetto (Avigliano et al., 2000, Vescovi et al., 2007) 203 trunks, and tree fragments were recovered. Most of the trees were not found ‘in situ’. They grew close to the bog and were overturned into the former lake, which was subject to aggradations later. Thus the trees were preserved in the sediment. The maximum number of tree rings varies between 281 for larch trees, 147 for spruces, 98 for birches, and 74 for poplars. Dendrochronological analyses of the three conifer species resulting in 7 groups of 34 trees, which fall in a period spanning ca. 1600 years of the Boelling-Alleroed interstadial (GI-1). The internal cross dating of this material revealed a strong common signal of the tree-ring series.

Floating tree-ring chronologies were calibrated using AMS ^{14}C age determinations, as a dendrochronological cross match to other regional chronologies has not been successful yet. The first group of spruce and larch trees germinated in early Boelling (GI-1e) at 14 600 cal BP (12 500 BP). This date indicates that reforestation in LGIT in the southern Pre-Alpine region started about 200 years earlier than North of the Alps on the Swiss Plateau, i.e. Dättnau (Section 2.1) and French Alps (Section 2.3).

3. Supra-regional and Central-European connections

3.1. Tree-ring teleconnection

3.1.1. Swiss–German synchronisation of regional Lateglacial chronologies

Friedrich et al. (1999, 2001a, b, 2004) constructed chronologies from various sites in different regions in East Germany (i.e. Reichwalde, 509 trees, 854 years), North Germany (Warendorf, 22 trees, 466 years), South Germany (Danube valley and tributaries LG2: 46 trees, 666 years, LG3: 13 trees, 334 years and LG4: 3 trees, 190 years) (Fig. 3). The regional chronologies show significant teleconnection among different remote sites over distances of up to 600 km (Danube – Reichwalde: ovl: 666 years, Glk: 60%, *t*: 4.0; Warendorf – Reichwalde: ovl: 466 years, Glk: 64%, *t*: 8,1; Danube–Warendorf: ovl: 406 years, Glk: 53,7%, *t*: 2,4).

Comparisons between those contemporaneous tree-ring series all established independently allowed a check for correct cross dating both for German and Swiss chronologies. The synchronisations are very encouraging. Here the comparisons to the chronology from the Danube valley are of special importance as correlation is extremely high with that chronology (ZHLG_1 – Danube LG2: ovl: 666 years, Glk: 59, *t*: 9,5; ZHLG_1 – Danube LG3: ovl: 334 years, Glk: 59, *t*: 6,1) and therefore both chronologies can be confirmed over their full length. Correlations of the Swiss Lateglacial Master Chronology (SWILM) to the North and East German sites are weaker, but still significant (Warendorf: ovl: 466 years, Glk: 59%, *t*: 3,9; Reichwalde: ovl: 854 years, Glk: 54%, *t*: 2,4).

There is a remarkable difference of correlation between the different local chronologies from Zurich to the South German chronology. The local chronology from LANBOAL correlates significantly stronger to Danube (ovl: 666 years, Glk: 61%, *t*: 11.5) than to GAENALCH (ovl: 366 years, Glk: 60%, *t*: 6.7). This fact indicates a different grade of supra-regional environmental imprint and local influences on tree-growth in the different chronologies respectively.

3.1.2. Formation of a Central European Lateglacial Master Chronology (CELM)

The perfect cross dating of the Swiss and South-German chronologies LG2 and LG3 determined us to build a Lateglacial master chronology from Central Europe, CELM (Fig. 5). For the presentation in this paper we stay with the raw data sets. The final 82 years of Gänziloh regional chronology, SWILM, and CELM are blanketed due to low replication and the dominating of both the juvenile as well as the age trends.

The high replication discloses the application of statistical means e.g. standardisation, power transformations, splines and RCS (regional curve standardisation) in the future. Friedrich et al. (2001a) and Schaub et al. (2008a,b) have attested the potential of coherent tree-ring series in combining different terrestrial (e.g. lacustrine varves and ice cores), as well as marine archives (e.g. marine varves). Nevertheless also our raw-data chronologies reveal several distinct signals. While long term swings in the series have to be interpreted with caution. We readopt this topic in the following section (Fig. 5).

3.2. Filtering of regional, continental, and superior signals reflected in the tree-ring series

Events reflected in tree-ring series are marked with lines or underlain with shadows and numbered consecutively (Fig. 5). Several high frequency signals can be differed in the regional chronologies as well as in the master chronology (Fig. 5) represented by distinct troughs in the series, in dendrochronology called pointer years (Schweingruber et al., 1990). Also long-term fluctuations appear. Low replicated intervals within the sequences are, as mentioned above (Section 2.1), the interval of 21 years between 931 and 953. Also 82 years at the end of chronology GAENALCH (ZHLG_1 resp.) after position 2290, are weak as well, where the chronology lashes out and is therefore blanketed.

Reichwalde chronology is not integrated into CELM. Nevertheless the signals coincide well and therefore Reichwalde is also

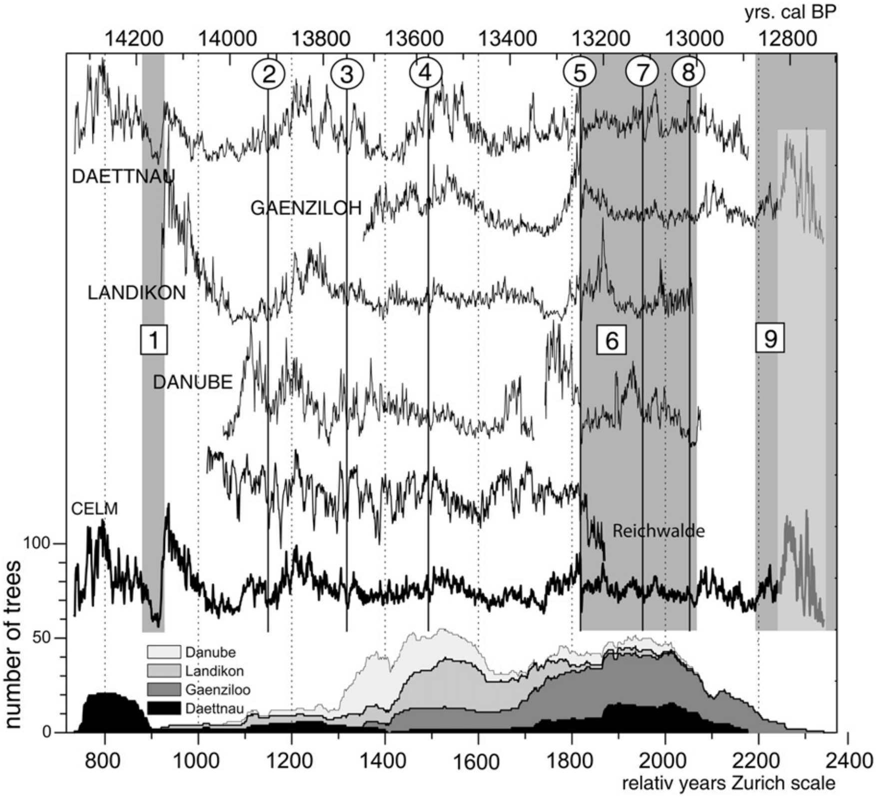

Fig. 5. Lateglacial Central-European Master Chronology CELM: Combination of SWILM with chronology LG2 and LG3 from Southern Germany embedded. The scope of mean series of cross-dated Lateglacial chronologies is displayed and recorded supra-regional environmental signals marked with numbers. For better visualisation of their range regional chronology Reichwalde is added in the plot. The regional chronologies belonging to SWILM and CELM are identified in capital letters.

displayed in Fig. 5 to see the geographical expansion of growth pattern or signals respectively.

Progression of the tree-ring chronology from the onset to 12 880 cal BP agrees with the characteristics of the GI-1. Event 1 reflects most likely OD (GI-d), as a distinct growth disturbance lasting in Central Europe more than 20 years. This finding is in coincidence with Friedrich et al. (2001a). Event 2 is a short signal. Trees in Reichwalde recover faster and more intensively than those in the south. Event 3 affects the trees in Reichwalde earlier than in the south.

Event 4 leaves a distinct short mark in every tree-ring sequence. The most distinct in the whole Alleroed GI-1c-a) is event 5. Schaub et al. (2008b) described it, suggesting that by south-westerly winds tephra ejected by volcano Puy de la Nugère in the Massif Central of France (Vannière et al., 2004) created this distinct trough, which dates back to 13 360 ± 130 cal BP. The rebound appears in all chronologies of that interval and retarded the recovery of the Reichwalde forest from a previous reversal. Since the tephra of this particular eruption called "La retombée de la Moutade" has been detected only in Lake Lautrey, Jura (France), which is about halfway between the volcano and Zurich, we suggest that according to Rampino et al. (1988) and Scuderi (1990) not the tephra but the acidic fumes ejected into the stratosphere producing aerosol clouds may have caused the signal. Gerlach et al. (1996) describe the same phenomenon as Pinatubo effect.

Interval 6 corresponds to Gerzensee deviation (IACP Inner Alleroed Cold Period, GI-1b) (Eicher, 1980; Siegenthaler et al., 1984; Johnsen et al., 1992; Lehman and Keigwin, 1992). The GI-1b is a slight climatic setback in the tree-ring chronology of 265 years, divided into two troughs 160 and 105 years in duration. It is seen in the most δ^{18}O records in the Greenland ice cores (Siegenthaler et al., 1984), lake marl (Eicher, 1980), even in stable isotope records derived from land snails in Dättnau and lacustrine molluscs from Wylermoos near Bern, Switzerland (Kaiser and Eicher, 1987; Kaiser, 1993).

Event 7 is described as the effect of the Laachersee eruption, LSE (Kaiser, 1993; Friedrich et al., 1999; Schmincke et al., 1999, Schmincke, 2004: Schaub et al., 2008b), and is evidenced by high precision ^{14}C age determinations both on poplars found in a pyroclastic flow at Kruft as well as in the tree rings of Dättnau (Baales et al., 1999; Litt et al., 2003). The different ash fans of LST spread all over Switzerland south to Grenoble (France) and Torino (Italy) and are found in lake marl of numerous lakes on the Swiss Plateau (Eicher, 1979; Ammann and Lotter, 1989; Lotter et al., 2000; Hajdas et al., 1995; Merkt and Müller, 1999;). Again, only a high amount of sulphur dioxide and other acids blown up into stratosphere forming aerosol clouds explains the distinct backlash of 5–8 years in growth (van den Bogaard and Schmincke, 1985; Rampino et al., 1988, Scuderi, 1990).

Finally the backlash of event 7 initiates the decline of the forest stands in the Dättnau valley at the end of Alleroed (GI-1a) and the transition into YD (GS-1) (cold stadial 9). Schaub et al. (2008a) observed in the pines of the Zurich area a distinct reduction in life span down to 150 years while the growth performance remained (ring widths) at the Alleroed/YD transition and in early YD (GS-1). They interpreted that as a general climatic shift into more continentality with temperate summers similar to Alleroed but pronounced colder and also longer winters. The same phenomenon occurs predominantly during late Boelling (GI-1e) (DAEBOECH) and late Alleroed GI-1a) (DALCH4) at the Dättnau site (Fig. 3). On top of that the reaction of the trees in this respect causes higher growth variability, which results in worsening correlation coefficients. The lake of Zurich provides a balancing temperature effect, which we assume, promoted the persistence of the Lateglacial pioneer vegetation in the area of Zurich and vicinity mainly in Gänziloh in contrast to the area of Winterthur.

3.3. Actual state of ^{14}C data sets

^{14}C dating of the Lateglacial chronologies is important for two aspects: (1) in the initial stages of chronology building ^{14}C predates can define a narrow window to search for ring-width synchronisation; (2) once the chronology is built and verified by dendrochronological techniques tephra-dates and additional ^{14}C dates become the foundation of a narrowly spaced ^{14}C data series to be used for ^{14}C calibration, as soon as the chronology is connected with statistical certainty to the absolutely dated chronology.

For pre-dates generally sections of 20–60 outer rings, taken from the pith were submitted. As the positions within the potential chronology are unknown at the time of sampling, the resulting distribution of ^{14}C dates in the chronology is far from an equal spacing, and the large number of rings renders these dates less suitable for calibration. Therefore in the second step decadal and equally spaced samples were taken from trees securely anchored in the chronology. In total 48 pre-dates and 131 decadal dates of the Swiss chronologies were obtained, as shown in Fig. 6.

This dataset complements the already published ^{14}C series of the floating German pine chronology (Kromer et al., 2004), and extends it into the Younger Dryas chronozone. Once a statistically robust dendrochronological link to the absolute chronology will be established, these data sets will be combined to extend the terrestrial ^{14}C calibration back to ca. 14.000 cal BP.

An approximate estimate of the calendar age span of the ^{14}C age sequence as presented in Fig. 6 can be obtained by comparison to the ^{14}C calibration data set IntCal09 (Reimer et al., 2009). However, as discussed by e.g. Muscheler et al., 2008 and Hua et al., 2009, the marine based section of IntCal09 may suffer from uncertainties in the marine reservoir age correction in the Lateglacial, especially at the onset of the Younger Dryas. Hence, at this time only approximate ages can be given. Using the D_Sequence option of OxCal 3.10 ring 899 of SWILM chronology is anchored in years 14092–14064 cal BP (2σ). Hence the onset of SWILM chronology dates back to 14224–14196 cal BP.

4. Discussion

4.1. Potential of different sites

Mainly the sites from Switzerland reveal how the chance of chronology developing arises from a high number of individual

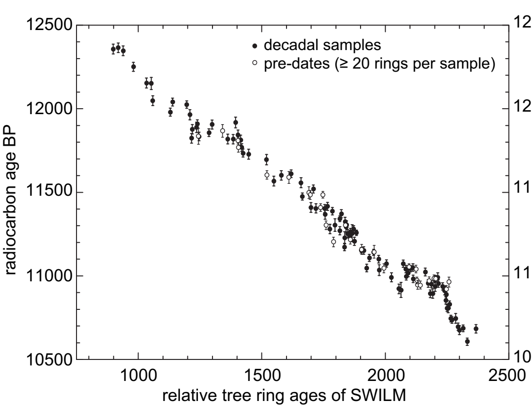

Fig. 6. Display of the entire scope of predates and decadal ^{14}C age determinations versus tree-ring ages of SWILM chronology.

trees. The higher the abundance of trees the more outlier may occur. Nevertheless we positioned several floating trees we were unable to incorporate into a site chronology e.g. Dättnau by a satisfying cross match. Also the handicap of unreadable tree-ring pattern in the innermost heartwood and peripheral sapwood rings (Fig. 2), forced us to rely on overlaps of ≥100 rings minimum. Using trees from adjacent sites like the extension of LANBOEAL by cross dating with DAEBOEAL or fixing the positions of floating chronologies from Dättnau using LANBOEAL, GAENALCH, and ZHLG_1 respectively, because sufficient intra-site correlations in Dättnau were lacking.

The formation of genuine site chronologies was recompensed by excellent coincidence between remote site such as LANBOEAL (Switzerland) and LG2 (Germany) as well as among the different German sites. It seems that the variability of environmental and/or climatic conditions North of the Alps encompassed entire Central Europe during the Alleroed (GI-1c-a) as well as during mid YD (GS-1), while the environmental and climatic variability increased during both transitions Boelling/OD/Alleroed (GI-1d) and Alleroed/YD (GI-1/GS-1).

Sites West and South of the Alps seem to underlie influences from either Mediterranean Sea like in Northern Italy or from Atlantic or both (France). In the Durance basin, due to its seclusion against North and East, site variability in relation to North and South side of the Alps seems to be much higher. We refer that to the windward exposition of this particular area of the French Alps. The outcome of the high environmental variability leads to the difficulties in forming tree-ring chronologies due to great differences of the growth pattern among the trees of the same site as well as between the sites.

4.2. Coincidence of regional chronologies

The successful combination among the German sites reveals the potential of high replicated tree-ring sequences and the formation of supra regional chronologies. The same statement may apply to the Swiss chronologies. For the North-European lowland as well as the German low mountain range and the Swiss Plateau bear several multi-proxy archives reconstructing environmental variations e.g. lacustrine varves of Lake Gosciaz, Lake Persepilno (Poland) (Goslar et al., 1993, 1999) and contemporary lakes such as Soppensee, Holzmaar, and Haemelsee (Hajdas et al., 1993, 1995, Brauer et al., 1999; Leroy et al., 2000; Litt et al., 2001), or Lago di Grande Monticchio, Southern Italy (Huntly et al., 1999), or Lake Suigetsu, Japan, (Kitagawa and Van Der Plicht, 1998a,b).

In the Southern French Alps chronologies will be extended and replications will be improved in the near future. At now in French Alps tree ring provide unrepeatable annual resolution information for Lateglacial. In Southern Alps, no other data in such resolution exists, and no other proxy provides environmental information back to the onset of Boelling. At regional scale, with a lower time resolution, paleoenvironmental information hold in tree rings could be compared with other proxies e.g. lake level changes (Digerfeldt et al., 1997; Magny, 2004; Magny et al., 2006).

4.3. Predates and decadal radiocarbon dates, ^{14}C-calibration

As mentioned above predates and decadal ^{14}C age determinations of fossil tree-ring sections are an important tool to identify time windows for valid cross dating. This relies exclusively on tree-ring statistical parameters (ovl, Glk and *t*-values). Since the German pine dates have already been published, now the task is to combine German and Swiss pine ^{14}C dates in a fixed (decadal) binning, with screening of dates according to some model of the plausible variance, as was done for the IntCal data set. This laborious task goes beyond the scope of this paper.

5. Conclusions

We updated the site chronologies from Winterthur and Zurich, Switzerland. In Germany highly replicated regional chronologies were formed in the NW, Warendorf, in the NE at Reichwalde, and from various sites of Danube and tributaries (mainly Guenz and Isar). High replication and supra-regional growth pattern as well as numerous decadal ^{14}C age determinations facilitate cross dating. These synchronisations led to the formation of a 1606 year Master Chronology (SWILM) consisting of 144 pines and from teleconnection over 200–300 km arose chronology CELM expressing coherent wide-ranging environmental signal within the Swiss and the Bavarian Plateau. The French sites due to the very particular regional character of the Durance basin and the high variability intra-site as well as between the sites cannot be combined to as well replicated sequences like on the Northward side of the Alps. This fact and caused by divergent signals between Central Europe at the Northern slope of the Alps and the Southern French Alps with their westward orientation teleconnection is visible but weak.

As of the Drouzet chronologies they may serve as a backing to synchronisation as soon as the numerous sequences are linked. A major cohort of trees as evidenced by the series from Central Europe reveals better supra-regional signals. Similar problems arise from the Barbier find situation. Numerous ^{14}C data attest the position within the late Alleroed (GI-1a) and early YD (GS-1) exactly in a most sensitive area between the onset of the absolute chronology and the short chronology YD_A and the long CELM and short floating chronologies.

Acknowledgements

We thank the “Tiefbauamt des Kantons Zürich” (O. Schnelli) for financial and technical support and Jäckli AG Zürich; Geologie-Geotechnik-Grundwasser) for administrative processing. The ^{14}C analyses were done within the German DEKLIM program (Federal Ministry of Education and Research) and the ESF-program EUROCLIMATE “Dendrochronology, 14C time-scale and mechanism of rapid climate change during the last deglaciation (TREE_14, FP14)”. The French branch was supported by CNRS projet PICS n° 4418 “ Longues séquences dendrochronologiques, calibration et reconstitutions paléoclimatiques au Tardiglaciaire en Europe médiane et méditerranéenne”. We are also indebted to the Swiss Federal Research Institute WSL (Switzerland) for hospitality and access to their facilities. Prof. Urs Schmid kindly checked our English.

Appendix. Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.quascirev.2010.07.009.

References

Ammann, B., Lotter, A.F., 1989. Late-Glacial radiocarbon – and pollenstratigraphy on the Swiss plateau. Boreas 18, 109–126.

Avigliano, R., Anastasio, G.D., Improta, S., Peresan, M., Ravazzi, C., 2000. A new late glacial to early Holocene palaeobotanical and archaeological record in the Eastern Pre-Alps: the Palughetto basin (Cansiglio Plateau, Italy). Journal of Quaternary Science 15 (8), 789–803.

Baales, M., Bittmann, F., Kromer, B., 1999. Verkohlte Bäume im Trass der Laacher See-Tephra bei Kruft (Neuwieder Becken). Archäologisches Korrespondenzblatt 28, 191–204.

Baillie, M.G.L., Pilcher, J.R., 1973. A simple cross-dating program for tree-ring research. Tree-Ring Bulletin 33, 7–14.

Becker, B., 1993. An 11,000-year German oak and pine dendrochronology for radiocarbon calibration. Radiocarbon 35 (1), 201–213.

Becker, B., Kromer, B., 1986. Extension of the holocene dendrochronology by the preboreal pine series, 8800 to 10,100 BP. Radiocarbon 28, 961–967.

Björck, S., Walker, M.J.C., Cwynar, L., Johnsen, S., Knudsen, K.L., Lowe, J., Wohlfarth, B., 1998. An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. Journal of Quaternary Science 13 (4), 283–292.

Brauer, A., Endres, C., Günter, C., Litt, T., Stebich, M., Negendank, J.F.W., 1999. High-resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. Quaternary Science Reviews 18, 321–329.

Bogaardvan den, P., Schmincke, H.-U., 1985. Laachersee Tephra: a widespread isochronous late Quaternary ash layer in Central and Northern Europe. Geological Society of America Bulletin 96, 1554–1571.

Corona, E., 1984. Una curva trisecolare per larice del Dryas Antico. Dendrochronologia 2, 83–89.

Casadoro, G., Castiglioni, G.B., Corona, E., Massari, F., Moretto, M.G., Paganelli, A., Terenziani, F., Toniello, V.L., 1976. Un deposito Tardowurmiano con tronchi subfossili alle Fornaci di Revine (Treviso). Bollettino Comitato Glaciologico Italiano 24, 22–63.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjornsdottir, A.E., Jouzel, J., Bond, G., 1993. Evidence for general instability of past climate from a 250-Kyr ice-core record. Nature 364, 218–220.

Digerfeldt, G., Beaulieu, de, J.L., Guiot, J., Mouthon, J., 1997. Reconstruction and paleoclimatic interpretation of Holocene lake-level changes in Lac de Saint-Léger, Haute-Provence, southeast France. Palaeogeography, Palaeoclimatology, Palaeoecology 136, 231–258.

Eicher, U., 1979. Die 18O/16O- und 13C/12C-Isotopenverhaeltnisse in spaetglazialen Suesswasserkarbonaten und ihr Zusammenhang mit den Ergebnissen der Pollenanalyse. Ph.D. dissertation. University of Bern, 205 pp.

Eicher, U., 1980. Pollen- und Sauerstoffisotopenanalysen an den spätglazialen Profilen vom Gerzensee, Faulenseemoos und vom Regenmoos ob Boltigen. Mitteilungen der Naturforschenden Gesellschaft Bern 37, 65–80.

Fairbanks, R., 1989. A 17000-year glacio-eustatic sea level record: Influence of glacial melting rates on the the YD event and deep-ocean circulation. Nature 342, 637–642.

Friedrich, M., Kromer, B., Spurk, H., Hofmann, J., Kaiser, K.F., 1999. Paleo-environment and radiocarbon calibration as derived from Lateglacial/Early Holocene tree-ring chronologies. Quaternary International 61, 27–39.

Friedrich, M., Kromer, B., Kaiser, K.F., Spurk, M., Hughen, K.A., Johnsen, S.J., 2001a. High-resolution climate signals in the Bølling-Allerød Interstadial (Greenland Interstadial 1) as reflected in European tree-ring chronologies compared to marine varves and ice-core records. Quaternary Science Reviews 20, 1223–1232.

Friedrich, M., Knipping, M., von der Kroft, P., Renno, A., Ullrich, O., Vollbrecht, J., 2001b. Ein Wald am Ende der letzten Eiszeit. Untersuchungen zur Besiedelungs-, Landschafts- und Vegetationsentwicklung an einem verlandeten See im Tagebau Reichwalde, Niederschlesischer Oberlausitzkreis. Arbeits- und Forschungsberichte zur sächsischen Bodendenkmalpflege 43, 21–94.

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

Gerlach, T.M., Westrich, H.R., Symonds, R.B., 1996. Pre-eruption vapor in magma of the climactic Mount Pinatubo eruption: source of the giant stratospheric sulfur dioxide cloud. In: Newhall, C.G., Punongbayan, R.S. (Eds.), Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines. Philippine Institute of Volcanology and Seismology, and the University of Washington Press, Quezon City; Seattle, p. 1126 pp..

Goslar, T., Kuc, T., Ralska-Jasiewiczowa, M., Rozanski, K., Arnold, M., Bard, E., Van Geel, B., Pazdur, M.F., Szerozynska, K., Wicik, B., Wieckowski, K., Walanus, A., 1993. High-resolution lacustrine record of the Lateglacial/Holocene transition in Central Europe. Quaternary Science Reviews 12, 287–294.

Goslar, T., Balaga, K., Arnold, M., Tosnerat, N., Starnawaska, E., Kuzniarski, M., Chróst, A., Walanus, A., Wieckowski, K., 1999. Climate-related variations in the composition of the Lateglacial and early Holocene sediments of Lake Perespilno (eastern Poland). Quaternary Science Reviews 18, 899–912.

Grissino-Mayer, H.D., 2001. Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. Tree-Ring Research 57 (2), 205–221.

Hajdas, I., Ivy-Ochs, S.D., Beer, J., Bonani, G., Imboden, D., Lotter, A.F., Sturm, M., Suter, M., 1993. AMS radiocarbon dating and varve chronology of Lake Soppensee: 6,000 to 12,000 ^{14}C years BP. Climate Dynamics 9, 107–116.

Hajdas, I., Ivy-Ochs, S.D., Bonani, G., Lotter, A.F., Zollitschka, B., Schlüchter, C., 1995. Radiocarbon age of the Laacher See tephra: 11,230 ± 40 BP. Radiocarbon 37 (2), 149–154.

Hua, Quan, Mike, Barbetti, David, Fink, Klaus, Felix Kaiser, Michael, Friedrich, Bernd, Kromer, Vladimir A., Levchenko, Ugo, Zoppi, Andrew M., Smith, Fiona, Bertuch, 2009. Atmospheric ^{14}C variations derived fromtree rings during the early Younger Dryas. Quaternary Science Reviews 28, 2982–2990.

Hughen, K.A., Overpeck, J.T., Lehman, S.J., Kashgarian, M., Southon, J., Peterson, L.C., Alley, R.B., Sigman, D.M., 1998a. Deglacial changes in ocean circulation from an extended radiocarbon calibration. Nature 391, 65–68.

Hughen, K.A., Overpeck, J.T., Lehman, S.J., Kashgarian, M., Southon, J.R., 1998b. A new C-14 calibration data set for the last deglaciation based on marine varves. Radiocarbon 40, 483–494.

Huntley, B., Watts, W.A., Allen, J.R.M., Zolitschka, B., 1999. Palaeoclimate, chronology and vegetation history of the Weichselian Lateglacial: comparative analysis of the data from tree cores at Lago Grande di Monticchio, southern Italy. Quaternary Science Reviews 18, 945–960.

Hughen, K.A., Southon, J.R., Lehman, S.J., Overpeck, J.T., 2000. Synchronous radiocarbon and climate shifts during the last deglaciation. Science 290, 1951–1954.

Johnsen, S.J., Clausen, H.B., Dansgaard, W., Fuhrer, K., Gundestrup, N., Hammer, C.U., Iversen, P., Jouzel, J., Stauffer, B., Steffensen, J.P., 1992. Irregular glacial interstadials recorded in a new Greenland ice core. Nature 359, 311–313.

Kaiser, K.F., 1993. Beiträge zur Klimageschichte vom Hochglazial bis ins frühe Holozän, rekonstruiert mit Jahrringen und Molluskenschalen aus verschiedenen Vereisungsgebieten. Ziegler Druck- und Verlags-AG, Winterthur, –206 pp.

Kaiser, K.F., Eicher, U., 1987. Fossil pollen, molluscs, and stable isotopes in the Daettnau valley, Switzerland. Boreas 16, 293–303. Oslo.

Kitagawa, H., Van Der Plicht, J., 1998a. Atmospheric radiocarbon calibration to 45,000 yr B.P.: late glacial fluctuations and cosmogenic isotope production. Science 279, 1187–1190.

Kitagawa, H., Van Der Plicht, J., 1998b. A 40,000 years varve chronology from Lake Suigetsu, Japan: extension of the ^{14}C calibrations curve. Radiocarbon 40, 505–515.

Kromer, B., Spurk, M., Remmele, S., Barbetti, M., Toniello, V., 1997. Segments of atmospheric ^{14}C change as derived from Lateglacial and early Holocene floating tree-ring chronologies. Radiocarbon 40 (1), 351–358.

Kromer, B., Friedrich, M., Hughen, K.A., Kaiser, K.F., Remmele, S., Schaub, M., Talamo, S., 2004. Late Glacial ^{14}C ages from a floating, 1382-ring pine chronology. Radiocarbon 46 (3), 1203–1209.

Lehman, S.J., Keigwin, L.D., 1992. Sudden changes in North Atlantic circulation during the last deglaciation. Nature 356, 757–762.

Leroy, S.A.G., Zolitschka, B., Negendank, J.F.W., Seret, G., 2000. Palynological analyses in the laminated sediment of Lake Holzmaar (Eifel, Germany): duration of Lateglacial and Preboreal biozones. Boreas 29, 52–71.

Litt, T., Brauer, A., Goslar, T., Merkt, J., Balaga, K., Müller, H., Ralska-Jasiewiczowa, M., Stebich, M., Negendank, J.F.W., 2001. Correlation and synchronisation of Lateglacial continental sequences in northern central Europe based on annually laminated lacustrine sediments. Quaternary Science Reviews 20, 1233–1249.

Litt, T., Schmincke, H.-U., Kromer, B., 2003. Environmental response to climate and volcanic events in central Europe during the Weichselian Lateglacial. Quaternary Science Reviews 22 (1), 7–32.

Lotter, A.F., Birks, H.J.B., Eicher, U., Hofman, J., Schwander, J., Wick, L., 2000. Younger Dryas and Allerod summer temperatures at Gerzensee (Switzerland) inferred from fossil pollen and cladoceran assemblages. Palaeogeography, Palaeoclimatology. Palaeoecology 159, 349–361.

Magny, M., 2004. Holocene climatic variability as reflected by mid-European lake-level fluctuations, and its probable impact on prehistoric human settlements. Quaternary International 113, 65–80.

Magny, M., Aalbersberg, G., Begeot, C., Benoit-Ruffaldi, P., Bossuet, G., Disnar, J.R., Heiri, O., Laggoun-Defarge, F., Millet, L., Peyron, O., Vanniere, B., Walter-Simonet, A.V., 2006. Environmental and climatic changes in the Jura mountains (eastern France) during the Last Glacial–Interglacial transition: a multi-proxy record from Lake Lautrey. Quaternary Science Reviews 25, 414–445.

Merkt, J., Müller, H., 1999. Varve chronology and palynology of the Late Glacial in northwest Germany from lacustrine sediments of Hämelsee in Lower Saxony. Quaternary International 61, 41–59.

Miramont, C., Sivan, O., Edouard, Jl., Jorda, M., Rosique, T., 2000a. Subfossil trees (*Pinus silvestris* L.) of the Durance basin (Southern Alps, France): environmental changes from Allerod to Atlantic. Dendrochronologia 18, 83–89.

Miramont, C., Sivan, O., Rosique, T., Edouard, J.L., Jorda, M., 2000b. Subfossil trees deposits in the middle Durance (Southern Alps, France). Environmental changes since Allerod to Atlantic. Radiocarbon 42 (3), 423–435.

Muscheler, R., Kromer, B., Björck, S., Svensson, A., Friedrich, M., Kaiser, K.F., Southon, J., 2008. Tree rings and ice cores reveal 14C calibration uncertainties during the Younger Dryas. Nature Geoscience 1, 263–267.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., S.TalamoTurney, C.S.M., van der Plicht, J., Weyhenmeyer, C.E., 2010. INTCAL09 and MARINE09 Radiocrabon Age Calibration Curves, 0–50,000 YEARS CAL BP. Radiocarbon 51 (4), 1111–1150.

Rasmussen, S.O., Andersen, K.K., Svensson, A.M., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.-L., Johnsen, S.J., Larsen, L.B., Bigler, M., Ro, thlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.E., Ruth, U., 2006. A new Greenland ice core chronology for the last glacial termination. Journal of Geophysical Research 111, D06102 doi: 10.1029/ 2005JD006079.

Rinn, F., 1996. TSAP – Time Series Analyses Presentation. Version 3.0. Referenz manual, Heidelberg. 262.

Rinn, F., 2003. TSAP-Win, time series analysis and presentation for dendrochronology and related applications. User Reference Version 0.53. Rinn Tech, Heidelberg.

Rampino, M.R., Self, S., Stothers, R.B., 1988. Volcanic Winters. Annual Reev. Earth Planet Science 16, 77–99.

Schaub, M., 2007. Lateglacial environmental conditions on the Swiss Plateau. A multi-proxy approach using tree rings and sediment-based proxies. Physische Geographie 54 (Haeberli W. & Maisch M. eds). 164 pp.

Schaub, M., Kaiser, K.F., Frank, D.C., Buentgen, U., Kromer, B., Talamo, S., 2008a. Environmental change during the Allerod and Younger Dryas reconstructed from tree-ring data. Boreas 37, 74–86.

Schaub, M., Büntgen, U., Kaiser, K.F., Kromer, B., Talamo, S., Andersen, K., Krog, R., Sune, O., 2008b. Lateglacial environmental variability derived from Swiss tree rings. Quaternary Science Reviews 27, 29–41.

Strasser, A., Weidmann, M., Hochhuli, P.A., 1999. Sédimentation postglaciaire fluviatile et palustre près d'Avenches (Suisse): implications climatique. Bull. Soc. Frib. Sc. Nat 88, 5–26.

Scuderi, L.A., 1990. Tree ring evidence for climatically effective volcanic eruptions. Quaternary Research 34, 67–85.

Schmincke, H.-U., 2004. Volcanism. Springer-Verlag, Berlin, Heidelberg, New York, 324 pp.

Schmincke, H.U., Park, C., Harms, E., 1999. Evolution and environmental impacts of the eruption of Laacher see volcano (Germany) 12,900 a BP. Quaternary International 61, 61–72.

Schweingruber, F.H., Eckstein, D., Serre-Bachet, F., Bräcker, O.U., 1990. Identification, presentation and interpretation of event years and pointer years in dendrochronology. Dendrochronologia 8, 9–38.

Siegenthaler, U., Eicher, U., Oeschger, H., 1984. Lake sediments as continental d18O records from the Glacial/Postglacial transition. Annals of Glaciology 5, 149–152.

Sivan, O., 2002. Activité érosive et évolution des paléoenvironements alpins postglaciaires. Etude dendrogéomorphologique des gisements de troncs subfossiles dans les Alpes du sud. Thèse. Université d'Aix-Marseille I, 274 pp.

Sivan, O., Miramont, C., 2008. Les variations temporelles et spatiales de la morphogenèse postglaciaire des fonds de vallons sud-alpins. L'exemple du bassin versant du Drouzet (Hautes-Alpes; France). Quaternaire 19 (3), 229–238.

Spurk, M., Friedrich, M., Hofmann, J., Remmele, S., Frenzel, B., Leuschner, H.H., Kromer, B., 1998. Paleo-environment and radiocarbon calibration as derived from Lateglacial/Early Holocene tree-ring chronologies. Quaternary International 61, 27–39.

Vannière, B., Bossuet, G., Walter-Simonnet, A.-V., Ruffaldi, P., Adatte, T., Rossy, M., Magny, M., 2004. High-resolution record of environmental changes and tephrochronological markers of the Last Glacial-Holocene transition at Lake Lautrey (Jura, France). Journal of Quaternary Science 19 (8), 797–808.

Vescovi, E., Ravazzi, C., Arpenti, E., Finsinger, W., Pini, R., Valsecchi, V., Wick, L., Ammannn, B., Tinner, W., 2007. Interactions between climate and vegetation during the Lateglacial period as recorded by lake and mire sediment archives in Northern Italy and Southern Switzerland. Quaternary Science Reviews 26, 1650–1669.

Weber, U.M., Schweingruber, F.H., 1995. A dendroecological reconstruction of western spruce budworm outbreaks (Choristoneura occidentalis) in the Front Range, Colorado, from 1720 to 1986. Trees 9, 204–213.