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LATE GLACIAL TREE-RING CHRONOLOGIES FROM PALUGHETTO BOG, VENETO PRE-ALPS, ITALY

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ABSTRACT: A Late-glacial / Early-Holocene lacustrine and peat succession, with conifer macro-remains and including some palaeo-mesolithic flint artefacts, was investigated in several steps in the Palughetto intermorainic basin (Venetian Pre-Alps). Published data on the geomorphic and stratigraphic relations, 14C chronology, pollen series and archaeology allow a reconstruction of the environmental history of the basin and provide significant insights into the reforestation and human peopling of the Pre-Alps. In this dendrochronological study, we analysed 203 trunks and branches from the subfossil tree assemblage of Palughetto mire, resulting in seven groups of 34 trees, which fall in a period of 1600 years of the Bølling-Allerød Interstadial between c. 14,900-12,800 cal BP. Cross dating was facilitated by numerous decadal AMS ^{14}C age determinations. Most of the trees were not found 'in situ'. They fell into the wetland and were preserved in the sediment. The forest mainly consisted of the species spruce (*Picea abies* Karst.), larch (*Larix decidua* Mill.), birch (*Betula pubescens* Erh.), poplar (*Populus* sp.) and willow (*Salix* sp.), confirming results from palynology and botanical remains analyses. Growth rates are different for each species. Spruce trees show wide rings and 'complacent' tree growth. Larch tree rings were narrower with higher interannual variability. The high growth rate of spruce indicates favourable growing conditions such as moderate temperatures and sufficient water supply during the vegetation period of the Bølling-Allerød in Palughetto, which is similar to the modern situation of the area.

Keywords: vegetation history, archaeology, Late Glacial, Eastern Pre-Alps.

1. INTRODUCTION

Previous investigations confirmed that the Palughetto basin at the northern edge of the Cansiglio Plateau, in the Eastern Italian Pre-Alps, has a rich potential for Late Glacial palaeobotanical research (see Avigliano et al., 2000; Vescovi et al., 2007). In earlier excavations cones, needles and parts of trees were found in the Palughetto peat bog, and during coring, pieces of a spruce trunk were recovered. Hence, it appeared promising to conduct further excavation. In 2006 a multi-disciplinary group, including students from several universities in Italy and Germany, conducted a field week at the site in the frame of wider research projects. Here we focus on the mega remains that were recovered (trunks, branches, roots) and their dendrochronology and described in a preliminary report (Friedrich et al., 2009).

2. PRESENTATION OF THE PALUGHETTO BASIN ON THE CANSIGLIO PLATEAU AND SUMMARY OF THE POLLEN SEQUENCE

The Palughetto is a lacustrine basin situated on the northern edge of the Cansiglio Plateau at 1,040 m a.s.l., in the Venetian and Carnic Pre-Alps, and enclosed by the drainage systems of the Piave and Livenza rivers (Fig. 1). The Cansiglio Plateau is a limestone massif featuring a central polje set at around 1,000 m a.s.l. encircled by ridges at elevations of 1,500 m, delimited to the east and to the south by tectonic lines joining to the west with the more important Belluno line. To the northwest, the Cansiglio is connected to the Santa Croce late-glacial lacustrine basin by a gentle and vast slope. The Cansiglio has an independent drainage system. This clearly increases its already karstic nature as testified by the countless dolines, sinkholes, and other features. A steep slope connects the Cansiglio with the Livenza karst spring system located to the southeast at the foot of the mountain. The highest elevation is reached at the Cavallo Mount (2,251 m a.s.l.), a group of peaks limited by glacial circles and ridges.

Superficial deposits and landforms of Palughetto are assigned to three episodes of the Piave glacier. Two well-preserved moraine ridges associated to fluvioglacial landforms are referred to the younger (C) and intermediate (B) episodes, while the older (A) episode is related to the spread of diamicton containing quartzites, sandstones and volcanoclastic sandstones, quartzitic phyllites, siltstones, micaschists, and igneous rocks typical of the Piave alpine basin (Avigliano et al., 2000). The last C episode dammed the basin to the North (Fig. 2). A

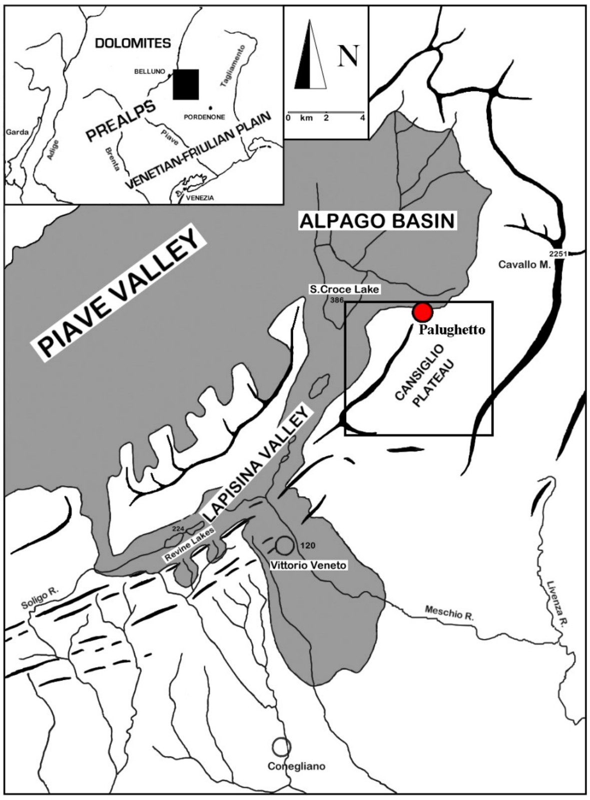


Fig. 1 - Map of a part of Venetian Pre-Alps showing the extent of the Piave glacier (shaded) during the LGM. The inset shows the location of the larger map within the region. The rectangle shows the area of the Cansiglio plateau (after Avigliano et al., 2000).

lacustrine-palustrine succession deposited in this small intermorainic basin at Palughetto until the opening of a sinkhole at the NE edge of the basin leading to the activation of a vertical drainage pattern.

Three archaeological sectors were identified in the area investigated, the first two refer to human settlements at the end of the recent Epigravettian on moraines B and C (respectively Palughetto MO and Palughetto MN), the third one within the peat-bog near its NW boundary is dated to the Sauveterrian period (Palughetto UST6; Peresani et al., 2011). Palughetto sites are part of a late Palaeolithic and early Mesolithic ensemble of settlements system discovered in the Cansiglio Plateau and surroundings (Peresani et al., 1999-2000; Visentin et al., 2016).

3. THE STRATIGRAPHIC SEQUENCE

The stratigraphic sequence was explored at the NW boundary of the basin through pits, trenches, and extensive archaeological excavations. The basin fill unconformably overlies a basal diamicton and gently inclines southeastwards, rapidly thickening towards the inner basin. Three main groups of litho- and pedo-stratigraphic units were observed (Fig. 3; Avigliano et al., 2000):

- Units T14-T11, are deposits composed of light-gray clayey silt and silt laminae with rare, striated pebbles (T14), dark-gray silt (T13), massive light-gray clay poor in organic matter with sporadic dwarf pine (*Pinus mugo*) cones (T12) and silty clay gradual coarsening to silt with organic matter (thin organic debris, sporadic birch leaves and larch cones still in connection with their bearing branchlets, sporadic dwarf pine cones) increasing upwards (T11). At the top of T11 there are thin laminae rich in organic debris, i.e., broad-leaved leaves (*Alnus* and *Betula*) and needles (*Larix*). The upper contact with the overlying organic deposits is transitional, marked by a rapid increase in leaves and cones and other organic debris.
- Units T10-T7 compose a thick organic layer extended above the clay-silt succession throughout the basin. The base layer is organic mud (gyttja) rich in plant debris (conifer needles, Characeae oogones, mosses, sporadic cones), overlaid by sedentary peat deposits. T10 is a moderately humified litter made of needles and very rich in cones and branchlets. *Larix decidua* is the main peat-forming plant. T9 is a highly humified peat made of wood, bark, branches, roots, needles, fruits, and thin interbeds rich of mosses. Vegetative parts of trees (both conifers and broad-leaved plants) are abundant throughout this unit, but its middle part is dominated by woody material, such as branches, crashed trunks, and in situ stumps. T8 is a thin layer of reddish little-decomposed laminated moss-peat rich

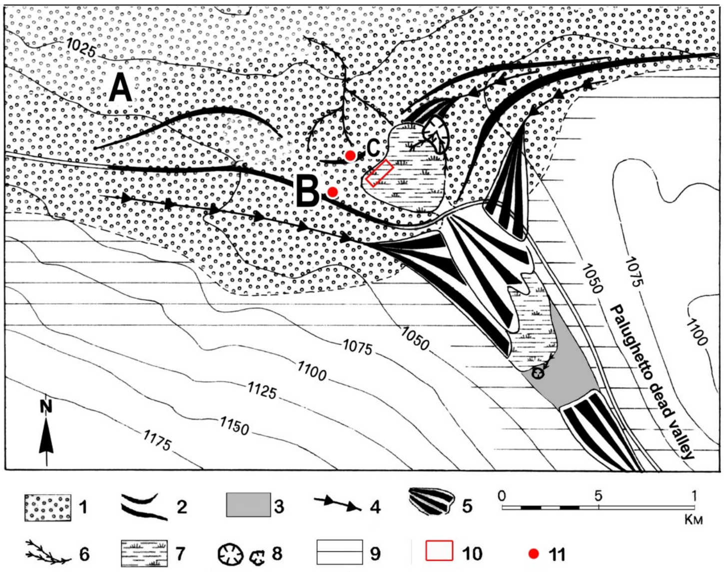


Fig. 2 - The Palughetto area with the three glacial episodes (A, B and C) recognised and position of the palaeolithic sites Palughetto MN and Palughetto MO (on the moraine ridges C and B respectively) and of the excavated area for dendrochronology at the northern side of the basin. Key: 1, glacial deposit; 2, moraine ridge; 3, loess cover; 4, fluvioglacial stream trace; 5, fluvioglacial fan; 6, present-day drainage; 7, silty clay and peat deposits; 8, dolines and sinkholes; 9, eluvial-colluvial and slope waste deposit; 10, excavated of the excavated area for dendrochronology; 11, palaeolithic site (after Avigliano et al. 2000, modified).

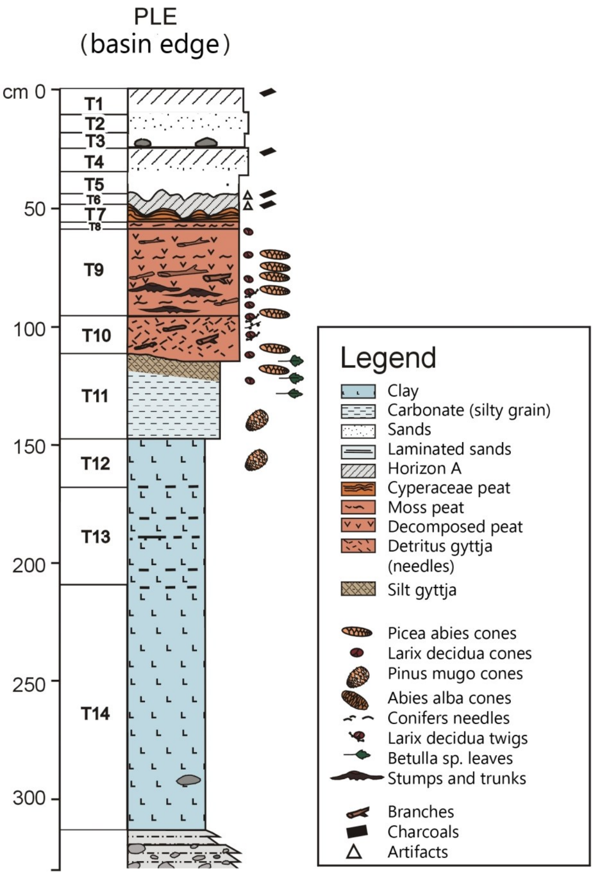


Fig. 3 - Log of the palynologically studied stratigraphic successions on the littoral basin (PLE) (after Ravazzi & Vescovi, 2009, modified).

in *Picea* and *Larix* needles, covering unit T9 with a sharp boundary. T7 is a thin layer formed by moderately decomposed Cyperaceae-peat, laminated, including sporadic *Picea* needles and *Larix* branchlets at its base. T9 also contains fragments of charred wood, late Epigravettian and early Mesolithic lithic artifacts (Peresani et al., 2011) and a lithic cache (Bertola et al., 1997) discovered during survey in 1995 and archaeological excavation in 1997 and 2001.

- Units T6-T1 show pedogenic features. A sharp, undulating boundary separates T7 from T6, a gray clay silt with rarely preserved plant remains (*Picea* needles and charred particles) and hydromorphic features. T5 is a massive clay bed covered by T4 to T1, thin layers of organic silt.

4. SUMMARY OF THE PALUGHETTO POLLEN SEQUENCE

The Palughetto lacustrine-palustrine succession produced chronological data. Associations of vegetal macroremains, charcoal particles and pollen enriched the reconstruction of vegetation changes of the Italian Prealps during the last glacial-interglacial transition (Vescovi et al., 2007). The fossil forest originated from trees growing in situ in peat or hanging on the central pond during the entire time span of the Bølling-Allerød interstadial complex, after buried at the onset of the Younger Dryas. The palaeoenvironmental history of the basin is based on two high resolution (60 years each sample) pollen records, a first one from the littoral, and a second one from the central basin infill (Ravazzi & Vescovi, 2009).

- After the glacier retreat, as early as 16 ka cal BP *Pinus mugo* scrubs had already extended over the sunny slopes surrounding the lake, whereas the bottoms and karstic plateaux were occupied by steppes, mostly formed by chamephytes (Fig. 4.1). At 15.0±0.6 ka cal BP *Pinus mugo* was hanging on the lake shore, as testified by direct ^{14}C-dating on in situ fossil cones.
- At 14.7 ka cal BP the altitude of Palughetto was override by an advancing larch-spruce forest (Fig. 4.2). The lag between trees establishment and forest closure is roughly shown by sedimentary interval of increasing APpercentage values and constrained by boundary stable conditions. A closed canopy was established since 14.3 ka cal BP, thus the development of forest population took about 4 centuries. This estimate helps in the evaluation of the diachronism between climate change and the duration of the triggered vegetation response. Furthermore, these forest dynamics attest the participation of larch and spruce in the early afforestation of the mountain belt in the South-Eastern Alps at the beginning of the Bølling-Allerød interstadial complex. Considering the time lag of *Picea* immigration in the inner Alps, which occurred several hundred years later than at Palughetto, it is proposed that the lateglacial spruce settled on the Cansiglio plateau acted as founding populations for the subsequent Holocene migration towards inner and western ranges of the Alps (Ravazzi, 2002).
- Between 14.7 and 13.7 ka cal BP a dense conifer forest occupied the Cansiglio plateau and the surrounding slopes, until 1700 m a.s.l.. Meantime the conifer forest expanded toward the basin centre and trees of *Larix*, *Picea* and *Betula* settled on peat, thus forming an accumulation of trunks, cones, litter, i.e. the fossil forest preserved in units T10 and T9 (Fig. 4.3).
- Afterwards (13.8 to 12.85 ka cal BP), broad-leaved tree species immigrated in the prealpine region, but expansion took place at a quite slower rate and probably broad-leaved individuals did not get the altitude of Palughetto, perhaps owing to its northern aspect and to the competition by previously settled conifers. The northern border of the Palughetto basin continued to sustain a (*Larix*)-*Picea-Betula* forest, accumulating coarse debris of trunks, wood and bark (woody peat) in unit T9 (Fig. 4.3).
- The onset of Younger Dryas at 12.85 ka cal BP triggered a forest withdrawal from the Palughetto wetlands, whereas the well-drained slopes continued to sustain a closed conifer forest throughout the Younger Dryas (Fig. 4.4).
- The transition to the Holocene is marked by the arrival of several broad-leaved species competing with larch and spruce. The first Holocene millennium is characterized by mixed forests (Fig. 4.5). Paleo-Mesolithic hunters settled the border of the peat bog (Fig. 4.6).

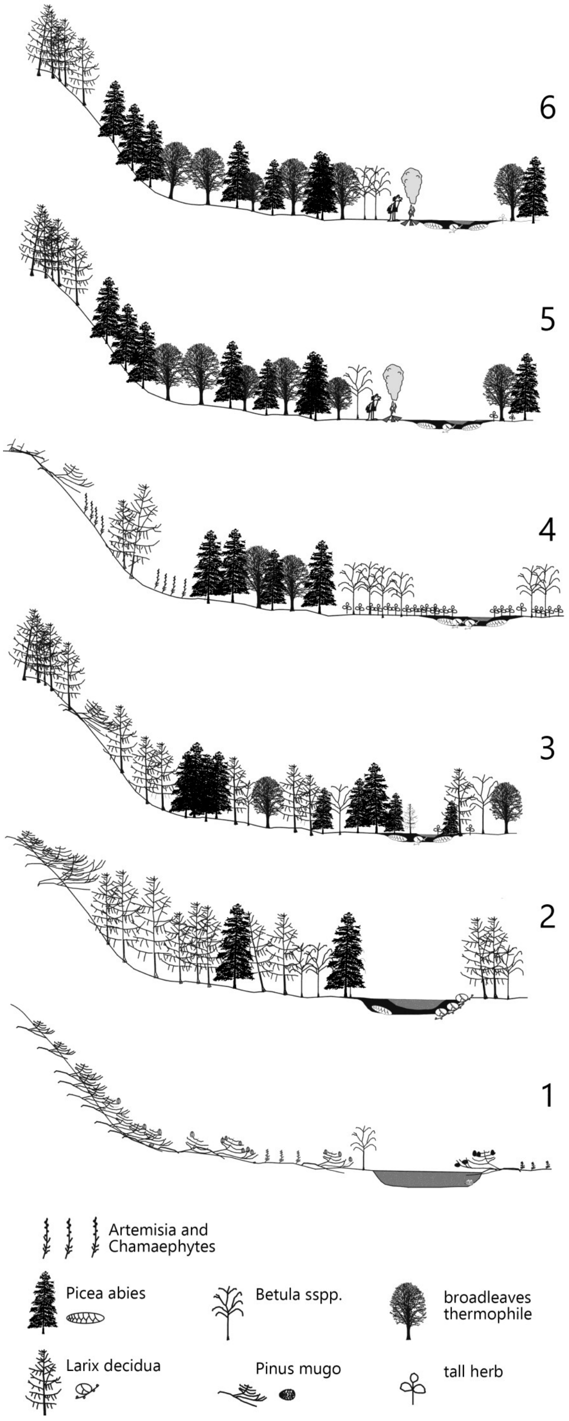


Fig. 4 - The main steps of the environmental history of the Palughetto area during the last glacial-interglacial transition: 1, scrub of mountain pine and chamephytes (ca. 16 ky cal BP); 2, forest of *Picea-Larix* in the lake surroundings (14.7-14.3 ky cal BP); 3, forest extended at the edge of the bog (14.3-13.0 ky cal BP); 4, forest retreat from the edge of the bog (12.85 ky BP); 5, broad-leaves and conifers mixed forest (11.3 ky BP); 6, broad-leaves and conifers mixed forest (10.8 ky BP); (after Ravazzi & Vescovi, 2009, modified).

5. SUMMARY OF THE PRESENT-DAY CLIMATE CONDITIONS IN THE CANSIGLIO PLATEAU

The today's climate of the Cansiglio Plateau is cool -temperate without summer drought. Mean annual air temperature at Palughetto is 11-12 °C, the January mean is -3 °C, and the July mean is 15 °C (Vescovi et al., 2007). Mean annual air temperature is 4.9 °C at the meteorologic station of Pian Cansiglio. The Cansiglio-Cavallo ridge represents an important barrier for the warm and humid southern air masses originating from the Mediterranean Sea basin. In contrast to nearby Mediterranean climate, precipitation here is concentrated during autumn and spring. Mean annual precipitation is 1700-1900 mm (Di Anastasio & Peresani, 1995). During the winter period the climate is harsh due to cold winds from the northeast.

The forest vegetation is dominated by *Fagus sylvatica* and *Abies alba* at altitudes between 800 and 1600m a.s.l., followed at higher elevations by a narrow subalpine *Picea abies*-belt, which forms the timberline at 1700-1800m a.s.l. *Picea abies* is also abundant on the plateau because of historical plantations (Hofmann, 1965). *Pinus mugo*-shrubs extend in the subalpine belt and along avalanche tracks.

The alpine vegetation is mainly formed by calciphilous *Sesleria varia-Carex sempervirens* grasslands, including plants of cold steppe (e.g. *Linum alpinum*), screes (e.g. *Dryas octopetala*), and snow beds (dwarf *Salix* species).

6. RECOVERY, PREPARATION AND ANALYSIS OF THE DENDROCHRONOLOGICAL SAMPLES

Infills of previous archaeological excavations were removed by an excavator in a 5x11 m area in May 2006 (Fig. 5). Horizontal roots of larch and spruce were frequent, but most of the trees were not found 'in situ' and to synchronize the horizons of the trees into the existing stratigraphy additional sediment profiles were described (Fig. 6). After woody remains were carefully excavated manually, described and documented briefly, we sampled and analysed all remnants of trunks, branches and roots with a minimum number of 10 tree rings (Fig. 7).

Tree-ring analyses of the wood started after the excavation. At the excavation, 203 fossil trees remnants were sampled by cutting disc cross-sections using a chain saw (Tab. 1). Whether possible, the lowermost disc samples were taken 0.5 m above the root system, to obtain ring-width sequences less prone to any irregularities or eccentricities from root disturbances. Samples were then prepared for tree-ring analyses at the tree-ring laboratory in Hohenheim. Even if the preservation of the wood seemed to be excellent, most of the cellulose appeared decomposed. Therefore, we kept the samples saturated with water and froze the wood before surfacing. Wood identification was done by microscopic analyses of thin slices of the samples using the identification keys of Schweingruber (1990) with special regard on the differentiation of the two conifer species spruce and larch (Bartolin, 1979). This is of special importance as both species have very similar wood anatomy, especially when subfossil (Schweingruber, 1990). Frozen sec-

Fig. 5 - Map of the 2006 excavation carried out at Palughetto in the archaeological sectors of the 1997 and 2001 excavations. The position of the trenches and of the largest arboreal remains brought to light and sampled are reported (drawn by M. Peresani).

Fig. 6 - A: *Picea* trunk. B: Various fragments of coniferous trunks. C: One among the largest Picea trunks in course of exposition. D: *Larix* trunk repositioned in the bog after sampling.

Nr.	Section	Species	Pith	Bark	Rings	Sample type	Diameter [cm]	Length [m]
300	T1	Spruce	M	+	91	trunk	30	5
301	T1	Populus	M	-	29	trunk fragment	12	n.d.
302	T1	Spruce	M	-	71	trunk fragment	20	n.d.
303	T1	Populus	M	+?	66	trunk fragment	15	n.d.
304	T1	Spruce	M	-	76	trunk fragment	20	n.d.
305	T2	Larch	M	+?	281	trunk fragment	20	1,2
306	T3	Birch	M	+	98	trunk fragment	30	0,4
307	T3	Birch	n	-	91	trunk fragment	30	0,8
308	T3	Larch	M	+	242	trunk fragment	25	1
309	T3	Birch	M	-	42	trunk fragment	15	0,5
310	T2	Larch	-	+	123	trunk	30	1,2
311	T5	Spruce	M	+	80	trunk fragment	45	>1,4
312	T5	Spruce	M	+	20	trunk fragment	10	0,25
313	T4	Spruce	M	+	78	trunk fragment	45	> 1,5
314	T3	Larch	M	+	90	trunk fragment	10	0,8
315	T3	Populus	n	-	31	trunk / branch	15	0,4
316	T6	Spruce	M	+	46	trunk fragment	17	2,5
317	T7	Larch	M	+	131	trunk fragment	35	1,5
318	T5	Spruce	M	+?	147	trunk fragment	10	n.d.
319	T1	Birch	M	-	25	trunk / branch	7	0,4
320	T1	Birch	M	+	31	trunk fragment	5	0,3
321	T1	Spruce	M	+	77	trunk fragment	5	0,4
322	T1	Birch	M	-	33	n.d. fragment	5	0,1
323	T4	Spruce	M	-	24	trunk fragment	12	1,6
324	T4	Larch	M	+	32	trunk fragment	15	1,1
325	T4	Spruce	M	-	47	trunk fragment	20	>1,0
326	T4	n.d.	n.d.	n.d.	n.d.	trunk fragment	10	n.d.
327	T8	Spruce	-	+	94	root	10	n.d.
328	T8	Spruce	n	-	111	trunk fragment	40	2,4
329	T4	Larch	-	-	106	n.d.	10	0,4
330	T4	Spruce	-	+	108	n.d.	10	0,45
331	T4	Birch	n	-	42	n.d.	5	0,25
332	T4	Willow	-	-	23	n.d.	5	0,45
333	T7	Birch	M	+	40	n.d.	7	n.d.
334	T6	Spruce	M	+	21	trunk fragment	20	>1,0
335	T5	Larch	M	+	134	trunk fragment	30	>0,8
336	T5	Birch	M	-	62	n.d.	10	>1,0
337	T4	Larch	M	-	31	trunk fragment	15	0,8
338	T4	Spruce	M	+?	71	trunk fragment	30	0,7
339	T4	Larch	M	+	88	trunk fragment	5	0,5
340	T4	Spruce	-	-	41	trunk fragment	ott-40	>1,0
341	T8	Spruce	M	+?	66	branch	5	0,4
342	T8	Spruce	M	+	50	trunk fragment	15	>1,0
343	T8	Birch	M	+	35	trunk fragment	7	0,1
344	T8	Spruce	M	+	29	trunk fragment	10	2
345	T8	Populus	M	+	29	branch	5	0,25
346	T8	Spruce	M	+?	73	trunk	20	>1,5
347	T8	Spruce	M	+	45	trunk	20	0,7
348	T8	Spruce	-	-	29	n.d.	5	0,1
349	T8	Spruce	M	+	108	trunk/branch	15	0,3
350	T6	Spruce	M	+	28	trunk	20	>1,0
351	T6	Spruce	M	+	33	trunk	20	n.d.
352	T6	Larch	M	+	128	trunk/root	10	>0,5
353	T6	Spruce	M	+	57	trunk	30	n.d.
354	T6	Spruce	M	+?	29	trunk	15	>1,0
355	T8	Birch	M	+	41	trunk	15	0,5
356	T8	Spruce	-	+?	46	trunk	15	n.d.
357	T7	Spruce	M	-	21	trunk/branch	10	1,8
358	T4	Willow	n	+?	43	trunk	10	0,3
359	T4	Larch	M	-	61	trunk	15	>1,0
360	T4	Spruce	-	-	49	n.d.	7	0,25
361	T6	Birch	-	+?	23	trunk	15	n.d.
362	T7	Birch	M	-	53	trunk	12	n.d.
363	T7	Birch	M	+	38	trunk fragment	12	0,25
364	T8	Larch	M	-	186	trunk	10	>1,5
365	T1	Spruce	M	+	28	n.d.	12	0,35
366	T7	Birch	M	+	41	n.d.	7	n.d.
367	T7	Birch	M	+	34	n.d.	7	n.d.
368	T6	Spruce	M	-	22	trunk	15	0,5
369	T8	Birch	M	+	35	n.d. fragment	15	0,4
370	T8	Spruce	n	-	23	n.d. fragment	n.d.	0,2
371	T7	Larch	-	+?	56	trunk	30	0,5
372	T6	Spruce	M	+	39	trunk	15	>1,0
373	T7	Larch	M	-	139	trunc/branch	5	1,5
374	T8	Spruce	-	-	32	trunk	15	1,5
375	T8	Birch	M	+	36	trunk	10	0,25
376	T7	Spruce	M	+	20	trunk	12	>0,5
377	T7	Larch	M	+	107	n.d.	7	1
378	T2	Larch	M	+	128	branch	5	0,7
379	T2	Birch	M	-	40	n.d.	10	0,25
380	T2	Larch	M	+?	102	branch	5	0,3
381	T2	Willow	M	+	57	trunk fragment	10	0,3
382	T2	Birch	-	-	33	trunk fragment	8	0,15
383	T2	Larch	M	-	30	trunk fragment	8	0,2
384	T2	Willow	-			trunk fragment	10	0,2
385	T2	Birch	n	-	83	branch	14	0,2
386	T2	Populus	M	-	34	branch	10	0,6
387	T2	Larch	M	+	146	root	6	0,3
388	T2	Larch	M	+	140	root	7	0,5
389	T2	Larch	M	-	108	root	10	0,8
390	T2	Larch	-	-	66	trunk fragment	14	0,25
391	T2	Spruce	n	-	32	trunk fragment	15	0,25
392	T2	Populus	-	-	74	trunk fragment	20	0,2
393	T2	Spruce	M	-	34	trunk fragment	10	0,4
394	T2	Larch	M	-	141	trunk	5	0,4
395	T2	Spruce	-			trunk fragment	7	0,15
396	T2	Larch	M	+?	84	trunk/branch	5	0,3
397	T2	Birch	n	+	11	trunk fragment	10	0,15
398	T2	Birch	-	-	49	n.d.	5	0,15
399	T2	Birch	M	-	23	branch	5	0,1
400	T2	Populus	n	+?	30	trunk fragment	5	0,1
401	T2	Birch	M	-	69	trunk	5	0,15

Tab. 1 - Catalogue of wooden macroremains at the excavation in 2006 with reference to the trench in the excavated area, species, presence of pith and bark, number of rings, type of sample, diameter and length. (1 - 2 of 4)

Nr.	Section	Species	Pith	Bark	Rings	Sample type	Diameter [cm]	Length [m]
402	T2	FASY	M	+	89	trunk/branch	5	0,15
403	T2	Larch	M	+?	138	branch	5	0,25
404	T2	Larch	M	+	64	branch/root	3	0,15
405	T2	Larch	M	+?	144	trunk fragment	5	0,3
406	T2	Birch	-			bark	n.d.	n.d.
407	T6	Spruce	M	+	78	trunk/branch	7	0,5
408	T6	Larch	M	+?	105	trunk/branch	5	0,4
409	T6	Larch	M	+?	41	trunk fragment	15	>1,0
410	T6	Spruce	M	+	103	trunk	40	2
411	T6	Spruce	M	+	20	trunk	15	>1,5
412	T6	Spruce	M	+?	39	trunk	10	n.d.
413	T8	Spruce	M	+	104	trunk	10	n.d.
414	T8	Larch	M	+	106	trunk	12	n.d.
415		Larch	M	+	133	n.d.	n.d.	n.d.
416	T1	Spruce	M	-	80	n.d.	n.d.	n.d.
417	T1	Spruce	M	+?	89	n.d.	n.d.	n.d.
418	T1	Spruce	M	+	27	n.d.	5,4	n.d.
419	T1	Willow	-	+?	63	n.d.	n.d.	n.d.
420	T1	Spruce	M	+?	47	n.d.	n.d.	n.d.
421	T1	Larch	M	-	82	n.d.	5	n.d.
422	T1	Larch	M	+	114	n.d.	4	n.d.
423	T1	Spruce	M	+	85	n.d.	6	n.d.
424	T1	Birch	-	+?	~25	n.d.	n.d.	n.d.
425	n.d.	Populus	-	-	45	n.d.	n.d.	n.d.
426	n.d.	Spruce	M	-	25	n.d.	n.d.	n.d.
427	n.d.	Spruce	M	-	33	n.d.	n.d.	n.d.
428	n.d.	Birch	n	-	56	n.d.	n.d.	n.d.
429	n.d.	Spruce	M	-	12	n.d.	n.d.	n.d.
430	n.d.	Spruce	M	+	77	n.d.	4,5	n.d.
431	n.d.	Populus	-	-	45	n.d.	n.d.	n.d.
432	n.d.	Birch	n	+?	54	n.d.	n.d.	n.d.
433	n.d.	Spruce	-	+	24	n.d.	n.d.	n.d.
434	n.d.	Populus	-	-	49	n.d.	n.d.	n.d.
435	n.d.	Populus	-	-	30	n.d.	n.d.	n.d.
436	n.d.	Populus	-	-	42	n.d.	n.d.	n.d.
437	n.d.	Spruce	M	-	24	n.d.	n.d.	n.d.
438	n.d.	Spruce	n	+	60	n.d.	4	n.d.
439	n.d.	Spruce	M	+?	56	n.d.	3	n.d.
440	n.d.	Birch	M	+?	~25	n.d.	3,2	n.d.
441	n.d.	Birch	M	+?	~25	n.d.	n.d.	n.d.
442	n.d.	Larch	M	+?	49	n.d.	2,5	n.d.
443	n.d.	Spruce	-	-	33	n.d.	n.d.	n.d.
444	n.d.	Spruce	M	+	45	n.d.	2	n.d.
445	n.d.	Larch	M	+	31	n.d.	1,8	n.d.
446	n.d.	Larch	M	+?	62	n.d.	1,3	n.d.
447	n.d.	Larch	M	+	24	n.d.	0,9	n.d.
448	n.d.	Spruce	-	-	69	n.d.	n.d.	n.d.
449	n.d.	Larch	-	-	65	n.d.	n.d.	n.d.
450	n.d.	Spruce	n	+	76	n.d.	n.d.	n.d.
451	n.d.	Spruce	M	+?	74	n.d.	4	n.d.
452	n.d.	Spruce	M	+	43	n.d.	3,3	n.d.
453	n.d.	Birch	M	+?	~25	n.d.	2	n.d.
454	n.d.	Spruce	M	+?	76	n.d.	2	n.d.
455	n.d.	Larch	M	+?	39	n.d.	1,5	n.d.
456	n.d.	Willow	M	+	19	n.d.	2	n.d.
457	n.d.	Larch	M	+	68	n.d.	n.d.	n.d.
458	n.d.	Larch	M	-	71	n.d.	1,7	n.d.
459	n.d.	Larch	M	+?	~40	n.d.	1,4	n.d.
460	n.d.	Birch	M	+?	~20	n.d.	1,1	n.d.
461	n.d.	Spruce	M	+	22	n.d.	0,8	n.d.
462	n.d.	Larch	M	+?	~30	n.d.	0,7	n.d.
463	n.d.	Larch	-	-	36	n.d.	n.d.	n.d.
464	n.d.	Larch	-	-	43	n.d.	n.d.	n.d.
465	n.d.	Larch	-	-	38	n.d.	n.d.	n.d.
466	n.d.	Larch	-	-	38	n.d.	n.d.	n.d.
467	T1	Larch	M	+	41	n.d.	2	n.d.
468	T1	Larch	M	+	~30	n.d.	1,8	n.d.
469	T1	Spruce	M	+?	67	n.d.	4	n.d.
470	T1	Spruce	M	+?	58	n.d.	2,6	n.d.
471	T1	Spruce	M	+?	84	n.d.	3,5	n.d.
472	T1	Spruce	M	+	54	n.d.	2	n.d.
473	T1	Spruce	M	+	52	n.d.	1,8	n.d.
474	T1	Spruce	M	+	55	n.d.	2	n.d.
475	T1	Spruce	-	-	14	n.d.	n.d.	n.d.
476	T1	Willow	M	-	62	n.d.	1,3	n.d.
477	T1	Larch	M	+?	~30	n.d.	1	n.d.
478	T1	Larch	M	+	33	n.d.	1,5	n.d.
479	T1	Larch	M	-	60	n.d.	1,9	n.d.
480	T1	Larch	M	+?	34	n.d.	1,3	n.d.
481	T1	Larch	M	+?	61	n.d.	2	n.d.
482	T1	Larch	M	+	25	n.d.	1,1	n.d.
483	T1	Spruce	M	+?	~25	n.d.	0,9	n.d.
484	T1	Spruce	M	+	53	n.d.	2,8	n.d.
485	T1	Spruce	M	-	~15	n.d.	2,5	n.d.
486	T1	Spruce	M	+?	55	n.d.	3,2	n.d.
487	T1	Spruce	M	-	82	n.d.	3,7	n.d.
488	T1	Spruce	M	+	65	n.d.	3,5	n.d.
489	T1	Larch	M	+?	58	n.d.	2,3	n.d.
490	T1	Spruce	M	+	51	n.d.	2,5	n.d.
491	T1	Spruce	M	+	51	n.d.	2,4	n.d.
492	T1	Spruce	M		~170	n.d.	2,5	n.d.
493	T1	Spruce	M	-	77	n.d.	3	n.d.
494	T1	Spruce	M	+?	77	n.d.	2,3	n.d.
495	T1	Spruce	M	+	44	n.d.	2,5	n.d.
496	T1	Spruce	M	+	39	n.d.	2	n.d.
497	T1	Spruce	M	+?	~50	n.d.	2,2	n.d.
498	T1	Spruce	M	+	46	n.d.	2,2	n.d.
499	T1	Populus	M	+?	~40	n.d.	1,7	n.d.
500	T1	Spruce	M	+	11	n.d.	2,5	n.d.
501	T1	Spruce	M	+	25	n.d.	2	n.d.
502	T1	Spruce	M	+	20	n.d.	1,8	n.d.
503	T1	Larch	n	+	55	n.d.	2,8	n.d.

Tab. 1 - (3 - 4 of 4)

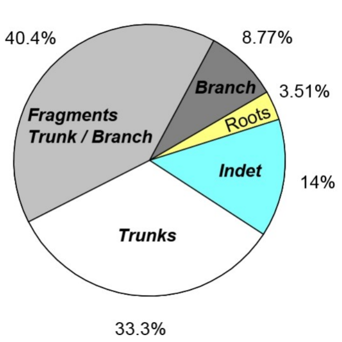


Fig. 7 - Types of wood sampled.

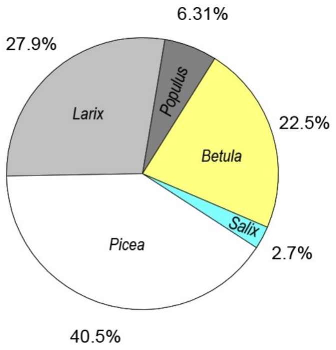


Fig. 8 - Genera of the sampled trees.

tions of wood were manually surfaced with razor blades for tree-ring analyses, and the surface was then whitened with chalk to obtain a better contrast. Annual tree-ring width was measured on the Hohenhein tree-ring device at 0.01 mm resolution. For tree-ring cross-dating and statistics we used the tree-ring analyses program TSAP (Rinn, 1996). Multiple radii were measured per each disc, the measurement series obtained per individual tree were then cross-dated visually and screened for missing rings. All tree radii were averaged to form tree mean series, which were subsequently averaged into chronologies.

7. RADIOCARBON DATING AND CHRONOLOGY BUILDING

Gram-size samples of tree-ring blocks of a few years were taken for AMS-^{14}C-analyses, pre-treated to cellulose, combusted to graphite in Heidelberg and measured in the Lund AMS facility. Chronologies were

Lab No. Hd-	Sample	Lab No. AMS Lund	start ring	end ring	number of rings	14C age	+-	cal BP from (1σ)	to
Hd-24850	Cansiglio 151	Gas counting	31	40	10	12344	31	14800	14180
25489	PL 303	LuS50126	27	31	5	11330	102	13310	13120
25478	PL 304 / 1	LuS50122	14	19	6	12197	67	14210	14020
25483	PL 304 / 2	LuS50120	65	70	6	12268	85	14790	14060
25497	PL 305 / 1	LuS50130	1	10	11	12370	60	14810	14210
25498	PL 305 / 2	LuS50131	outermost ring	-15	11	12331	67	14800	14140
25492	PL 306 / 1	LuS50128	1	10	11	11530	80	13470	13320
25493	PL 306 / 2	LuS50125	outermost ring	-10	11	11236	62	13180	13090
25484	PL 307	LuS50119			0	10970	59	12970	12760
25454	PL 311	LuS50134	70	78	9	10992	52	13000	12830
25491	PL 313	LuS50132	70	75	6	12444	60	14860	14350
25652	PL 314 B	LuS50170	70	80	9	12525	64	15020	14540
25643	PL 316 B	LuS50166	40	45	5	12210	67	14230	14030
25456	PL 317	LuS50136	120	125	6	11786	92	13760	13520
25651	PL 318 B OS	LuS50169	50	60	9	11313	59	13300	13120
25455	PL 327	LuS50135	outermost ring	-5	6	10993	54	13050	12830
25490	PL 328	LuS50129			0	10867	63	12840	12740
25477	PL 329	LuS50121	40	50	11	11766	57	13750	13510
25654	PL 335	LuS50172	10	20	9	11214	58	13170	13090
25457	PL 338	LuS50133	outermost ring	-10	11	12250	100	14800	14030
25475	PL 346	LuS50124	10	20	11	12137	59	14110	13870
25642	PL 347 B	LuS50165	30	40	9	11630	60	13590	13430
25641	PL 349 B	LuS50164	10	WK	10	10995	65	13060	12830
25480	PL 352	LuS50123	outermost ring	-5	6	11686	61	13600	13480
25650	PL 364	LuS50168	10	20	9	12464	66	14940	14430
25476	PL 364 / 1	LuS50127	outermost ring	-15	16	12154	156	14760	13790
25485	PL 364 / 2	LuS50118	1	10	11	12459	83	14930	14350
25640	PL 371 E	LuS50163	1	5	4	11901	67	13980	13600
25644	PL 405	LuS50167	20	30	10	11651	57	13590	13450
25653	PL 413 B	LuS50171	90	103	12	11054	66	13080	12910

Tab. 2 - ^{14}C ages of the trees from Palughetto (for reference to the dated sample see Table 1).

built based on cross-dated tree-ring series. Calendar ages of groups of synchronous trees (chronologies) were then obtained by calibrated ^{14}C-ages (Tab. 2). We based calibration on the calibration dataset IntCal20 (Reimer et al., 2020).

8. RESULTS AND DISCUSSION

According to our tree finds the forest in the area mainly consisted of the species spruce (*Picea abies* Karsten), larch (*Larix decidua* Mill.), birch (*Betula pubescens* Erh.), poplar (*Populus spec.*) and willow (*Salix spec.*) (Fig. 8) confirming results from palynology and botanical remains on the same site (Vescovi et al., 2007). The maximum length of the preserved trunks is 5m with diameter of up to 45 cm (Tab. 1). The maximum number of tree rings varies between 281 for larch, 147 for spruce, 98 for birch and 74 for poplar (Fig. 9). The age distribution shows that mean individual ages of larch trees was twice that of the spruce and birch (Fig. 10). Mean growth rates are different for each single species. Spruce trees show extremely wide rings of up to 6mm per year and show ‘complacent’ tree growth. Larch tree rings were much narrower of 1-2 mm per year and with higher interannual variability (Fig. 11). The high growth rate indicates that growth of spruce at the site was apparently not limited strongly by climatic factors. The growth rates of the spruces indicate favourable growing conditions such as moderate temperatures and sufficient water supply during the vegetation period, which is comparable to the modern situation in the area. In contrast to spruce, mean growth of larch is much smaller, which shows the better adaptation of spruce to the site conditions, especially the good water supply during the Bølling-Allerød in Palughetto.

8.1. Dendrochronology

The dendrochronological analysis of the tree-ring series of 203 wooden remnants from the subfossil forest of Palughetto, resulted in seven groups of 34 trees, which fall in a period of c. 1600 years of the Bølling-Allerød interstadial (Fig.s 12 and 13). The internal cross-dating of this material both visually and statistically was possible due to the strong common signal in the tree-ring series. The common signal of the trees is significantly higher for larch, but lower for spruce. Neverthe-

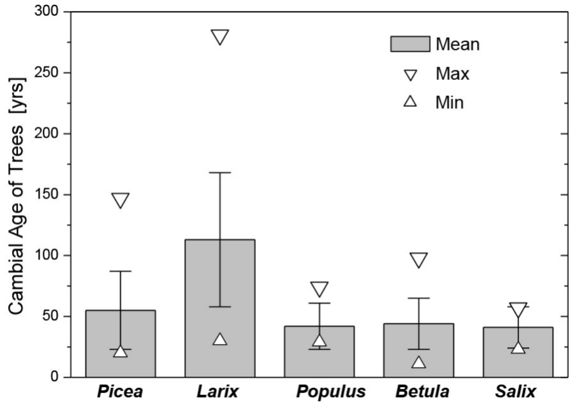


Fig. 9 - Individual ages of the trees sampled.

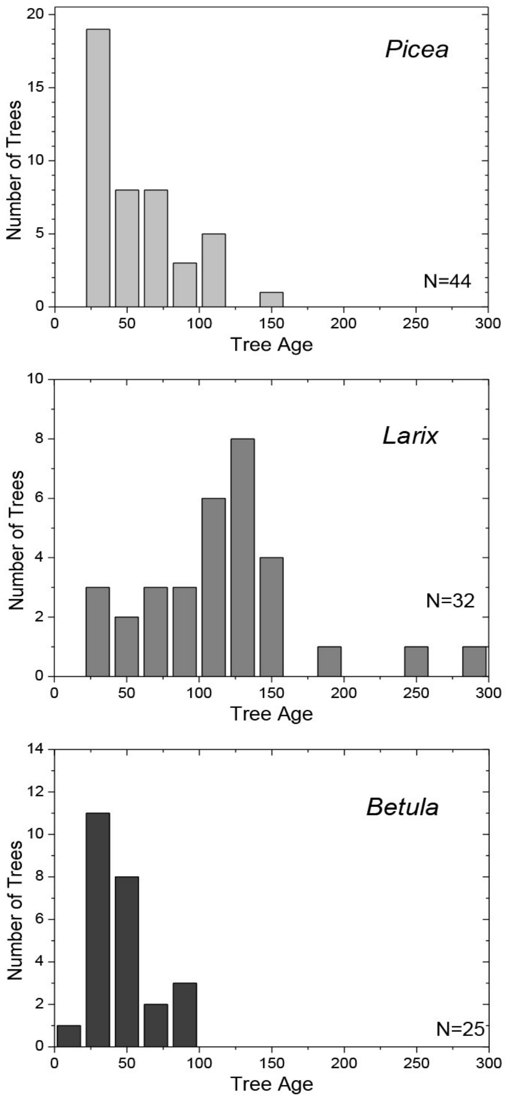


Fig. 10 - Distribution of individual age of the trees: (a) *Picea, (b) Larix, (c) Betula.*

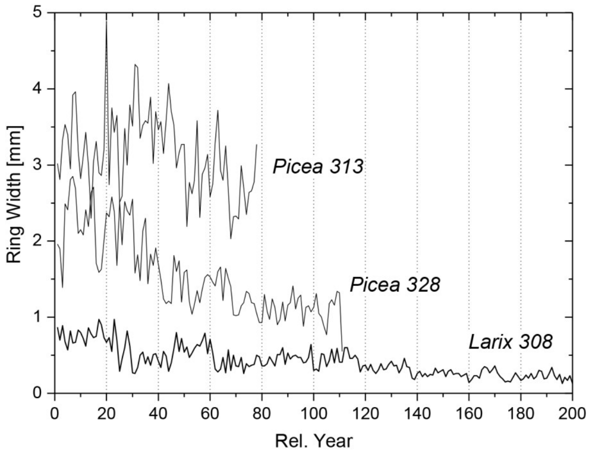
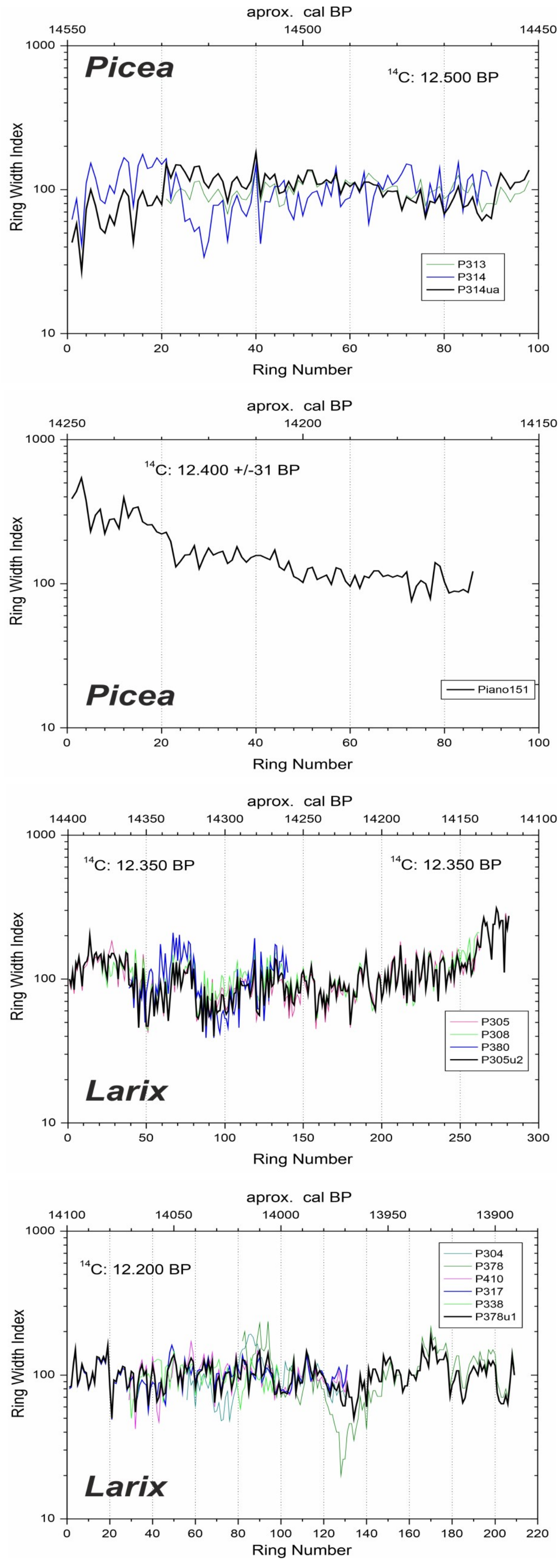


Fig. 11 - Typical tree growth of the two species larch and spruce. Wide rings in spruce, narrow rings in larch.



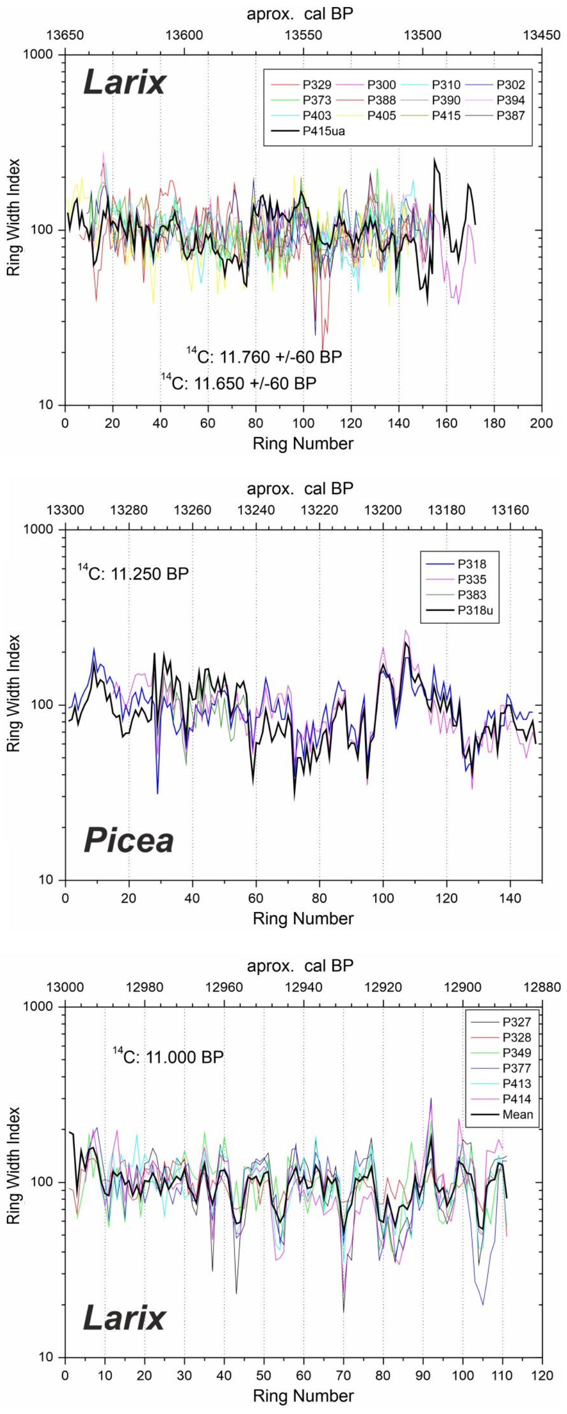


Fig. 13 - Floating tree-ring chronologies from Allerød (post 14,000 BP): (a) Larch trees from 11,760 conv. BP; (b) Spruce trees from 11,250 conv. BP; (c) Larch trees from 11,000 conv. BP.

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Fig. 12 - Floating tree-ring chronologies from Bølling (pre-14,000 BP): (a) Spruce trees from 12,500 conv. BP; (b) Spruce trees from 12,400 conv. BP; (c) Larch trees from 12,350 conv. BP; (d) Larch trees from 12,200 conv. BP.

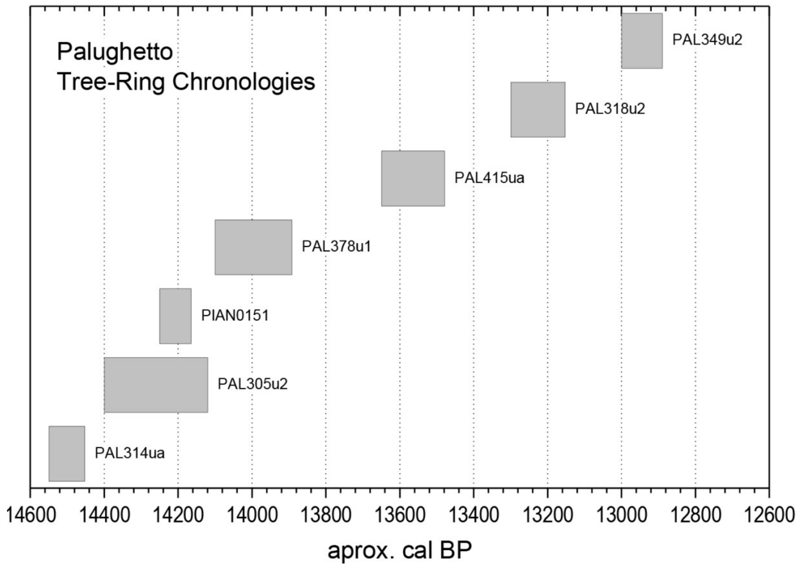

Fig. 14 - Bar graph of the tree-ring chronologies from Palughetto dated by ^{14}C.

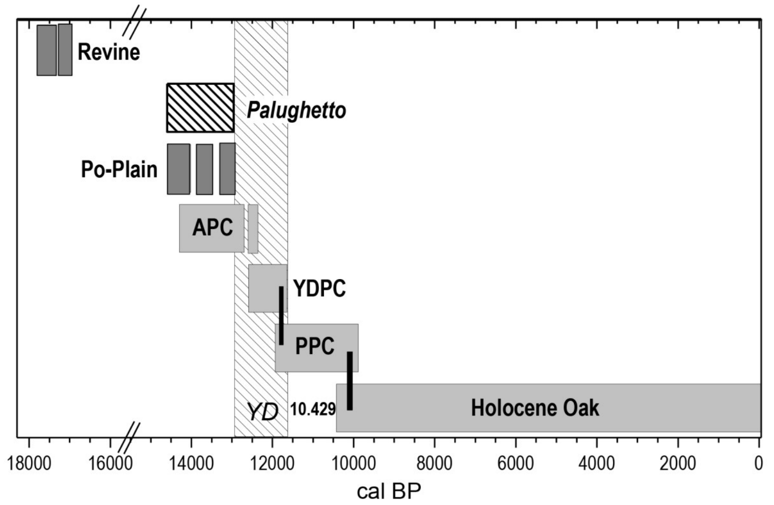

Fig. 15 - Overview of Late Glacial tree-ring chronologies from northern Italy from sub-fossil trees of Palughetto and from the Po-plain (dark grey) compared to the absolutely dated tree-ring chronologies from Germany (Friedrich et al., 2004) and the combined floating Bølling-Allerød chronologies from Germany and Switzerland (Friedrich et al., 2004; Kromer et al., 2004; Schaub et al., 2008) (light grey) (PPC: Preboreal Pine Chronology; YDPC: Younger Dryas Pine Chronology; APC: Allerod Pine Chronology).

less, cross-dating of all groups could be done with sufficient statistical significance. In this initial work we first focused on the conifer species to construct chronologies, as they show the better common signal, but we also found good correlation between the other species.

To anchor the floating tree-ring chronologies in time we used AMS radiocarbon measurements on defined tree-ring samples (Fig. 14). The earliest group of trees of spruce and larch started to grow in the early Bølling chronozone at 14,600 cal BP. The presence of well growing spruce trees in this early period of the Late Glacial with mean ring width comparable to modern spruce trees on the Cansiglio plateau and the relatively low common signal strength suggest that the potential tree-line in the southern alpine region must have been considerably higher than the Palughetto mire during the Bølling. There are still gaps between the different floating chronologies, but many trees present sufficient number of tree-rings, which could not be matched to one of the chronologies yet, and therefore have the potential to fill the gaps. Additionally, more dendrochronological work will be done to cross-date series of the deciduous tree species such as birch, poplar and willow.

The possibility of dating Late Glacial trees by dendrochronology was made possible by the pine tree-ring chronology extensions (Kromer et al., 2004; Schaub et al., 2008). Additionally, several floating segments of tree-ring chronologies from the Bølling-Allerød Interstadial could be combined to a 1,500 years long tree-ring chronology spanning the ^{14}C age-interval between 12,300 to 10,600 ^{14}C BP. It is based on pines (*Pinus sylvestris* L.) from sites in Germany and Switzerland (Schaub et al., 2008). Our own extensive fieldwork in the Po-plain of northern Italy and dendrochronological analyses on those samples resulted in a number of ‘floating’ tree-ring chronologies of several hundred years, which could be dated by radiocarbon (Kaiser et al., 2012; Adolphi et al., 2017). The earliest chronology of pine trees from the Po plain started their growth at 12,500 ^{14}C BP, indicating that re-forestation during the first warm period of the Late Glacial (Chronozone Bølling) in the southern pre-alpine region started several hundred years earlier than in Central Europe, i.e. pine trees from Dättnau, Switzerland (Kaiser, 1993). The high similarities in some periods of the Allerød between the regional tree-ring chronologies of eastern Germany, southern Germany and Switzerland with distances of up to 600 km indicate a higher spatial coherence of meteorological summer conditions during the Bølling-Allerød compared to the modern situation. The high spatial coherence offers the opportunities to cross-date tree-ring series in the Late Glacial over large distances and therefore open the perspective to cross-date the floating tree-ring chronologies from Italy to the Bølling-Allerød pine chronology of Central Europe (Friedrich et al., 2001).

9. CONCLUSION AND OUTLOOK

We have constructed tree-ring chronologies of spruce and larch from Palughetto from Late Glacial (12,500 to 11,000 ^{14}C BP) and spanning the entire Bølling-Allerød chronozone. Chronologies are still ‘floating’ but ongoing work on tree-ring chronologies from Late Glacial subfossil pines from several locations in the Po-valley may give the opportunity in the future to combine trees from northern Italy and link it to the Central European absolute tree-ring chronology (Fig. 15).

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Author contributions: B.K. and M.F. designed research; M.F. and B.K. analyzed primary dendrochronological data; M.F., B.K. and M.P. wrote and edited the manuscript.

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