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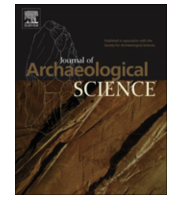

Dating of 4th millennium BC pile-dwellings on Ljubljansko barje, Slovenia

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ABSTRACT

We present absolute dates of seven late Neolithic pile-dwellings on Ljubljansko barje, Slovenia. They were settled from ca. 3600 to 3332 (±10) and from 3160 to 3071 (±14) cal BC, as shown by investigations of wood using dendrochronology and radiocarbon wiggle-matching. We defined eleven periods of intensive tree felling (and building activities) and one major settlement gap (when no trees were felled) from 3332 to 3160 cal BC. A major settlement gap presumably also followed after 3071 cal BC (i.e., after the end date of the investigated sites). Our investigations included over 2500 pieces of wood, mainly from the piles on which the dwellings were built. Among important wooden artefacts were a wheel with axle (one of the oldest preserved wheels in the world) and two dugout canoes, all from the settlement phase from 3160 to 3100 cal BC. As shown by parallel studies, the economy in the sites was characterized by copper metallurgy, skilful wood processing and use, cultivation of domestic plants, gathering of wild plants, animal husbandry, hunting and fishing. The settlements were contemporaneous with a number of sites in the north of the Alps, the younger ones coincided with the lifetime of the Neolithic Iceman (Ötzi). Since Ljubljansko barje has a strategic position at the crossroads between western central and (south) eastern Europe the presented absolute dates provide a basis for their comparison with other dated contemporaneous sites (in the west), to revise the chronology of similar sites in the (south) east (which are not yet exactly dated), and to evaluate their interconnection and roles in cultural development in prehistory.

1. Introduction

Prehistoric pile-dwellings SE of the Alps are important for understanding the cultural interaction between north-western and south-eastern Europe at the time of their existence. However, their exact dating is crucial to be able to compare them with contemporary sites in the surrounding regions. Archaeological timbers, often well preserved in wetlands, have the potential to provide exact dates when the trees were felled (e.g., Haneca et al., 2009). Dendrochronological dating is only possible if adequate reference tree-ring chronologies are available for the region, tree species and period of interest. When they are not available, it is necessary to check whether a teleconnection exists and whether a dating can be made with remote reference chronologies. When even this is not possible, radiocarbon analysis can be used for absolute dating of the wood. Dating can be especially precise when several sequentially spaced ^{14}C dates are obtained and calibration can be performed with the aid of the wiggle-matching methodology (e.g., Kromer, 2009).

Ljubljansko barje is a 180 km^2 large floodplain in central Slovenia, situated at the SE edge of the Alps (Fig. 1). It has a strategic position at the crossroads between the Danube and the Po river lowlands and between the Eastern Alps and the Balkans and is known for its prehistoric pile-dwellings, which were first discovered in 1875. Since then, several archaeological excavations have taken place in the area and approximately 40 pile-dwelling sites have been documented (Velušček, 2004a). The settlements were not accurately dated for a long time after their discovery and exact dating was badly needed to evaluate their role in cultural development and interactions between western and south-eastern Europe in the late Neolithic.

In 1995, interdisciplinary research supervised by the Institute of Archaeology of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts started excavations with the aim of systematically collecting wood for dendrochronological and radiocarbon dating. Since then, numerous dendrochronological (University of Ljubljana) and radiocarbon (Heidelberg Academy of

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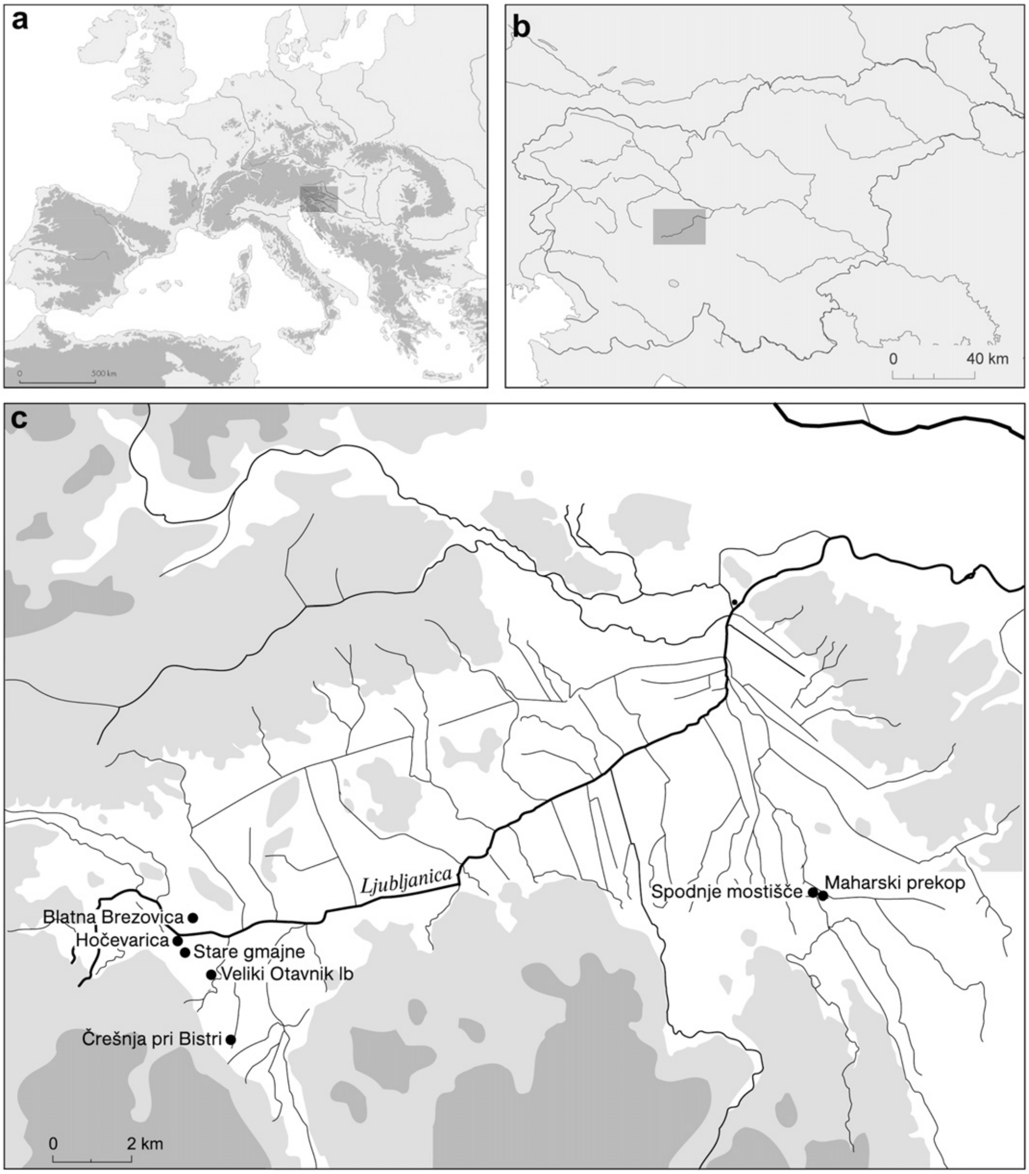

Fig. 1. The location of (a) Slovenia in Europe and (b) Ljubljansko barje in Slovenia. (c) The 4th millennium BC pile-dwellings on Ljubljansko barje from the oldest to the youngest: Hočevarica (HOC), Maharski prekop (MP), Črešnja pri Bistri (CB), Spodnje mostišče (SM), Stare gmajne (SG), Veliki Otavnik (VO), and Blatna Brezovica (BB).

Sciences) analyses have been performed. All this has provided us with the first absolute dates of the pile-dwelling settlements, from the oldest, dated to approx. 4600 cal BC, to the youngest ones from the beginning of the 2nd millennium BC (e.g., Velušček and Čufar, 2002; Velušček, 2006). With the exception of the oldest one from 4600 cal BC and few Early Bronze Age settlements, all other sites can be dated to the Late Neolithic (Eneolithic in Slovenian terminology) period, when copper metallurgy played a crucial role in the society (Velušček, 2004a).

This article is devoted to a group of lakeshore pile-dwellings of the 4th millennium BC. Culturally, the oldest settlement belongs to the "Furchenstich" horizon, while the others are contemporaneous to the Baden culture, which dominated the central Danubian area (e.g., Kalicz, 1991; Forenbaher, 1993).

The objectives of this study were:

- to perform excavations on prehistoric pile-dwellings of Ljubljansko barje and to collect wood for dating by means of dendrochronology and the radiocarbon wiggle-matching methodology,
- to assess the time of existence of the pile-dwellings and to reconstruct possible construction phases and repairs on them,
- to discuss the selection of wood species for building timbers and their importance for better understanding of the surrounding environment, and
- to obtain information on the occupation and abandonment of the Ljubljansko barje and relate it to occupation in the surrounding areas.

2. Material and methods

2.1. Archaeological sites

Between 1995 and 2007, we performed archaeological excavations at seven wetland sites: Hočevarica (HOC), Maharski prekop (MP), Črešnja pri Bistri (CB), Spodnje mostišče (SM), Stare gmajne (SG), Veliki Otavnik (VO), and Blatna Brezovica (BB). They were all located at the southern edge of Ljubljansko barje (Fig. 1, Table 1).

Table 1
Dendrochronologically investigated 4th millennium BC pile-dwellings on Ljubljansko barje with the year of their discovery, years of archaeological research, years when dendrochronological investigations were used at the site, type of excavation, and total number of wood samples collected.

Site code	Site name	Discovery	Archaeological research	Archaeology & dendro–chronology	Type of research
HOC	Hočevarica	1992	1995, 1998	1995, 1998	Rescue excavation in the drainage ditch (1995, 1998) Excavation – trench (1998)
MP	Maharski prekop	1953	1970-1977, 2005	2005	Excavation (1970–1977) Re-excavation (2005)
CR	Črešnja pri Bistri	2003	2003	2003	Rescue excavation in the drainage ditch
SM	Spodnje mostišče	1876	1996, 1997	1996, 1997	Underwater research (in the river)
SG	Stare gmajne	1992	1995, 2002, 2004, 2006, 2007	2002, 2004, 2006, 2007	Rescue excavation in the drainage ditch (2002, 2004) Excavation – trench (2006, 2007)
VO	Veliki Otavnik Ib	2006	2006	2006	Underwater research (in the river)
BB	Blatna Brezovica	1942	1953, 2003	2003	Excavation (1953) Re-excavation (2003)

The wooden dwellings were built on piles that were pounded in the ground. Copper metallurgy played an important role in the economy of all sites. The dwellers produced moderately decorated black or dark grey pottery and used mainly stone tools. They were skilful in wood processing and using it for constructional purposes, dugout canoes, charts (Fig. 2), and other products. Their economy was based on the cultivation of domestic plants, gathering of wild plants, animal husbandry, hunting and fishing (Velušček, 2004a).

2.2. Archaeological excavations

We used various strategies to collect the wood: (1) re-excavation, (2) rescue excavation and (3) underwater archaeology (Table 1). Re-excavation of previously investigated sites was made to collect wood that had been documented during previous excavations and was then reburied. Rescue excavations included documentation and excavation of wood and other remains (archaeological artefacts, remains of plants and animals, etc.) in drainage ditches on terrain currently used for agricultural production. In Hočevarica and Stare gmajne, we additionally made trenches with dimensions from 8 to 15 m^2 for acquiring macro-botanical and other remains. Techniques of underwater archaeology were applied at the sites Spodnje mostišče and Veliki Otavnik Ib (Fig. 1; Table 1), where samples were taken from piles found in the river beds. In this case, most of the wooden parts (mainly vertical piles) were still *in situ*, but the cultural layer had been destroyed by erosion.

2.3. Wood for dendrochronology and radiocarbon dating

We collected a total of 2541 samples of wood (Table 2). They were taken from all preserved wooden finds, regardless of their form, size or wood species. The precise geographic coordinates were first determined for each of the wooden finds on the ground plans of the dwellings and then 10–20 cm long samples were cut for analysis. In the laboratory, they were smoothed and observed under a stereo microscope for tree-ring counting, wood identification, and dendrochronological analysis. The preservation of the wood was sufficient for such investigations, although its structure and characteristics had changed due to water-logging over millennia (Čufar et al., 2002, 2008b).

Microscopic wood identification was done with the aid of standard identification keys (Schweingruber, 1982). Furthermore, for each of the samples we noted whether the bark and the last ring below it were preserved and whether the last ring was completed (indicating that the tree was felled after the end of vegetation period). We then counted the number of tree-rings and the number of sapwood rings (if the sapwood could be differentiated from the heartwood).

In all oak (*Quercus* sp.) and ash (*Fraxinus* sp.) samples containing 45 or more tree-rings, their widths were measured with the aid of a LINTAB movable table, stereo microscope and the TSAP/X or TSAP-Win programmes. The tree-ring series (ring widths vs. time) were visually and statistically cross-dated and compared with each other by calculating the t-values according to Baillie and Pilcher (1973). All the series that demonstrated visual and statistical (t-value $>$ 3.5) agreement were combined into floating undated oak and ash chronologies. Further comparisons showed that the ash chronologies of different sites could not be cross-dated with other ash or oak chronologies, so we did not use them in the next steps of this study.

Since there are so far no absolutely dated reference chronologies for the prehistoric period in Slovenia, we attempted to date the oak chronologies with south German references (Billamboz, Tegel, Herzig, personal communication). These attempts were not successful, so we also prepared samples of wood for radiocarbon analysis.

Following the composition of the tree-ring chronologies, wood samples containing at least 40 g of wood were selected from each of the chronologies for radiometric radiocarbon dating. Because the wood (especially sapwood) was poorly preserved (see, e.g., Čufar et al., 2008b), we had to take 5–20 tree-rings from the outer heartwood to obtain the required mass of wood. The positions of the selected tree-rings were exactly documented on the chronologies. After the first ^{14}C dates had been obtained, we collected additional samples optimally to match the wiggles on the calibration curve. We thus obtained a series of closely sequentially spaced ^{14}C dates (Table 4, Fig. 3).

Calibration of the ^{14}C dates was done with the aid of the wiggle-matching methodology, which uses the non-linear relationship between the ^{14}C age and calendar age to match the shape of the ^{14}C calibration curve. In our case, the ^{14}C dates were calibrated using the "sequence" option of the OxCal 3.10 program using the IntCal04 calibration curve (Reimer et al., 2004). OxCal calculates the calibrated age and its confidence intervals for the midpoint of the youngest tree-ring sample, based on an optimal match of all the radiocarbon dates of the samples of the section (Galimberti et al., 2004).

3. Results and discussion

3.1. Wood species and oak chronologies

From a total of 2541 wood samples, oak (*Quercus robur* and *Quercus petraea*) and ash (*Fraxinus excelsior*) represented 41% and 36% of all samples, respectively (Table 2). The remaining wood

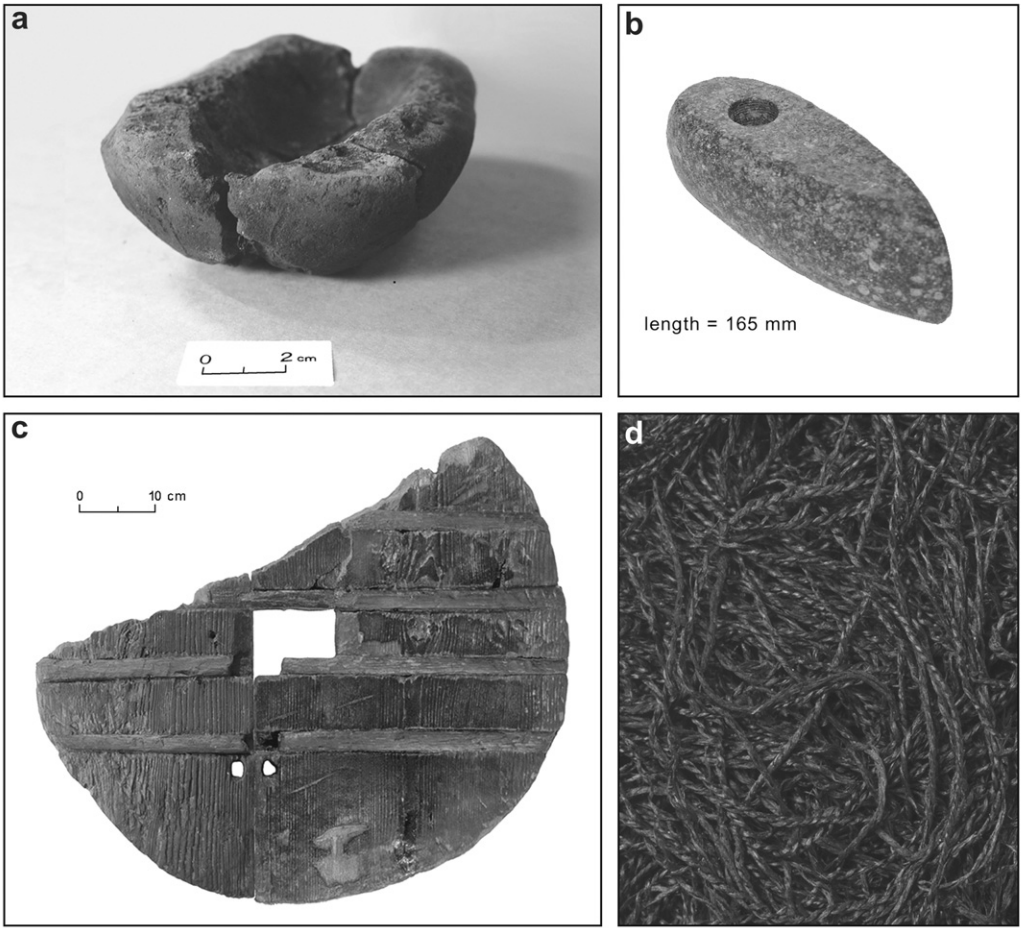

Fig. 2. Artefacts from the Stare gmajne pile-dwelling (after Velušček, 2009): (a) a crucible made of quartz-feldspathic siltite (34th century BC); (b) a shaft-hole axe made of metaultramafite (34th or 32nd century BC); (c) a wooden wheel (second half of the 32nd century BC or earlier); (d) restored remains of yarn (second half of 32nd century BC) probably made of the fibres of plants from the family of grasses (*Poaceae*).

belonged to alder (*Alnus glutinosa*), maple (*Acer* sp.), hornbeam (*Carpinus betulus*), hazel (*Corylus avellana*), beech (*Fagus sylvatica*), poplar (*Populus* sp.), willow (*Salix* sp.), elm (*Ulmus* sp.), silver fir (*Abies alba*) and yew (*Taxus baccata*). Only 18% of oak and 11% of ash had more than 45 tree-rings, which, on the basis of our observations, is the minimum number for performing statistically confirmed cross-dating. If the tree-ring series are shorter, they are less appropriate for building chronologies (e.g., Haneca et al., 2009) although they have research potential for studying wetland occupation (e.g., Billamboz, 2003).

Table 2
Number of samples of oak, ash and other species for each of the sites and the percentage of collected, dendrochronologically measured and cross-dated oak samples. Other species were: alder, maple, hornbeam, hazel, beech, poplar, willow, elm, silver fir and yew. For site names see Fig. 1 and Table 1.

Site code	Number of samples				Share of total (%)		
	Total	Oak	Ash	Other species	Oak	Oak measured	Oak cross-dated
HOC	361	57	213	91	16	5	4
MP	234	82	67	85	35	20	11
CR	124	61	25	38	49	19	14
SM	690	401	151	138	58	20	7
SG	932	334	409	189	36	21	9
VO	30	17	6	7	57	37	37
BB	170	87	55	28	51	11	8
	2541	**1039**	**926**	**576**	**41**	**18**	**9**

Measurements of tree-ring widths were therefore performed on samples of oak that had more than 45 tree-rings but only half of them (9% of the total) were cross-dated (Table 2). They were assembled into eight chronologies, two for Stare Gmajne (SG-old and SG-young) and one for each of the other sites (Table 3). Cross-dating (when t-values > 3.5) showed which chronologies overlap in time (Table 3). Finally, the overlapping chronologies MP-QUSP1, CR-QUSP1, SM-QUSP121 and SG-old could be joined into a composed chronology LJU4M-old. The chronologies SG-young and VO-QUSP1 were joined into LJU4M-young (Table 3, Fig. 4). The positions of HOC-QUSP1 and BB-QUSP1 could not be defined using the cross-dating procedure. We attempted to date the individual chronologies of sites and the two composed chronologies of Ljubljansko barje with south German references but the dating was not successful.

3.2. Calibrated ^{14}C dates and tree-ring chronologies

In the next steps, the chronologies were dated with the aid of ^{14}C dates calibrated with the wiggle-matching procedure (Table 4, Fig. 3). The radiocarbon dating of 8 samples of wood (Table 4) with known positions in the LJU4M-old chronology and their wiggle-matching with OxCal 3.10 (Fig. 3, white circles) helped to set the last ring of the chronology to 3342–3322 cal BC (2σ interval, 95% probability), i.e., 3332 $\pm$ 10 cal BC. Such a narrow interval ($\pm$10 years) could be obtained because we knew the distances (in years) among the individual ^{14}C dates. If we had calibrated each individual

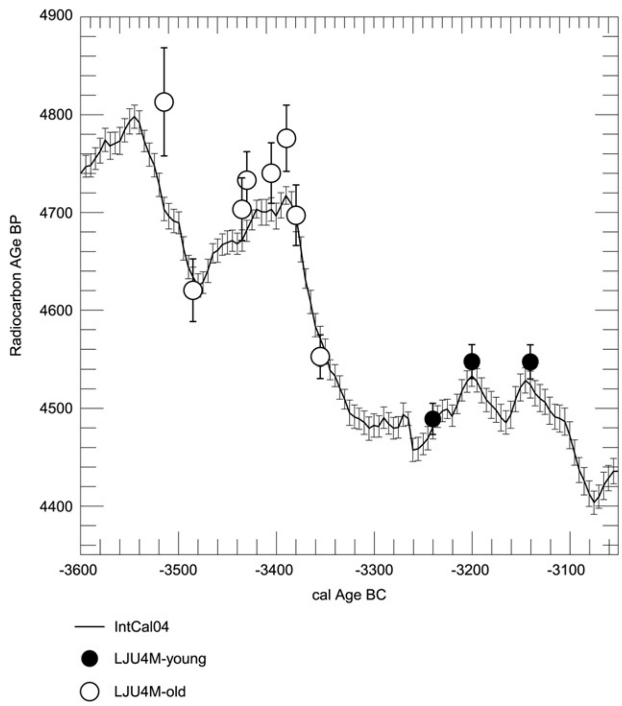

Fig. 3. Calibration using the "sequence" option of OxCal 3.10. Compare Table 4.

^{14}C BP date from the Table 4, we would have obtained much wider intervals of dating (e.g., 3890–3675 cal BC for sample Hd-22139; in Čufar and Kromer, 2004).

The further 3 samples for which we obtained 3 radiocarbon dates (Table 4, Fig. 3 black circles) helped us to set the last ring of the LJU4M-young chronology to 3123–3096 cal BC (2σ interval, 95% probability), i.e., 3109 ± 14 cal BC.

Since the end dates of the composed chronologies LJU4M-old and LJU4M-young were defined, we could also define the end dates of all chronologies cross-dated with them (Table 3, Fig. 4).

In addition to the samples described above, we also obtained three radiocarbon dates for Hočevarica (HOC) (Table 4) and their wiggle-matching helped to set the last ring of the chronology (HOC-QUSP1) to 3656–3636 cal BC (2σ interval, 95% probability). This indicated that HOC-QUSP1 was the oldest of all. Since the statistical parameters of its matching with other chronologies (e.g., MP-QUSP1, Table 3) were not significant, we matched the chronologies visually and estimated the end date of HOC-QUSP1 as ca. 3547 BC (Fig. 4).

The youngest chronology of Blatna Brezovica (BB-QUSP1) could also not be statistically significantly matched with other chronologies (Table 3). Its age was estimated by one sample dated to 4499 ± 21 BP (Table 4). The position of BB-QUSP1 is also estimated based on visual comparison with LJU4M-young chronology (end date 3071 cal BC).

3.3. *Occupation of sites and building activities inferred from dated tree-ring chronologies*

We could define the end date for each of the chronologies (year cal BC on the right of the chronologies, Fig. 4), indicating the year in which the youngest tree-ring was formed. Since in our study, most of the samples contained the bark and the last ring below it, we could assume that the end date of the chronology more or less corresponded to the final phase of site occupation. Based on the durability of oak wood, we can assume that constructions made from it could last for approximately a decade. However, despite this, according to our observations repairs were very frequent and they may have already started 1–2 years after the constructions were made.

Furthermore, we observed that in certain years or 1–3 year periods, larger amounts of trees were felled and piles with the same end year were located near to each other. Based on this, we assumed that building activities took place on the dwelling at a time when larger amounts of trees were cut. This could be particularly observed at Spodnje mostišče (SM) and Stare gmajne (SG), where we collected larger amounts of wood (Table 2). On this basis, we could estimate the time of occupation and the building activities at each of the sites. Individual trees felled in the years between building phases possibly indicated repairs to the constructions. Because we collected the wood from narrow ditches or small trenches we did not obtain enough data to reconstruct the exact ground plans of the dwellings.

The oldest settlement was Hočevarica with the end date of the oak chronology estimated to 3547 ± 10 cal BC. Previous investigations have shown that this was the second phase of the settlement, which had already appeared in the late 37th century BC (Čufar and Kromer, 2004).

Soon after Hočevarica was abandoned, the Maharski prekop pile-dwelling was settled on the other side of Ljubljansko barje. The samples indicate an occupation that lasted more than 20 years and ended around 3489 ± 10 cal BC (Figs. 1 and 4).

Sixty years later, Spodnje mostišče, located less than 200 m away from Maharski prekop, was occupied. We recorded several building phases, which ended around 3428, 3409, 3373, and 3353 ± 10 cal BC. At the same time, Črešnja pri Bistri was inhabited, in the opposite south-western part of Ljubljansko barje. Only one building phase was recorded here, with an end date of 3409 ± 10 cal BC, which coincided with one of the building phases at Spodnje mostišče. At Stare gmajne, in the south-western part of Ljubljansko barje, we recorded one phase of occupation, with an end date of 3332 ± 10 cal BC. After this, Ljubljansko barje was probably abandoned for approximately 170 years.

Table 3
Cross-dating parameters (*t*-values) and overlapping of the chronologies. The *t*-value is not given if the overlap is less than 50 years or when $t < 3$. For the codes, see also Table 1 and Fig. 4.

Chronology	Time span	Length	Maximal replication	*t*-Value/Overlap (years)			
	Cal BC	years	(No. of samples)	MP-QUSP1	CR-QUSP1	SM-QUSP123	SG-young
HOC-QUSP1	3685–3547 ± 10	139	16				
MP-QUSP1	3661–3489 ± 10	173	25				
CR-QUSP1	3545–3409 ± 10	137	17	4.9/57			
SM-QUSP123	3558–3353 ± 10	206	49	5.1/70	4.3/137		
SG-old	3506–3332 ± 10	175	6		3.7/98	4.7/154	
SG-young	3285–3109 ± 14	177	118				
VO-QUSP1	3239–3108 ± 14	132	11				8.8/131
BB-QUSP1	3145–3071 ± 14	75	13				

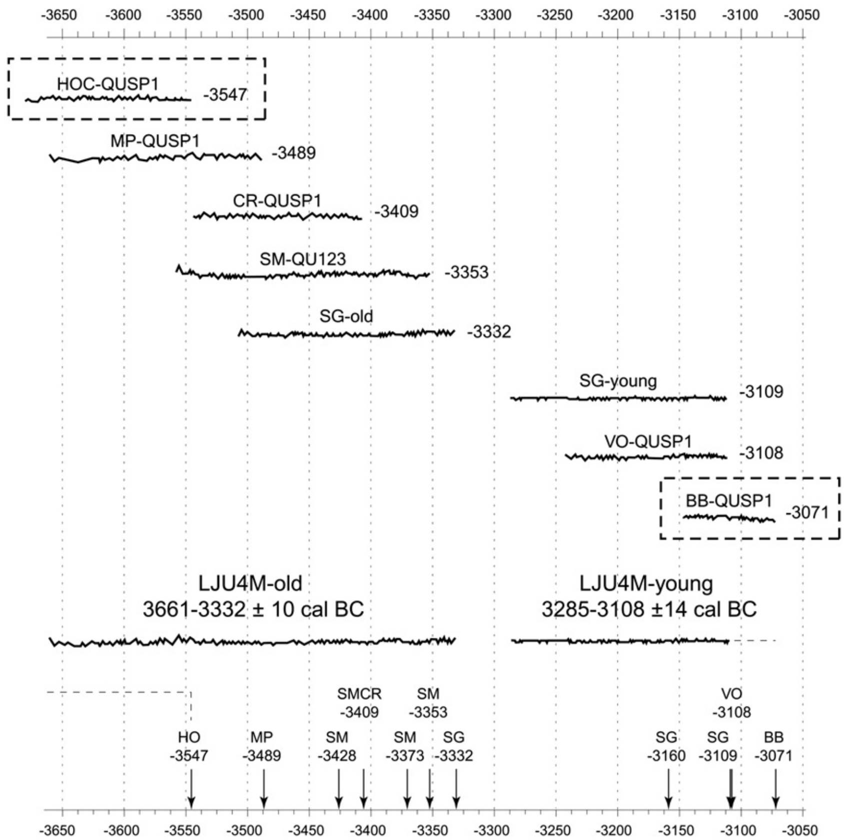

Fig. 4. Tree-ring chronologies of oak (QUSP) from Ljubljansko barje. Cross-dated chronologies of settlements MP, SM, CR, SG-old, SG-young, and VO, and most probable positions of HOC and BB (for legend of codes see Table 1 or Fig. 1). The numbers on the right represent the cal BC year of the last (youngest) tree-ring. Below: composed chronologies: LJU4M-old (MP, SM, CR, SG-old) with the last ring set at 3332 ± 10 cal BC and LJU4M-young (SG-young, VO) with the last ring set at 3109 ± 14 cal BC. Arrows show the years of intensive tree felling, indicating building phases at settlements.

After this gap, we recorded several renewed building activities at Stare gmajne (SG-young), from 3160 to 3109 ± 14 cal BC (Fig. 4). This period was characterized by intensive building activities that took place in 10–15 year intervals all over the site (Velušček, 2009). The end date of Stare gmajne coincided with that of Veliki Otavnik Ib (last ring 3108 ± 14 cal BC), located about 1 km away (Figs. 1 and 4). Visual matching of an ash chronology from Stare gmajne (not presented here) suggests that the settlement continued for some years after 3109 ± 14 cal BC. The Blatna Brezovica site, located less than 500 m away from Stare gmajne, was the youngest of all and was abandoned around 3071 cal BC.

After 3071 BC, Ljubljansko barje probably remained uninhabited for the next 300 years. The next phase of occupation was recorded at Parte-Iščica in the 29th/28th centuries BC (Velušček and Čufar, 2002).

Numerous building phases are presumably due to repairs that were necessary because of limited wood durability and due to needs to enlarge the settlements. However, dendrochronological research cannot explain the reasons for larger gaps between building activities, as for example between 3332 ± 10 and 3160 ± 14 cal BC. This gap could be due to a lack of preserved archaeological wood or more likely due to an occupation hiatus on Ljubljansko barje.

3.4. Characteristics of society and life on the pile-dwellings as inferred from archaeological finds

The collection of wood and other finds that was evaluated in parallel interdisciplinary investigations has helped us to obtain information on prehistoric society, its life in wet environments and its contacts with other settlements.

Interdisciplinary investigations were performed at locations at which cultural layers were sufficiently preserved, such as Hočevarica (Velušček, 2004b), Črešnja pri Bistri (Velušček et al., 2004), Stare gmajne (Velušček, 2009), Maharski prekop (Bregant, 1996) and Blatna Brezovica (Velušček, 2009). They included investigations of archaeological artefacts (pottery, tools), metal

Table 4
Radiocarbon dating. The samples of wood are sorted according to their positions on the calibration curve and dendrochronological matching with LJU4M-old or LJU4M-young tree-ring chronologies (compare Fig. 3). (AnaNrHd – sample code of the radiocarbon laboratory in Heidelberg, Nr(LJU) – sample number of the laboratory in Ljubljana, (*) position on chronology estimated visually).

AnaNrHd	NrLJU	$\delta^{13}C$	^{14}C BP	Cross-dated with
22 139	HOC-34	−28.37	4867 ± 26	LJU4M-old*
22 305	HOC-56(1)	−29.47	4825 ± 25	LJU4M-old*
20 765	HOC-56(2)	−29.19	4748 ± 26	LJU4M-old*
18 856	SM-564(1)	−27.76	4813 ± 55	LJU4M-old
21 329	SM-242	−29.34	4620 ± 32	LJU4M-old
18 785	SM-564(2)	−28.65	4703 ± 32	LJU4M-old
18 787	SM-619	−25.66	4733 ± 29	LJU4M-old
19 354	SM2-56(1)	−25.52	4740 ± 31	LJU4M-old
19 357	SM2-56(2)	−25.37	4766 ± 34	LJU4M-old
18 784	SM-26	−27.09	4697 ± 31	LJU4M-old
27 697	SG-745	−26.8	4552 ± 22	LJU4M-old
22 911	SG02-406	−27.86	4489 ± 16	LJU4M-young
27 938	SG-499	−29.8	4589 ± 26	LJU4M-young
22 385	SG02-441	−27.52	4547 ± 17	LJU4M-young
24 497	BB-03-48	−28.16	4499 ± 21	LJU4M-young*

objects and smelting equipment, botanical remains (pollen, macrobotanical samples, wood), remains of animals (domestic and wild mammals, birds, fish), and other finds. At the Spodnje mostišče and Veliki Otavnik Ib sites, which are underwater (in the river), the cultural layer is eroded, so interdisciplinary research was very limited.

The remains of pottery are important, because the typology served to estimate the age of the settlements before dendrochronology was introduced to Ljubljansko barje (e.g., Parzinger, 1984).

At Hočevarica, black and dark grey pottery prevailed (Fig. 5). The characteristic shapes were, for instance, a bowl with a large banded handle and ladle with a solid handle. Some fragments were decorated with furrowed incisions, an ornament that suggests that the settlement belonged to the Retz-Gajary culture after Dimitrijević (1980) or to the horizon of pottery with furrowed incisions, characteristic of Transdanubia in nearby Hungary (Kalicz, 1991; Velušček, 2004b).

At the slightly younger Maharski prekop, very moderately decorated black or dark grey pottery with many shapes similar to those at Hočevarica was found. We also observed some differences: for instance, vessels with handles were absent, furrowed incisions were lacking, and plastic decorations were present. At least some individual vessels therefore indicate contacts with the Boleráz group of the Baden culture (e.g., Parzinger, 1984; Velušček, 2009).

Pottery assemblages from Stare gmajne, which resemble the pottery from other studied settlements, strongly indicate contacts with groups of the Baden culture in the central Danube area and those from the *Caput Adriae*, the eastern Adriatic coast and the Alpine world in the second half of the 4th millennium BC (Velušček, 2009).

Nevertheless, the differences in pottery of the entire second half of the 4th millennium BC proved to be too small to be used for dating. Dendrochronology could not confirm the previous relative (and absolute) dating of the sites based on the typology of the pottery (Parzinger, 1984).

Copper metallurgy played an important role at all sites and it seems to have been introduced in the area for the first time in the 36th century BC at Hočevarica, where the remains of a crucible, a drop-shaped piece of copper and a flat copper axe were found (Velušček, 2004b; Trampuž Orel and Heath, 2008). Fragments of crucibles have also been found at other sites. At Stare gmajne, for instance, two complete crucibles were found, one made of clay and one of stone (Fig. 2a) (Velušček, 2009).

Fig. 5. Fragment of a pitcher from Hočevarica. The rich incised decoration on the outer surface is characteristic of the period of the “Furchenstich” horizon in the SE Alpine region.

The stone tools discovered show exploitation of local raw materials. Tuffs and tuffites originating not far from Ljubljansko barje were, for instance, used for axes and other tools. Imported materials were certainly used as well. Polished stone artefacts, such as two flat axes, for example, were made of HP metaophiolites, which can be found in north-western Italy, a few shaft-hole axes were made of serpentinites, which might have originated from central Austria and of metaultramafites (Fig. 2b), which might have come from areas more to the east. These finds indicate that Ljubljansko barje played a key role as a place of mediation between the Po lowland and the Danubian area and between the Eastern Alps and the Balkans (Bernardini et al., 2009).

Remains of mammals indicate that animal husbandry and hunting played an important role in all settlements. The studies of the remains of domestic animals indicate that stock-raising (both of cattle and small stock) was probably primarily oriented to the production of meat and fat (Velušček et al., 2004). It was concluded, for example, from the bones of domestic pigs at Hočevarica that slaughtering occurred late in the autumn and at the end of winter (Toškan and Dirjec, 2004). This indicated that the sites were settled all year around. Game, particularly roe deer and red deer, were also important sources of meat and fat.

The pile-dwellers on Ljubljansko barje grew barley and two types of wheat (*Triticum monococcum* and *dicoccum*). Poppy and flax seeds were also detected (Tolar et al., 2010). Large amounts of pips of the wild grape vine have been found in all settlements (Jeraj et al., 2009; Tolar et al., 2008).

The pile-dwellers needed large amounts of wood to build their dwellings. The wood was cut in the more or less nearby forests. We mainly investigated the remains of piles on which dwellings had been built. The upper parts of the constructions were not preserved. At Maharski prekop, the wood also came from a double enclosure, which protected the settlement, being similar to what has been found at some lakeshore settlements in the pre-Alpine regions in western and central Europe of this period.

The selection of wood species used for piles indicates that the settlers preferred oak with durable heartwood, which possibly grew on drier terrain at the edge of the floodplain. Such selection and skilful use of wood for different purposes shows that they were aware of the wood properties. In addition to oak, they also used large quantities of ash. Among the main reasons for this is that ash was very abundant and the amount of more durable oak was limited. In addition, ash presumably grew closer to the pile-dwellings, since it can grow on more swampy terrain than oak. Ash also has good stump regeneration (coppice) which made it possible to cultivate more timber, with a short rotation. They achieved the most desirable diameter (ca. 10 cm) in short period of time (10–15 years). The dwellers also frequently used the wood of alder, which is a typical species of occasionally flooded terrains (e.g., Čufar et al., 1997; Čufar and Velušček, 2004).

The piles usually contained the bark. The last ring below the bark normally contained the entire latewood, which indicates that the trees were felled after the vegetation period, i.e., in autumn or winter. Only occasionally did we observe a discontinuous band of the first earlywood vessels, indicating that the trees had been felled in early spring. All this supports the assumption that the sites were also occupied in winter.

In addition to the piles, we found some wooden artefacts. In Hočevarica, a bow made of yew (*Taxus baccata*) was found (Velušček, 2004b). The most valuable of all is the prehistoric wheel (Fig. 2c) with axle from Stare gmajne (dated between 3160 and 3100 cal BC) (Velušček et al., 2009a). It is among the oldest wooden wheels in the world (Bakker et al., 1999; Hartmann, 2006; Ruoff, 2006). Its design and elaboration again shows that the pile-dwellers were very familiar with the properties of wood and that they were skilful in wood processing. Two dugout canoes from the same settlement phase represent the oldest canoes in the area (Veluščšek et al., 2009b).

3.5. Connection of Ljubljansko barje pile-dwellings to other contemporaneous sites

Many contemporaneous (dendrochronologically dated) pile-dwellings existed around lakes and peat bogs in Switzerland, SW Germany, SE France and northern Italy (Lake of Zürich, Lake of Constanz, Federsee, Lake of Chalain, Palù di Livenza, etc.) (e.g., Becker et al., 1985; Schlichtherle and Wahlster, 1986; Pétrequin et al., 1998; Billamboz, 1996, 2003; Čufar and Martinelli, 2004). On the other hand, settlements from eastern and south-eastern Europe are not as a rule exactly dated, so it is difficult to include them in comparisons.

Among the Alpine sites, those which were contemporaneous with the lifetime of the Alpine Iceman (Ötzi), who died between 3320 and 3050 cal BC (e.g., Kutschera and Müller, 2003), are particularly interesting. Jacomet (2009) made an overview and comparison of archaeobotanical data for several villages from the surroundings (radius ca. 100 km) of the place where the Iceman was found. They existed during his lifetime, and Jacomet (2009) reconstructed the use of plants and daily life in them in general. It was shown that even on exactly dated sites, comparisons can be difficult if recovery methods are not standardized.

The dating of prehistoric sites is not possible without dendrochronology supported by radiocarbon wiggle-matching, if no adequately long and replicated reference chronologies are available (e.g., Čufar, 2007; Haneca et al., 2009). A Slovenian reference tree-ring chronology for the 4th millennium BC does not yet exist. The majority of the investigated pieces of wood in our case had a low number of tree-rings and they could not be used for dendrochronology or we could only construct short chronologies. Although the chronologies are dated by radiocarbon, we could not exactly date them by means of dendrochronological teleconnection with remote references, for instance those from Germany (e.g., Becker et al., 1985). Future improvement and extension of Slovenian prehistoric chronologies should increase the likelihood of their teleconnection. Such teleconnection is already possible in the case of the 540 years long, well replicated, modern Slovenian oak chronology, which can be successfully cross-dated with chronologies within a radius of up to 700 km around Ljubljana (Čufar et al., 2008a).

Using the well replicated modern Slovenian oak chronology (time span A.D. 1456–2003) also confirmed that it could be a good reference point for developing dendrochronological dating in the regions SE of Slovenia, for which it does not yet exist (Čufar et al., 2008a).

Possible settlement gaps also deserve more attention, since occupation hiatuses have been detected on many places in west-central Europe in the 4th millennium BC (e.g., in Switzerland, SE France and SW Germany). They have been ascribed to climatic changes (towards a cooler and wetter climate), which seem to have been particularly turbulent in central Europe between 5550 and 5000 cal BP (Magny and Haas, 2004). The period from ca. 3332–3160 cal BC, when apparently no human activities (cutting of trees) took place on Ljubljansko barje, is particularly interesting for us. Future investigations should clarify whether this was a period of a settlement gap and whether it coincided with settlement gaps in other areas around the Alps.

4. Conclusions and future prospects

The presented dating of Ljubljansko barje tree-ring chronologies is so far the most accurate in the region. It has enabled us to assess settlement activities from ca. 3600–3071 cal BC, and an occupation gap from ca. 3332–3160 cal BC.

The dating fulfilled one of the basic requirements for comparisons of Ljubljansko barje with other archaeological sites. Comparisons with other Alpine sites could help to answer what role Ljubljansko barje had in the cultural development of the wider region. Located at the crossroads between west and east, it should be particularly interesting in this respect. Ljubljansko barje sites could also serve as a link to establish a revised absolute chronology for regions in eastern and south-eastern Europe that are not yet exactly dated. Examples of dendrochronological and ^{14}C dates from Ljubljansko barje have already indicated that a revision of the time of existence and interpretation of the mid 3rd millennium BC Pannonian cultures, e.g., the Late Vučedol and Samogyvár-Vinkovci cultures, is needed (Veluščšek and Čufar, 2003).

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