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First absolute chronologies of neolithic and bronze age settlements at Lake Ohrid based on dendrochronology and radiocarbon dating

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ABSTRACT

Specialized and systematic underwater fieldwork at the prehistoric site of Ploča Mičov Grad at Gradište (North Macedonia) on the eastern shore of Lake Ohrid was undertaken in 2018 and 2019. It has substantiated the archeological site's outstanding preservation condition, and furthermore proven the numerous construction timbers' suitability for dendrochronological analysis. Dendrochronological analysis on archaeological timbers was applied, combined with radiocarbon dating. Bayesian radiocarbon modeling allowed to 'wiggle match' the dendrochronological mean curves, i.e. allowed the precise chronological anchoring of 'floating' tree-ring sequences. Furthermore, radiocarbon dates of plant remains from the site's main archaeological layer are statistically evaluated.

Based on the new findings, the strikingly high density of wooden piles at the site can be attributed to several construction phases of Neolithic (middle of 5th millennium BC) and Bronze Age (2nd millennium BC: 1800, 1400 and 1300 BCE) settlements. Intense settlement activity is furthermore evidenced by a cultural layer of mainly organic material under the lakebed up to 1.7 m in thickness, which accumulated during the Neolithic occupation of the bay in the middle of the 5th millennium BC. The presented research enables precise absolute dating of a series of settlement phases at Ploča Mičov Grad from the Neolithic and the Bronze Age, and hence provides important reference points for an absolute chronological framework for the prehistory of the southwestern Balkans. The investigations underline the potential of future research on waterlogged prehistoric settlements in the region.

1. Introduction

Neolithic and Bronze Age settlement remains in lakes and bogs represent one of the most significant sources of information on Europe's prehistory. In waterlogged archeological layers, artifacts and structural components made of wood, bark and plant fiber remain intact for thousands of years due to the absence of oxygen and decomposing agents. In the same context, biological remains of cultivated crops and wild plants (fruits, seeds, pollen, spores), as well as faunal remains, are found in an excellent state of preservation. The wetland setting is

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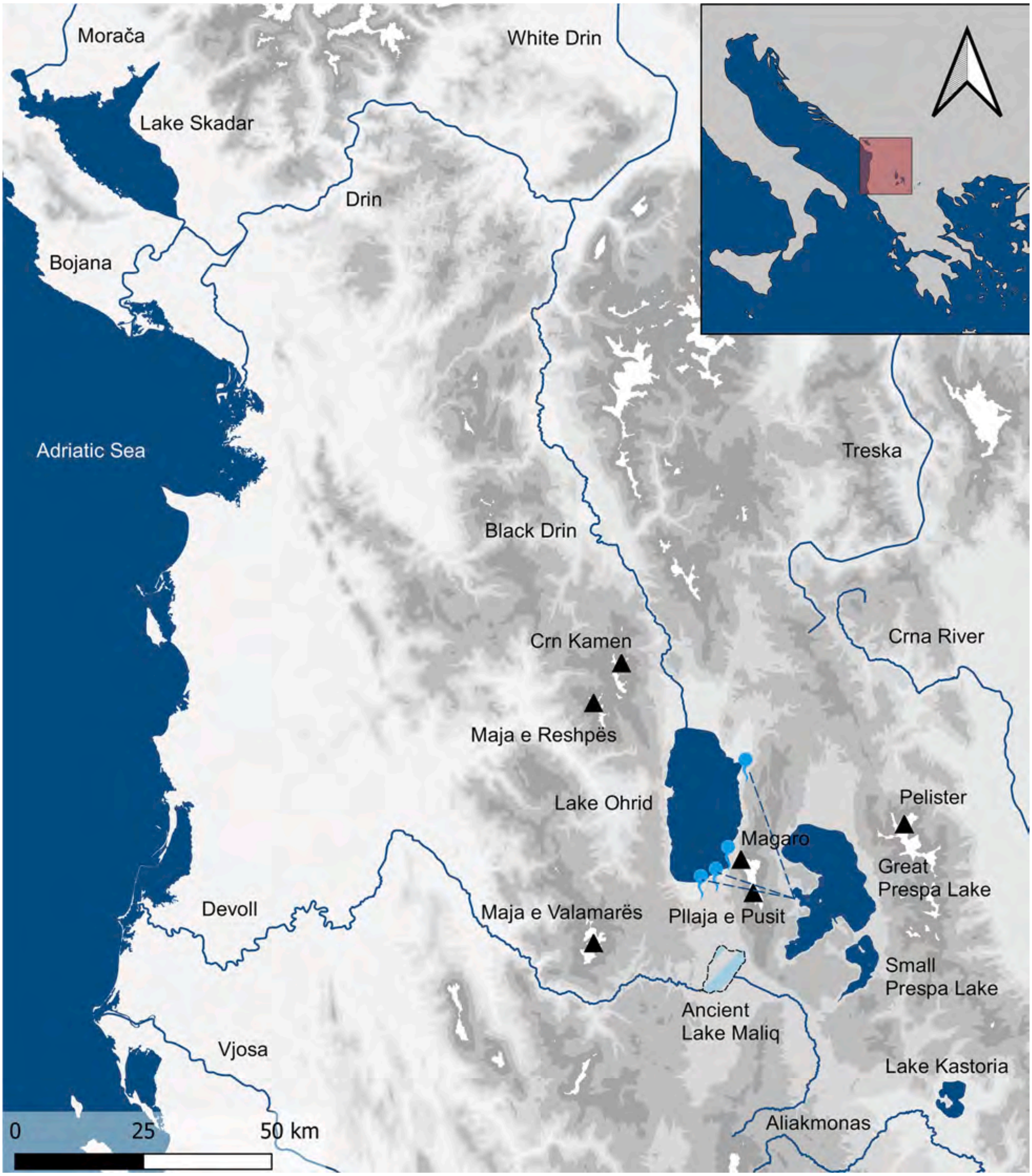

Fig. 1. The Drin river basin of the southwestern Balkan peninsula with the three lacustrine sub-basins of Prespa, Ohrid and Skadar, and the three riverine sub-basins of the rivers Drin, including the Black and White Drin, Morača and Bojana. The dashed lines refer to the underground connections between Great Prespa Lake and four spring areas on the eastern shore of Lake Ohrid, including the main feeder spring complexes at St. Naum and Tushemisht in the south (location of springs and underground connection after Eftimi and Zojer, 2015; Hauffe et al., 2011; Amataj et al., 2007). (J. Reich, EXPLO/UBern).

therefore ideal for archeobiological and paleoecological investigations related to high-resolution chronology, plant cultivation, animal husbandry and gathering activities, vegetation change, land cover and land use. Prehistoric wetland settlements are known from Europe and worldwide (Menotti and O'Sullivan, 2013). Compared to terrestrial archeological sites, they form an extremely rare category. The best documented cluster of waterlogged prehistoric sites is located around the Alps, where nearly 1000 sites are known. In 2011, a selection of 111 sites was inscribed on the UNESCO World Heritage list as serial site 'Prehistoric Pile Dwellings around the Alps'. Other European regions with archeological wetland sites are known, but in most cases, they offer only a small number of sites. In northwestern Europe, sites in lakes and bogs are known from the British Isles (Knight et al., 2019), the Northern European Plain (Kossian, 2007; Kampffmeyer, 1983) and from the Baltic and adjacent regions (Charniauski, 2007; Virtanen, 2006; Kriiska, 2003; Butrimas, 1998; Rimantienė, 1998; Girininkas, 1980). In Ireland and Scotland, a large number of artificial settlement islets are known as crannogs (Henderson and Sands, 2013). Prehistoric lake settlements on

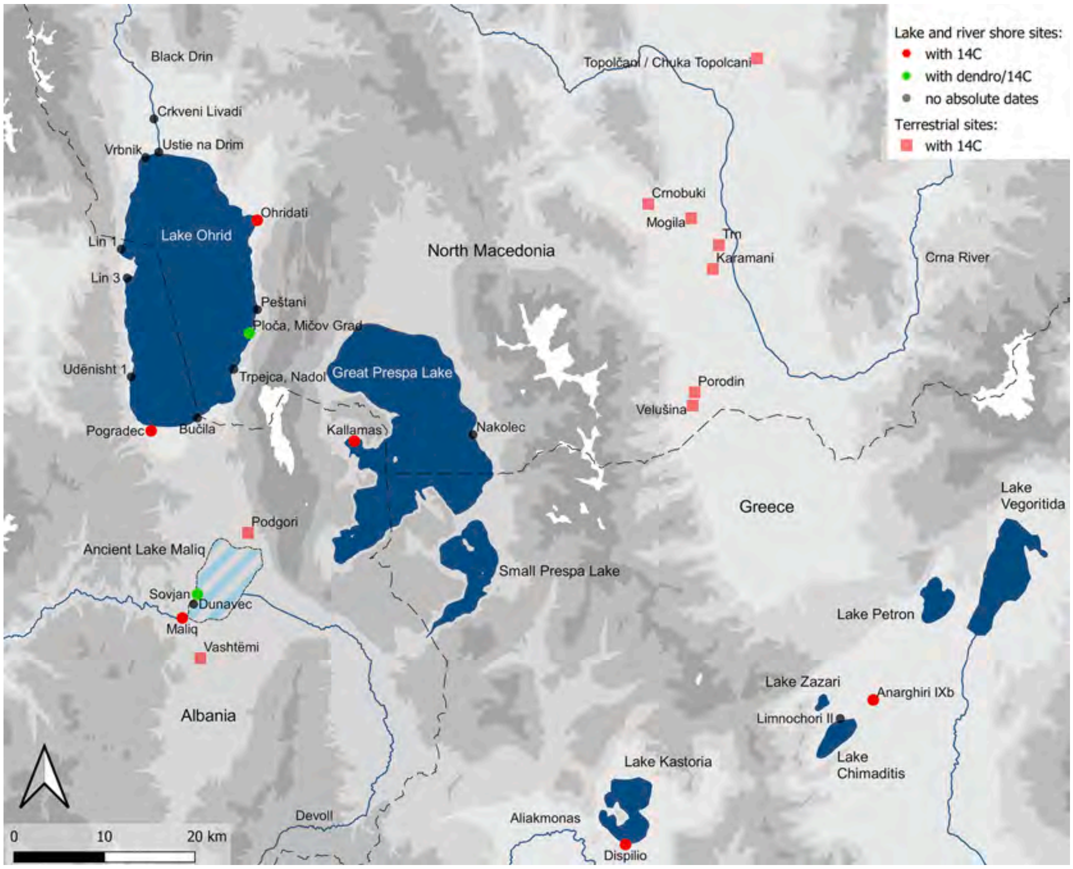

Fig. 2. Archeological sites in the southwestern Balkan lakes region from the Neolithic and the Bronze Age. The map summarizes the current state knowledge as far as the identification and precise localization of the shore sites around Lake Ohrid, and of one case on the Drin river bank, are concerned. A selection of terrestrial sites with published radiocarbon dates is included. (J. Reich, EXPLO/UBern).

the Iberian and Apennine peninsulas (Radi and Petrinelli Pannocchia, 2018; Antolín et al., 2014; Fugazzola Delpino et al., 1993) and in the southwestern Balkans are the southernmost examples of this phenomenon.

The southwestern Balkans' topography is comparable to the circum-alpine region: in present-day Albania, Greece, and North Macedonia, archeological sites from the Neolithic and the Bronze Age are preserved in numerous lakes (Naumov, 2016; Chrysostomou et al., 2015; Facorellis et al., 2014; Fouache et al., 2010; Touchais and Fouache, 2007). Despite offering a very high archeological potential, the lakes and bogs of the southwestern Balkans present a striking research gap. While the wetland dwellings of the Alpine region have been intensively investigated for the last 150 years, until recently only a few research activities have taken place in the southwestern Balkan lakes. The importance of the lake region of the southwestern Balkans for prehistoric archeology becomes all the more evident as it occupies a key geographical position between western Asia and central Europe. Thus, the region is the first continental European 'station' in the spread of the Neolithic from Anatolia to central-western Europe in the 7th millennium BC. The adaptation of the early farming strategies to the climate conditions of the Balkans was an essential prerequisite for the successful transmission of an agriculture-based economy to western and central Europe (Lang, 1994). Pollen records suggest that farming activities in this area started in the second half of the 7th millennium BC (Gassner et al., 2020; Chrysostomou et al., 2015; Karamitrou-Mentessidi et al., 2013). Moreover, the region is to be considered as a cultural interaction zone and a melting pot of different influences, as the topographical setting offered ideal conditions for supra-regional contacts, mobility and exchange.

Since 2019, the ERC-funded Synergy project *'Exploring the dynamics and causes of prehistoric land use change in the cradle of European farming'* (EXPLO) aims to improve substantially the understanding of how Neolithic and Bronze Age economies and societies developed in the strategic region of the southwestern Balkans through the unique lens of preserved archeological lakeshore settlement remains. In this article, the first results in regard to absolute dating from two underwater field campaigns at the site of Ploča Mičov Grad at Gradište on the eastern shore of Lake Ohrid (North Macedonia) are presented. We focus on the absolute dating of the Neolithic and Bronze Age lakeside settlements from this site (the designation of epochs follows the Greek terminology [cf. Reingruber et al., 2017]). This is done through dendrochronological analysis in combination with radiocarbon dating. This methodological approach allows high precision dating and sets important absolute chronological baselines for the prehistory of the southwestern Balkans (cf. Maczkowski et al., 2021). Hence, these are the first steps in filling a significant supra-regional research gap.

1.1. The natural setting of the Drin river basin

In order to understand the settlement environment of these prehistoric wetland settlements around Lake Ohrid, a closer look at the geographical context, in particular the water system, shall be taken. The Drin river basin in the southwestern Balkan Peninsula hosts a complex interconnected hydrological system (Fig. 1). It features three lacustrine sub-basins, i.e. the Lakes of Prespa, Ohrid and Skadar, and three riverine sub-basins, i.e. the eponymous Drin including its tributaries Black Drin and White Drin, the Morača which is the main inlet of Lake Skadar, as well as the Bojana which is the outlet of Lake Skadar into the Adriatic Sea. Whereas the main arm of the Drin (Drin i Madh) joins the Bojana, the smaller arm (Drin i Lezhës) runs directly into the Adriatic Sea.

The watershed of the Drin river basin extends over a large

Table 1
Water bodies of the Drin river basin. Geographical overview of localization and altitude, including information on volume and size. AL: Albania, GR: Greece, MK: North Macedonia; * interlinked basins, + depth in spring ponds (van der Schriek and Giannakopoulos, 2017; GIZ, 2015; Panagiotopoulos et al., 2014; Matzinger et al., 2006; International Lake Environment Committee Foundation, n.d.). (A. Hafner, EXPLO/UBern).

Lake name Coordinates Countries	Surface km^2	Altitude m a. s.l.	Depth max. m	Length km	Width km	Volume km^3	Shore length km	Watershed area
Ohrid 41°00' N 20° 45' E MK-AL	358	693	289	36.4 (N-S)	16.8 (E-W)	55.5	88	3,920 km^2 (*) Lake Ohrid sub-watershed: 1,400 km^2
Great Prespa 40° 54' N 21° 02' E MK-AL-GR	259	849	54	34.0 (N-S)	10.0 (E-W)	3	111 for both Prespa lakes	3,920 km^2 (*) Lake Prespa sub-watershed: 2,520 km^2
Small Prespa 40° 46' N 21°06' E AL-GR	47	853	7	10.6 (N-S)	6.6 (E-W)	0.3	-	3,920 km^2 (*) Lake Prespa sub-watershed: 2,520 km^2
Skadar 42° 10′ N 19° 19′ E AL-MK	350–470	7	9 (44) +	48 (NW-SE)	14 (NE-SW)	1.9	168	5,500 km^2

geographical area of ca. 19,000 km^2 in today's states of Albania, Greece, Montenegro, North Macedonia and Kosovo. The total length of the Drin is 285 km. Its origin lies in the Lake Prespa–Ohrid ecosystem and its surrounding mountains. Running from Lake Ohrid as Black Drin it later joins the White Drin.

In the Drin river basin, remains of prehistoric lakeshore settlements, most of them waterlogged, are so far only known from the lakes Prespa and Ohrid but not from lake Skadar, although based on the environmental conditions these could be expected there. Situated on the fluvial terrace of the Drin, the site of Crkveni Livadi is at the moment the only

Fig. 3. The Zaveri sinkhole at the western shore of Great Prespa Lake, view from the south. In front of the promontory with the village of Goricë e Vogël (Albania) the waters of Lake Prespa are led through a sinkhole and underground channels into the karst. They then emerge in springs which feed streams running into Lake Ohrid. (A. Ballmer, EXPLO/UBern).

known wetland site in the region not installed on a lakeshore, but on a river bank (Fig. 2) (cf. Kuzman, 2013). Lake Prespa and Lake Ohrid are located in today's border triangle of Albania, Greece and North Macedonia at an altitude of 700–850 m a.s.l. The two lakes are surrounded by different mountain ranges reaching altitudes of more than 2000 m. The peaks of Pelister (2601 m) in the Baba mountains (east of Lake Prespa), Pllaja e Pusit (2287 m) in the Mali i Thatë mountains and Magaro (2255 m) in the adjacent Galičica mountains between Lake Prespa and Lake Ohrid are the closest ones to the two lakes and the most important ones for the Drin river basin ecosystem. Further away, the following three elongated mountain ranges, featuring peaks with altitudes of more than 2000 m, are visible from Lake Ohrid: Maja e Valamarës (2373 m) of the Valamara range to the west, the Black Stone (Crn Kamen/Gur i Zi; 2257 m) of the Jablanica and Maja e Reshpës (2262 m) of the Shebenik range to the northwest. Despite the mountainous terrain, this landscape offers the most suitable connection between the Aegean Sea and the Adriatic regions of the southern Balkans.

The rather shallow Lake Prespa (Table 1) consists of two interlinked lakes, the so-called Great and Small Prespa Lakes. It drains the high-altitude sub-basin of the Drin. From Lake Prespa, which has no river outlet, large amounts of water run indirectly into Lake Ohrid, situated 150 m lower. With a maximal depth of 289 m, Lake Ohrid is an extremely deep karst lake. It is presumed to be one of the oldest existing lakes in Europe, most likely tectonically formed during the Pliocene (Wagner et al., 2017; Lindhorst et al., 2010; Popovska and Bonacci, 2007). Because of numerous endemic species (Albrecht and Wilke, 2008; Stanković, 1960) and an important series of cultural heritage, the Macedonian part of Lake Ohrid has been classified as a mixed natural and cultural UNESCO World Heritage site in 1993. In 2019, the World Heritage Site was extended to the Albanian part of the lake.

About half of the water running into Lake Ohrid comes from the two large karst spring areas at the southern end of the lake near the monastery at St. Naum (North Macedonia) and Tushemisht (Albania). These are partially fed by underground tributaries of Lake Prespa (via the Zaveri sinkhole) as well as from infiltrated precipitation from the surrounding mountainous karst regions Galičica and Mali i Thatë (Fig. 3). Environmental isotopic analysis has demonstrated that 37–42 and 52–54% of water emerging from the St. Naum and Tushemisht spring complexes, respectively, originates from Great Prespa Lake (Amataj et al., 2007). Two much smaller karst springs are located on the eastern shore of Lake Ohrid, one at St. Zaum, 5 km north of St. Naum, and another called Biljana, 22 km north of St. Naum. Further, several subaquatic spring areas as well as smaller precipitation-fed springs are known in and around Lake Ohrid (Jordanoska et al., 2013; Hauffe et al., 2011; Matzinger et al., 2006; International Lake Environment Committee Foundation, n.d.).

1.2. Shore settlements at Lake Ohrid and absolute chronology of the region

Based on the published *status quo*, the locations of a dozen prehistoric settlements are known along the shoreline of Lake Ohrid, most of them waterlogged pile dwellings (Fig. 2) (Naumov, 2020; Andoni et al., 2017; Kuzman, 2013, 2016, 2017; Todoroska, 2017; Allen and Gjipali, 2014). These sites have never been comprehensively investigated or systematically published, and knowledge of them is mainly based on archeological material, mostly pottery. From a typological point of view, their chronological attribution ranges from the Middle Neolithic in the 6th millennium BC to the Late Bronze Age/Early Iron Age in the 2nd millennium BC.

Despite the suitable material the sites have to offer – especially those where waterlogging is involved – the state of the art in regard to absolute dating is very modest at the moment. Two samples from a single construction timber from the site of Ohridati at Ohrid were radiocarbon dated between 5620 and 5380 cal BC (Westphal et al., 2010). Three radiocarbon dates from anthropogenic layers from the site of Pogradec

Fig. 4. Ploča Mičov Grad. A: The bay of Ploča Mičov Grad at the slope foot of the Galičica mountains on the east coast of Lake Ohrid. The open-air 'Museum on Water' features the reconstruction of a prehistoric settlement on the premises of the archeological underwater site. B: Removal of vegetation (macrophytes) and covering layer on the lake bottom. C: Collection of wood samples for dendrochronological analysis. (A: G. Milevski; B: M. Hostettler; C: C. Nymann, EXPLO/UBern).

(Albania) range between 6000 and 5700 cal BC (Allen and Gjipali, 2014). Dendrochronological dating was not a topic at Lake Ohrid until now, not least there were no reference curves available until now.

In general, the number of absolute dates from further lakeshore sites in the southwestern Balkans is rather modest (radiocarbon dating: Giagkoulis, 2019; Allen and Gjipali, 2014; Facorellis et al., 2014; Guilaine and Prendi, 1991; Lera and Touchais, 2003; Lera et al., 1996, 1997, 2012, 2016; Oberweiler et al., 2020; dendrochronological dating: Maczkowski et al., 2021; Westphal et al., 2010), and also from the terrestrial sites in the hinterland of the lakes and in the more remote areas currently only few radiocarbon dates are available (Allen and Gjipali, 2014; Srdoč et al., 1977; Valastro et al., 1977) (see Fig. 2). With this situation, the significance of a regional dendrochronology is underlined, all the more taking into account the wood preserved in the waterlogged lakeshore settlements.

As will be demonstrated, the pile dwellings of the southern Balkans in general and especially the Ohrid Lake sites have an outstanding potential for the application of dendrochronology, promising the establishment of a highly resolved temporal framework. In combination with radiocarbon dating, this approach is systematically applied at Lake Ohrid and in the Balkans in general for the first time in the context of the EXPLO-project. Although several attempts to dendrochronological dating have been undertaken in the past (Maczkowski et al., 2021; Pearson et al., 2014; Westphal et al., 2010), no breakthrough for prehistoric timescales in the Balkans has been achieved until today. It must be added that these dendrochronological analyses were performed on relatively small number of samples.

1.3. The site of Ploča Mičov Grad

One of the best-known lakeshore sites in the southwestern Balkans is situated at Ploča Mičov Grad (also known as 'Bay of Bones') at Gradište

Fig. 5. Ploča Mičov Grad. Section of field 1a after the removal of the macrophytes and the surface layer. The vertically installed wood piles are *in situ* but eroded to the lake bottom level. They are systematically tagged with identification labels. (J. Reich, EXPLO/UBern).

on the eastern shore of Lake Ohrid (North Macedonia). The ‘pile-dwelling’ settlement manifests in the archeological record by a large number of preserved wooden piles protruding from the lake bottom. Already in the 1970s, local fishermen reported prehistoric pottery finds from the surroundings of the Gradište peninsula (Kuzman, 2013). Underwater archeological investigations at Ploča Mičov Grad started in 1997, after the site’s official discovery by professional diver Milutin ‘Mičo’ Sekuloski under the lead of the archeologist Pasko Kuzman. Until 2005, the presence of more than 6000 of the piles visible on the lake bottom were recorded. The spatial extension of the piles *in situ* was estimated to 8000 m^2. The architecture of the settlement, concerning both individual buildings and the overall layout, as well as its development history, remained unexplored until now. While the details on the technical investigation approach are unpublished, preliminary reports mention the presence of an archeological layer of 150 cm thickness under the top layers at the lake bottom (Kuzman, 2013). Based on the vast amount of pottery, stone and bone artifacts retrieved from the surface of the lake bottom during several diving campaigns, the site of Ploča Mičov Grad was typologically attributed to the Late Bronze Age and Early Iron Age (Kuzman, 2013). It was interpreted as a single phase settlement, featuring a wooden platform on stilts on which the houses were built (Naumov, 2016; Kuzman, 2013). This interpretation has been directly applied onto a prehistoric village reconstruction on site, which functions as an open-air museum (‘Museum on Water’) since 2008

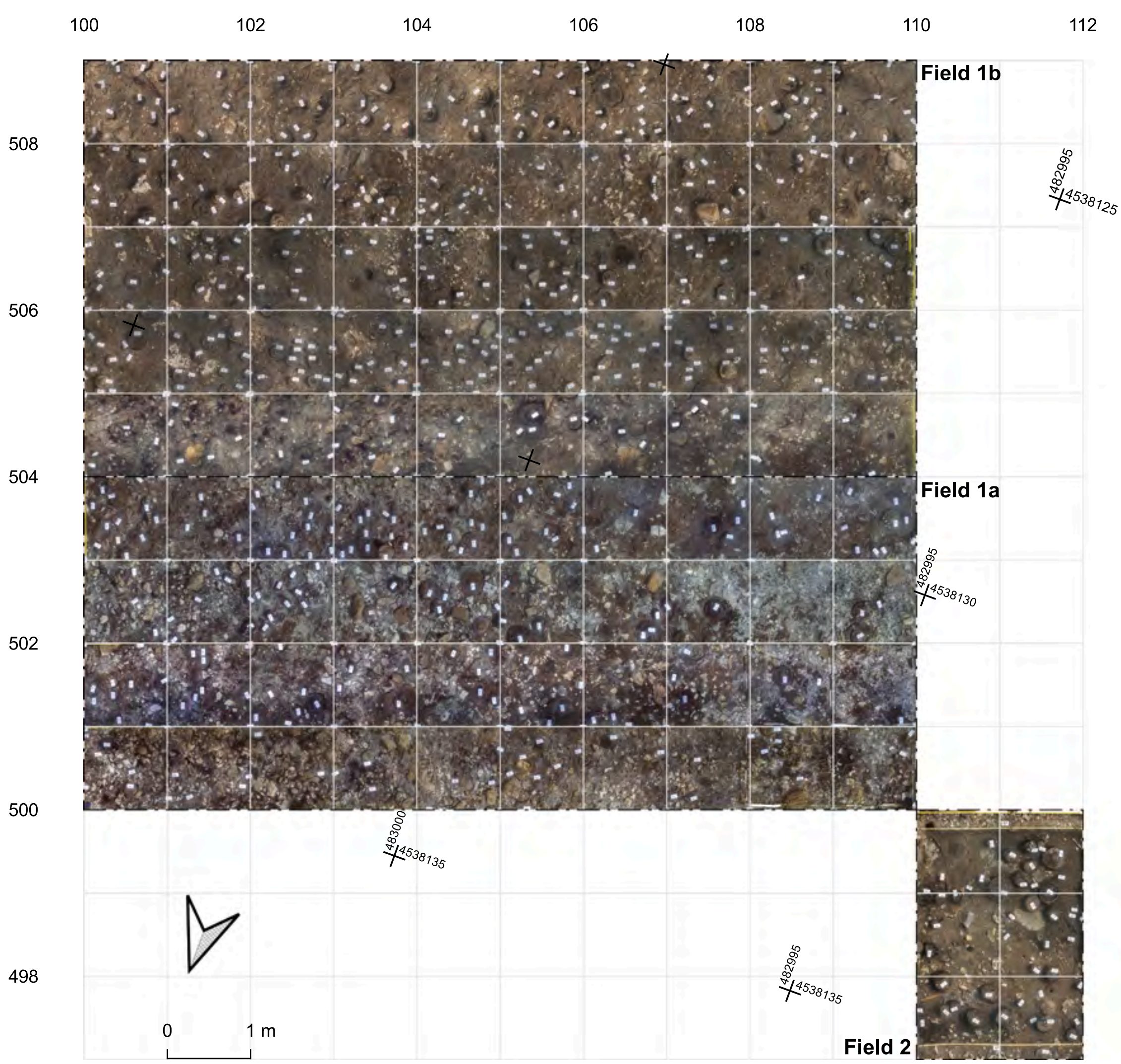

Fig. 6. Ploča Mičov Grad. Orthophotomosaic of the recovered and sampled area in the excavation campaigns 2018 and 2019. The grid is excavation-specific. Field 1a (2018): axis 500 to 504; Field 1b (2019): axis 504 to 509; Field 2: axis 497 to 500 (CRS: local and EPSG:32634). (J. Reich, EXPLO/UBern).

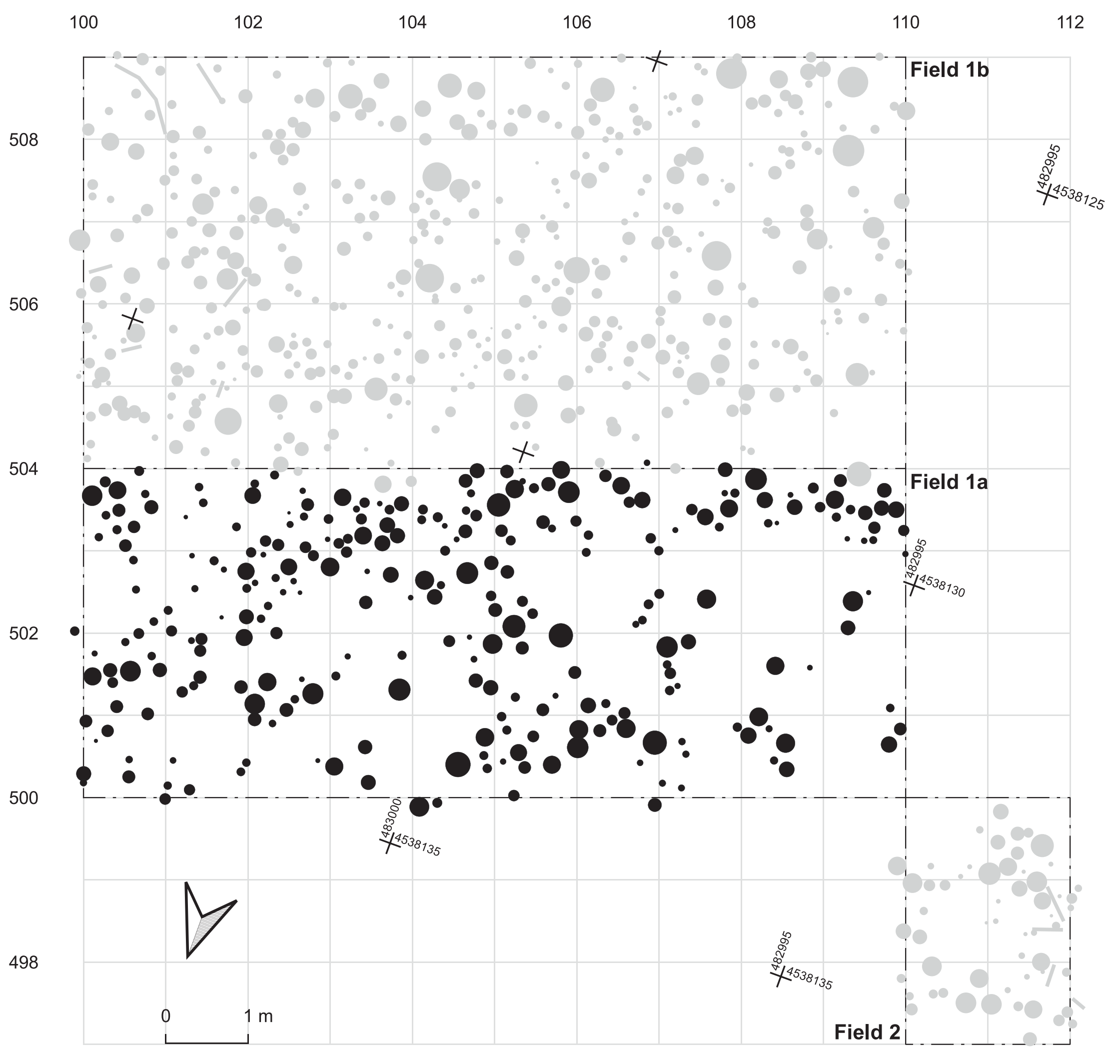

Fig. 7. Ploča Mičov Grad. Plan of recovered wood piles of the excavation campaigns 2018 (black) and 2019 (grey). Each circle marks the location of a wooden pile, indicating the piles' diameter surface area. The piles reach up to 39 cm in diameter (CRS: local and EPSG:32634). (J. Reich, EXPLO/UBern).

(Fig. 4A).

2. Methods

2.1. Setting and sampling

In the summer of 2018, a team consisting of the Institute for Archaeological Sciences of the University of Bern, the Museum of Ohrid and the Center for Prehistoric Research in Skopje resumed the research at the site of Ploča Mičov Grad and conducted an archeological underwater survey (Naumov et al., 2018). The aim was to re-evaluate the research potential of the site and to gain first dendrochronological data from the abundant wooden construction remains on the lake bottom.

During this pilot study in 2018, an area of 40 m^2 (Field 1a) in the center of the previously determined pile concentration was recorded, followed by wood sampling (Fig. 4B–C). In water depths of up to 5 m, the lakebed was first cleaned of vegetation, and a 10 to 20 cm thick sandy surface layer with stones was removed. This uppermost layer must most likely be understood as the result of heavy lake bottom erosion. While the organic matrix of several archeological layers has been completely dissolved, the durable remains accumulated on the next lower level. This interpretation is substantiated by the high quantity, the mixed nature and the eroded surface of the pottery fragments, stone tools and animal bones accumulated over time. Due to the ambiguity of this context, only a small selection of artifacts was recovered from the surface layer. After the removal of the sandy surface layer, numerous wooden piles protruding from the ground started to become visible (Fig. 5). Their tops were mostly flat due to erosion. Their lower parts were embedded in an organic layer with a high density of macroscopic plant remains. During the 2018 campaign, all piles were provided with an individual identification number and documented *in situ* by means of photogrammetry (Reich et al., 2019, 2021 (Fig. 6). For the subsequent dendrochronological analysis, a sample was taken from each pile (a slice of the whole diameter and of about 10 cm thickness was cut off with a handsaw underwater). In the area of Field 1a in total 265 piles were sampled, resulting in a density of 6.6 piles/m^2.

Following the pilot project of 2018, a more extensive underwater campaign was undertaken by the same group of researchers in the summer of 2019 (Naumov et al., 2019). On the one hand, the dendrochronological sampling was continued in Field 1b, and on the other, an excavation was carried out in a 2 m by 3 m square (Field 2) located in the NW-corner of Field 1 (Fig. 6 and Fig. 7). At a depth of 50 cm within the first potentially archeological layer, characterized by its striking organic matrix and the presence of material culture, no significant sediment sequence in the sense of a stratigraphy could be identified. The excavation was hence carried out in artificial spits of 10 cm depth each. Unlike the pottery originating from the surface layer, the finds from this organic layer were in a significantly better preservation condition, hinting to their rapid burial with sediments as well as their *in situ* quality – provided this concept is sensible in the context of a wetland settlement

Fig. 8. Ploča Mičov Grad. Aerial orthophoto of the archeological site underwater with the excavation area (square) next to the modern open-air 'Museum on Water'. The hatched area marks the extension of the wood pile remains at the lake bottom. Circles = location of core drillings from 2019; circles with red cross = core drillings with radiocarbon dated samples. (CRS: EPSG:32634). (J. Reich, M. Hostettler, G. Milevski, EXPLO/UBern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(cf. Bleicher, 2013). For time reasons, the excavation had to be stopped at 50 cm depth, without having reached the bottom of the layer. At the same time, crucial information on the nature of this organic layer could be retrieved from drill cores extracted from the site area in 2019. The main organic layer of the site was evidenced in 14 of these cores, showing an impressive thickness of up to 1.70 m (Fig. 8 and Fig. 9). Interestingly enough, this enormous layer does not appear to be subdivided by sterile layers which would show breaks in accumulation, or (even short) breaks in settlement activity, but must rather be considered as being the result of a continuous accumulation process.

2.2. Dendrochronological analysis

The sample processing and dendrochronological analyses were carried out during the archeological fieldwork in an improvised field laboratory in the infrastructure of the museum at Ploča Mičov Grad. On all samples, an on-site preliminary species selection was performed (oak, juniper, other conifers, deciduous trees), the approximate number of annual rings for prioritizing the dendrochronological analysis, the shape (full section, roundwood, half section, wedge section, or worked on all sides), the presence of a waney edge (i.e. the last growth ring) and particular characteristics (e.g. chopping marks or charring) were recorded. Special attention was given to rare samples with circumferential axe marks, as they are likely to originate from the tip area of the piles and hence provide important stratigraphical information. Additionally, all wooden slices were documented with photos and then vacuum-sealed for storage. Due to time constraints, the cross-sectional areas were not recorded until after the excavation. It is important to note that up to the moment of the investigation, neither dendrochronological reference curves nor information on the prehistoric wood exploitation were available.

The tree-ring width (TRW) measuring was carried out on a measuring table under a binocular microscope with the software Dendroplus (Ruoff, unpublished) and PAST5 (Version 5.0.610, SCIEM). The dendrochronological analysis was performed also with Dendroplus, which identifies cross-dating positons by using the standard dendrochronological statistical parameters, the percentage of parallel variation or *Gleichläufigkeit* (GLK) (Eckstein and Bauch, 1969) and the *t-value* (Baillie and Pilcher, 1973), and complemented by visual verification. The building of mean curves (MK) without any preexisting reference, i.e. without the possibility to check combinations of measured samples against a reliable standard curve, requires a particularly high quality of synchronization.

Additionally, the microscopic wood-anatomical features of the oak and conifer samples were identified and compared to standard reference literature (Akkemik and Yaman, 2012; Schweingruber and Baas, 1990).

2.3. Radiocarbon dating

Samples were taken on site and prepared and analyzed by the Laboratory for the Analysis of Radiocarbon with AMS at the University of Bern (LARA). The cellulose was extracted from wood samples using the BABAB method, i.e. a modified ABA procedure at 75 °C for all steps: the samples were treated in 4% NaOH overnight, followed by three repeated sequential treatments in 4% HCl and 4% NaOH of 1 h each, then several bleaching steps of 30 min each using 5% $NaClO_2$ and 2 drops of 4% HCl were performed until the color of the wood samples turned white (Szidat et al., 2014). The extracted cellulose was then transformed into graphite targets using an automated graphitization equipment (AGE) and ^{14}C dated on the Mini Carbon Dating System (MICADAS) AMS (Szidat et al., 2014). ^{14}C ages were calibrated to calendar ages with the IntCal20 calibration curve (Reimer et al., 2020).

2.4. Analysis

With the aim of achieving the most accurate chronological information possible, the obtained dendrochronological and radiocarbon measurements underwent statistical analysis.

The radiocarbon dates were evaluated within Bayesian chronological models. This approach has proven to deliver high-quality chronological output information extracted from groups of radiocarbon dates when calibrated and modeled with specialized software, in this case the program OxCal v.4.4.2 (Bronk Ramsey, 2009a, 2009b). The definition of the Bayesian approach in analyzing radiocarbon dates and its archaeological implementation has already been presented and discussed in detail (e.g. Bayliss, 2007, 2009). The modeled results ('posterior density

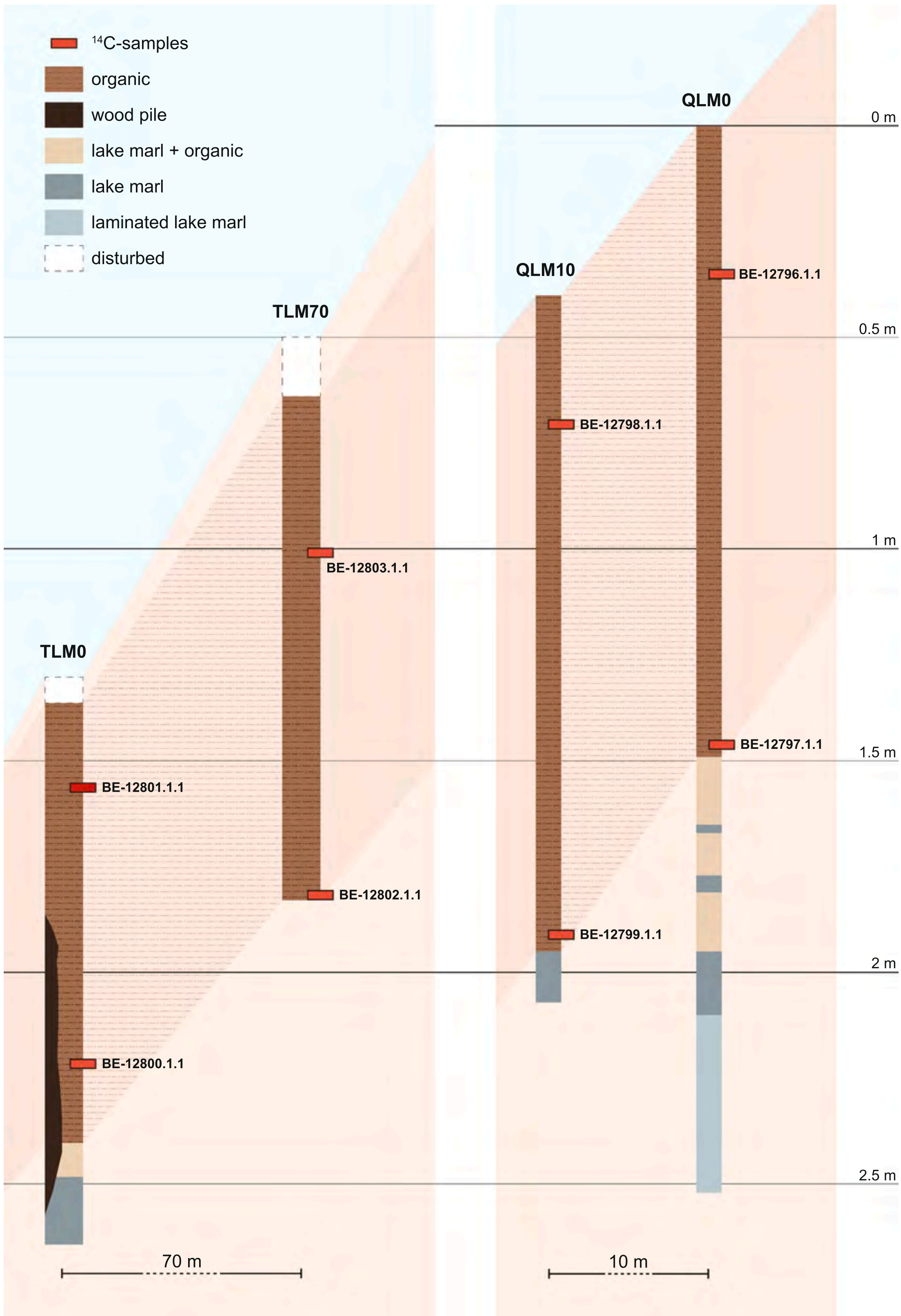

Fig. 9. Ploča Mičov Grad. Schematic illustration of the drill cores TLM 0, TLM 70, QLM 0 and QLM 10 specifying the location of the radiocarbon dated samples. (A. Bieri, UBern, J. Reich and A. Ballmer EXPLO/UBern).

Table 2
Ploča Mičov Grad. Wood species, proportions and numbers of measured wood samples from the 2018 pilot study. (M. Bolliger, EXPLO/UBern).

Wood species	n	%	remarks	measured
Quercus spp.	165	62		114
Juniperus spp.	31	12		3
Pinus sp. (cf. *P.nigra*)	51	19		0
Deciduous	20	7		0
Indet.	1	0	charred	0
	268	**100**		**117**

estimates') are a quantitative, statistical calendar-age approximation of the combined raw dates and the prior information used to define the model.

Radiocarbon samples from tree-ring sequences of which the exact calendar-year intervals are known were used for 'wiggle-matching', i.e. a type of Bayesian radiocarbon modeling enabling a more precise chronological anchoring of 'floating' sequences (Bayliss, 2007; Galimberti et al., 2004; Bronk Ramsey et al., 2001).

We also correlated radiocarbon measurements from organic remains in sediment layers with stratigraphical information, in order to narrow down the time intervals of the calibrated ranges. Therefore, a bi-phased Bayesian model including phase boundaries was established. To calculate the duration of both phases a Sequence-Phase model was applied in OxCal. Standard Boundaries facilitated the phases' separation from each other. In order to visualize each phase within the model, Kernel Density plots (KDE plots) were introduced (Bronk Ramsey, 2017).

3. Results

3.1. Dendrochronology and radiocarbon dating of wooden piles

In the following, we present the results of dendrochronological analyses of the prehistoric wood from Field 1a, sampled in 2018.

A total of 268 samples of wooden elements (265 vertically standing piles, and three horizontally oriented elements) were collected in 2018 (Table 2). Oaks and pines, the most suitable species for dendrochronological analyses, account for 81% of the samples. The wood anatomical analysis confirms the presence only of deciduous oak types. In the modern-day arboreal flora of the Galičica mountains five different deciduous oak species are abundant (*Quercus trojana*, *Q. frainetto*, *Q. cerris*, *Q. pubescens* and *Q. petraea*) (Matevski et al., 2011). All these oak species belong either to the Sections *Quercus* or *Cerris*, and species from both sections are present in the modern-day surroundings of the site. Since taxonomical differentiation of these oaks to the species level is not possible based only on wood anatomical analysis (Akkemik and Yaman, 2012), and no other tree organs were identified beside the stems, the oak samples in this study are defined as *Quercus* spp.

Based on the presence of large fenestriform pits in rays and the dentate end-walls of the ray tracheids, the pine samples are classified as belonging to the Section *Pinus.* The regionally present species of this Section, *Pinus nigra, P. sylvestris* and *P. mugo,* cannot be differentiated only on the basis of wood anatomy (Schoch et al., 2004), however, according to the ecological characteristics and modern-day flora the most probable candidate is *P. nigra* (V. Matevski 2021, pers. comm.).

All the other conifers belonged to the genus *Juniperus*, and its members cannot be differentiated anatomically. However, of the tree-like juniper species in the region, two form larger diameter stems with a clear hardwood/sapwood border (*Juniperus excelsa* and *J. foetedissima*). Based on today's ecology of these species and their distribution on Galičica both could have been used at the site as a building material, with *J. foetedissima* being the more likely species (V. Matevski 2021, pers. comm.).

More than half of the samples had more than 50 annual rings. Our main focus was on the oak woods, setting the basis for the chronologies. The measurements turned out to be extremely complex due to very narrow and hardly visible tree-ring sequences in some places, which was especially the case with samples with a large number of rings (>100). At the same time, these samples are of greatest importance in the establishment of reference chronologies. During the two weeks of measuring on site, 117 samples (114 oaks, three junipers) were dendrochronologically analyzed.

In the context of alpine lakeshore settlements, sites with only one occupation phase show a pile density of less than 1 pile/m^2 (Hafner and Suter, 2000; Leuzinger, 2000; Hafner, 1992). Thus, the density of almost 7 piles/m^2 suggests that the remains originate from numerous settlement phases and that only a few piles of the sampled 40 m^2 may belong to contemporaneous structures.

In the course of the cross-dating process, eight dendrochronological mean curves could be established (Fig. 10), with replication ranging between 2 and 11 samples (Table 3). The mean curve MK 1 is made up of the individual tree-ring series of eight oak piles with each having between 46 and 55 annual rings and very similar growth patterns. All samples have the waney edge preserved and the felling dates concentrate within a span of six years (Fig. 10).

The mean curve MK 4, on the other hand, consists of tree-ring series of oak with many annual rings. Each of the correlated series in MK 4 has an overlap of at least 100 annual rings, a t-value of $\geq$ 6.0 on other individual samples or groups of samples in this mean curve. Visual cross-dating confirmed the statistical synchronization. Unfortunately, only three of these oak samples have some sapwood rings preserved (Fig. 10). Sapwood estimates were not attempted in this study due to sample size constraints. However, if sapwood reconstruction (Bleicher et al., 2020) is taken into account, the partially preserved sapwood in MK 4 would indicate either more than one settlement phase or longer-lasting settlement activity.

A total of 36 samples for radiocarbon dating were taken from the wood samples for a preliminary chronological anchoring of the tree-ring chronologies (Table 4 and Fig. 11). The main objective was to wiggle-match the oak mean curves with a replication of three or more samples or those with more than 100 annual rings (MK 7 and 10). In addition, individual oak trees with a bigger number of annual rings and preserved sapwood, a few pines and junipers, and some oak trees with uncertain cross-dating for a potential extension of the mean curves were chosen (Fig. 11).

The results of the combined dendrochronological and radiocarbon dating clearly show at least three or four different main settlement phases (Fig. 12). Four mean curves and three individual timbers date back to the middle of the 5th millennium BC. The settlement activities around 1800 BCE are represented by one mean curve and two individual piles. Further settlement activity is evidenced in the years around 1400 BCE and around 1300 BCE. The gap of almost 60 years between the 2 sigma dating ranges of the most recent stages hints at two separate settlement phases.

3.2. Radiocarbon dating of the main organic layer

In addition to the dendrochronological dating of construction timbers, selected organic material from archeological contexts from Ploča Mičov Grad was radiocarbon dated in order to frame the formation time span of the main organic layer preserved under the cover layer.

In Field 1, two sediment samples from the top of the organic layer surrounding the piles were taken *en bloc*. From these samples, two plant macrofossils were radiocarbon dated. In addition, eight cereal chaff items from the main organic layer out of four drill cores were radiocarbon dated (Table 5 and Fig. 8). From each of these four drill cores one sample was taken from both the upper and the lower part of the organic layer (Fig. 9). The calibrated 2 sigma ages of the 10 samples in total mainly range between 4600 and 4300 cal BC (Table 5). Taking their stratigraphical position within the organic layer into account, and assuming that the four samples from the bottom part of the cores represent an earlier phase, followed by a later phase represented by the

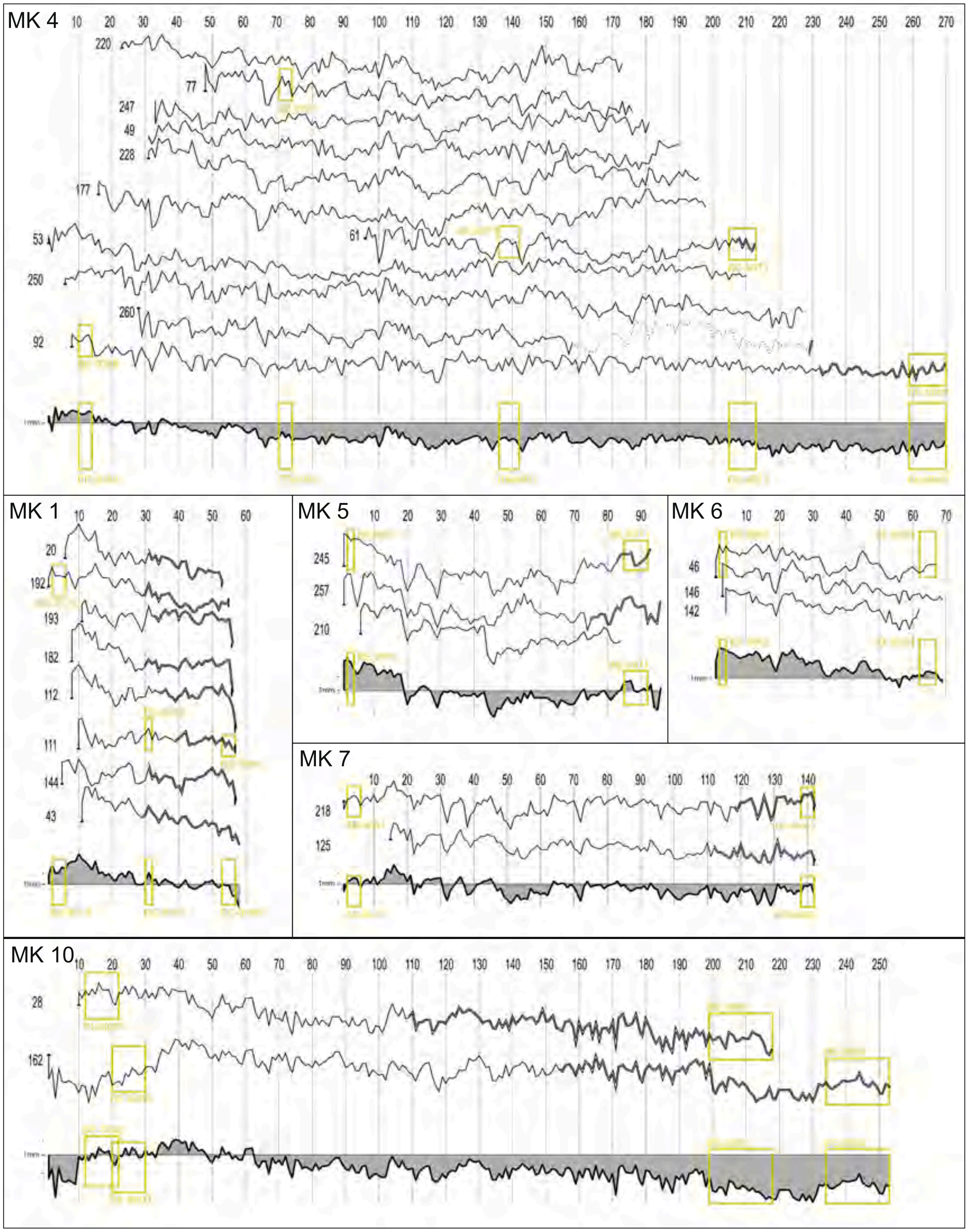

Fig. 10. Ploča Mičov Grad. Construction of oak mean curves MK 1, MK 4, MK 5, MK 6, MK 7 and the juniper mean curve MK 10. The numbers above the vertical straight lines correspond to the relative ring numbers. Sapwood is indicated by a double line. The green frames mark the tree-rings sampled for radiocarbon dating, including the respective laboratory number. Underlying data: https://doi.org/10.5281/zenodo.4560186 (M. Bolliger, EXPLO/UBern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

six samples from the top part of the cores, an OxCal sequence-phase model could be applied for their calibration (Fig. 13). Through the application of the calibration model, the accumulation time of the main organic layer can be estimated between the beginning of the 45th and the middle of the 44th century BCE. Based on this result, it is obvious that the organic layer can be attributed in its entirety to the construction timbers dated to the middle of the 5th millennium BC (Fig. 14). This means in turn that all the archaeological organic layers of the settlement phases of the 2nd millennium BC, as evidenced by dendrochronology, are already eroded. This finding applies definitely to the sampled area, but could very well apply to the entire site.

4. Conclusion

Recent research in 2018 and 2019 at the site of Ploča Mičov Grad at Gradište on the eastern shore of Lake Ohrid (North Macedonia) proves the extraordinary potential of the site for archeological research. This is primarily evidenced by the presence of numerous well preserved construction timbers as well as rich archeological layers. The predominantly occurring wood species – *Quercus* spp. (Sect. *Quercus* and *Cerris*),

Table 3
Ploča Mičov Grad. Dendrochronological mean curves 1–7 and 10, extent in annual rings (length), replication, wood species and calibrated end-date. (M. Bolliger, EXPLO/UBern).

Mean	Length	Replication	Species	End-date: Calendar age, 2 sigma (cal BC)
1	58	8	Quercus sp.	1453–1420
2	64	2	Quercus sp.	N/A
3	42	2	Quercus sp.	N/A
4	270	11	Quercus sp.	4453–4418
5	96	3	Quercus sp.	4448–4367
6	69	3	Quercus sp.	4601–4480
7	142	2	Quercus sp.	1879–1767
10	253	2	Juniperus sp.	4498–4453

Juniperus spp. and *Pinus* sp. (cf. *P. nigra*) – form a promising base for dendro-related research, which holds out the prospect of both highly precise absolute chronological dating of the prehistoric settlement phases and further regional dendroclimatological reconstructions.

The majority of the radiocarbon-dated or dendrochronologically synchronized construction wood from the researched area in the center of the site of Ploča Mičov Grad dates in the middle of the 5th millennium BC. The radiocarbon dates from the wood samples on the one hand, and the at least two different felling dates in MK 4 on the other, point to more than one single settlement phase. This is either evidence of continuous settlement activity over several decades, or of several successive settlements. Based on the experience from circum-alpine pile dwellings the latter option seems much more likely (Hafner, 2019; Stapfer et al., 2019). Based on radiocarbon dates, the enormous, up to 1.7 m thick organic layer was accumulated in its entirety in the middle of the 5th millennium BC.

A minority of the recovered timbers date from the 2nd millennium and indicate three settlement phases around 1800, 1400 and 1300 BCE. The situation encountered in the excavation in 2019 confirms that the anthropogenic layers of the 2nd millennium BC are completely eroded. While their organic matrix has completely perished, either washed away or destroyed, only durable materials with a certain weight were resistant to this process. This explains the vast amount of mostly inorganic artifacts and large quantities of pottery retrieved from the lake bottom in the first series of campaigns between 1997 and 2005 as well as in 2018–2019. Hitherto, these surface finds from the lake bottom were the core argument to attribute the entire site to the Late Bronze Age and Early Iron Age. It is noteworthy that until now the Early Iron Age is not represented in the absolute dates whatsoever. With the clear evidence of up to four subsequent settlement phases and their absolute dating into the 5th and 2nd millennium BC, the persistently postulated idea of a single settlement on one platform must be rejected.

Whereas the wood samples from 2019 (Fields 1b and 2) are currently still under investigation, the set of 2018 can be considered representative for the adjoining zones. This assumption is based on random checking of wood samples from 2019, and also on archeological observations regarding the settlement plan. It must therefore be expected that the dendrochronological results from the timbers from Fields 1b and 2 will consolidate the data basis, but will not considerably change the findings presented here.

With the new data and results from the pilot study in 2018 and the EXPLO-campaign in 2019, the basis for a local reference chronology at Lake Ohrid and the southwestern Balkans is set. Future research at Ploča Mičov Grad will aim at the investigation of further wooden remains in order to consolidate, specify and expand the existing data, in particular

Table 4
Ploča Mičov Grad. Radiocarbon dates from wood samples from 2018, calibrated with OxCal v4.4.2 (Reimer et al., 2020; Bronk Ramsey, 2009b, 2009a). (M. Bolliger, EXPLO/UBern).

Lab Code	^{14}C age (BP)	±1s (y)	Calendar age, 2 sigma (cal BC)	Wood-No.	Species	Sampled ring/rings
BE-9061.1.1	3615	20	2031–1900	218	Oak	2–6
BE-9062.1.1	3463	20	1880–1694	218	Oak	138–142
BE-9063.1.1	5754	22	4689–4537	46	Oak	2–4
BE-9064.1.1	5694	22	4602–4455	46	Oak	62–67
BE-9065.1.1	3098	20	1425–1293	111	Oak	21–23
BE-9066.1.1	3139	20	1494–1316	111	Oak	44–48
BE-9067.1.1	5825	22	4783–4607	77	Oak	23–27
BE-9068.1.1	5819	21	4780–4559	92	Oak	3–7
BE-9069.1.1	5583	21	4452–4356	92	Oak	252–263
BE-9070.1.1	5688	21	4590–4452	245	Oak	2–4
BE-9071.1.1	5578	21	4451–4355	245	Oak	86–92
BE-9072.1.1	5767	21	4689–4544	61	Oak	41–47
BE-9073.1.1	5704	21	4609–4457	61	Oak	110–118
BE-9074.1.1	5716	21	4656–4459	105	Oak	3–7
BE-9075.1.1	5610	21	4494–4361	105	Oak	140–150
BE-9076.1.1	5832	21	4785–4611	216	Juniper	3–7
BE-9077.1.1	5651	20	4542–4407	216	Juniper	223–243
BE-9078.1.1	3490	19	1883–1748	11	Oak	last rings
BE-9079.1.1	3221	19	1516–1437	192	Oak	2–6
BE-9080.1.1	3100	19	1426–1296	201	Oak	2–6
BE-9081.1.1	3076	19	1411–1277	201	Oak	94–104
BE-9082.1.1	5571	21	4448–4355	84	Oak	2–10
BE-9083.1.1	5544	20	4445–4344	84	Oak	93–102
BE-9084.1.1	3079	19	1413–1282	170	Oak	5–12
BE-9085.1.1	3064	19	1403–1266	170	Oak	111–121
BE-9086.1.1	3132	19	1489–1311	120	Oak	46–52
BE-9087.1.1	3199	19	1504–1430	120	Oak	2–4
BE-9088.1.1	3095	19	1422–1293	23	Conifer	last 8 rings
BE-9089.1.1	5326	20	4247–4052	25	Conifer	10
BE-9090.1.1	3254	19	1601–1450	264	Conifer	last 7 rings
BE-9091.1.1	3566	19	2012–1785	38	Oak	4–10
BE-9092.1.1	3525	19	1929–1770	38	Oak	115–125
BE-9093.1.1	5831	21	4784–4611	162	Juniper	ca. 20–30
BE-9094.1.1	5633	21	4537–4368	162	Juniper	last 20 rings
BE-9095.1.1	5854	21	4793–4623	28	Juniper	ca. 3–13
BE-9096.1.1	5631	21	4537–4366	28	Juniper	last 20 rings

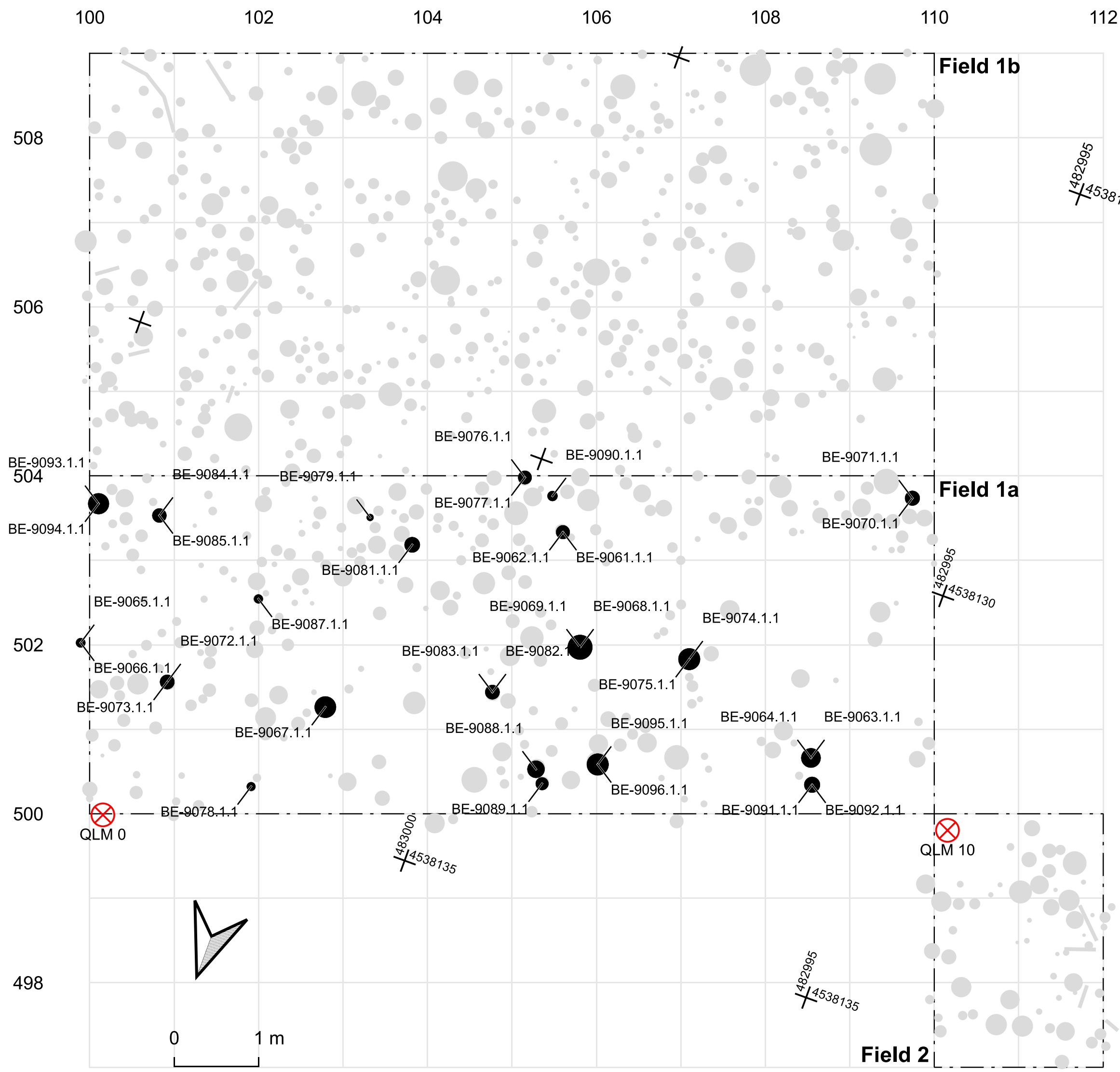

Fig. 11. Ploča Mičov Grad. Spatial distribution of the radiocarbon dated samples. Black circles: wood piles; circles with red cross: location of core drillings (CRS: local and EPSG:32634). (J. Reich, EXPLO/UBern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

also regarding the layout of the different settlements on the one hand, as well as archeological structures preserved in the archeological layer/s on the other. Further dendrochronological investigations in the south-western Balkan region will allow the extension of the reference curves with data for additional periods – with the promising perspective of a regional high-resolution chronology.

5. Data availability

5.1. Underlying data

Zenodo: Ploča Mičov Grad 2018. List of measured wood samples. https://doi.org/10.5281/zenodo.4560186

This project contains the following underlying data:

- Ploca_2018_measured_wood_samples.xlsx (list of measured wood samples)

Zenodo: Ploča Mičov Grad 2018. Radiocarbon raw data from wood samples. https://doi.org/10.5281/zenodo.4613033

This project contains the following underlying data:

Raw radiocarbon dating data:

- Ploca_2018_radiocarbon_raw_data_wood_samples.xlsx

Zenodo: Ploča Mičov Grad 2018/2019. Radiocarbon raw data from the main organic layer. https://doi.org/10.5281/zenodo.4612910

This project contains the following underlying data:

Raw radiocarbon dating data:

- Ploca_2018_radiocarbon_raw_data_macrofossil_samples.xlsx

6. Code availability

Analysis code available from:

Archived analysis code at time of publication:

- Oxcal code for Fig. 12: https://doi.org/10.5281/zenodo.4560125
- Oxcal code for Fig. 13: https://doi.org/10.5281/zenodo.4560161

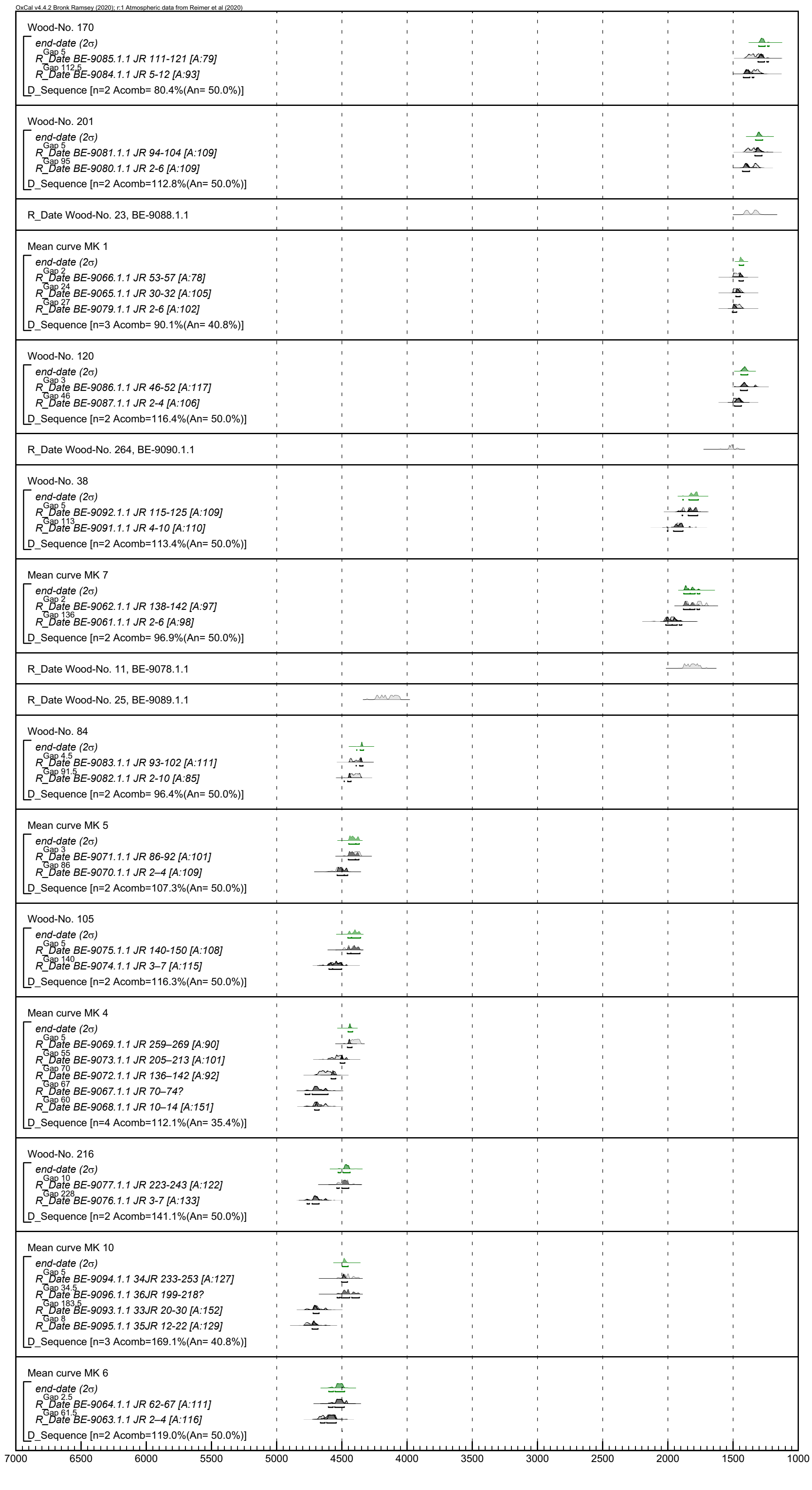

Fig. 12. Ploča Mičov Grad. Calibrated results of the radiocarbon dates of the wood samples. Green = results of wiggle matching; grey = single calibrations. Three to four main settlement phases are evidenced: a first one in the middle of the 5th millennium BC, and further ones around 1800 BCE, 1400 BCE and 1300 BCE. The gap of almost 60 years between the 2 sigma dating ranges of the most recent stages hints at two separate settlement phases. Modeled with OxCal v4.4.2 (Reimer et al., 2020; Bronk Ramsey, 2009a, 2009b; Bronk Ramsey et al., 2001). Underlying data: https://doi.org/10.5281/zenodo.4613033. Code: https://doi.org/10.5281/zenodo.4560125 (M. Bolliger, J. Reich, EXPLO/UBern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 5
Ploča Mičov Grad. Radiocarbon dates from the main organic layer. Samples from the pilot study 2018 and core drilling 2019. Dates calibrated with OxCal v4.4.2 (Reimer et al., 2020; Bronk Ramsey, 2009a, 2009b). (J. Reich, EXPLO/UBern).

Lab Code	^{14}C age (BP)	±1s (y)	C mass (μgC)	Calendar age, 2 sigma (cal BC)	Description	Material	Sample context
BE-10944.1.1	5529	85	93	4582–4072	Ploča 2018, Lake Ohrid	macrofossil	2018, 'top' sample
BE-10945.1.1	5604	23	841	4493–4358	Ploča 2018, Lake Ohrid	macrofossil	2018, 'top' sample
BE-12796.1.1	5608	51	468	4539–4351	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	QLM0, 'top' sample
BE-12797.1.1	5670	25	>1000	4584–4408	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	QLM0, 'bottom' sample
BE-12798.1.1	5536	60	324	4499–4256	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	QLM10, 'top' sample
BE-12799.1.1	5594	60	327	4546–4337	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	QLM10, 'bottom' sample
BE-12800.1.1	5599	57	376	4543–4343	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	TLM0, 'bottom' sample
BE-12801.1.1	5512	61	314	4491–4246	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	TLM0, 'top' sample
BE-12802.1.1	5551	23	>1000	4446–4347	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	TLM70, 'bottom' sample
BE-12803.1.1	5517	44	591	4451–4261	Ploča 2019, Lake Ohrid	cereal chaff (*Triticum*)	TLM70, 'top' sample

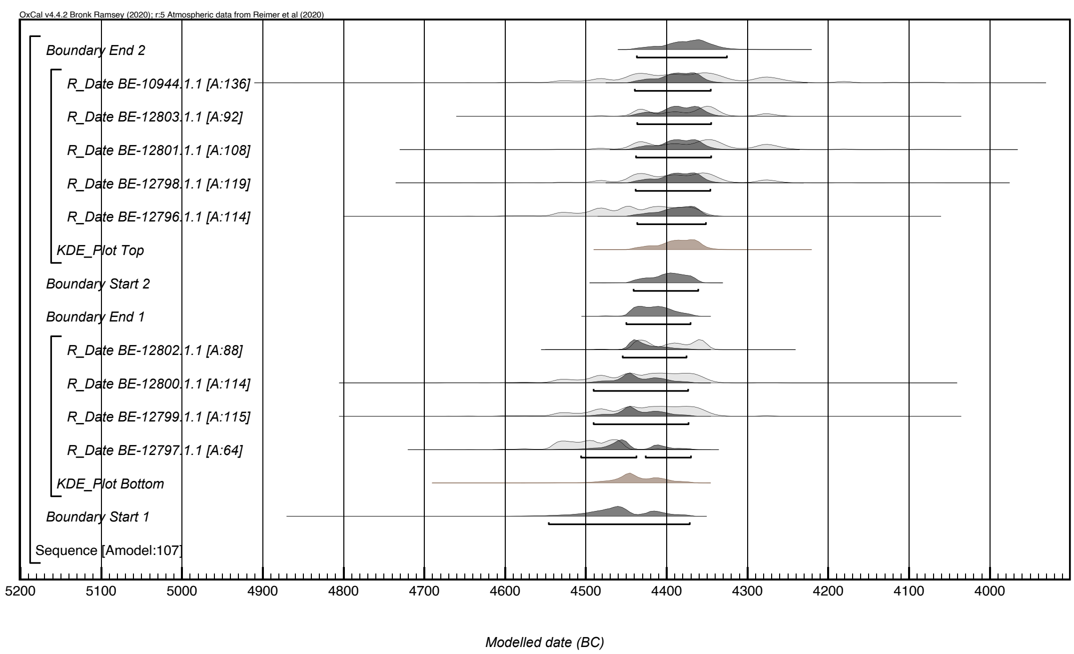

Fig. 13. Ploča Mičov Grad. Sequence-phase model of archeobotanical samples representing the 'top'- and 'bottom'-phase of the organic layer; brown = modeled kernel density estimation plots; grey = single dates. Modeled with OxCal v4.4.2 (Reimer et al., 2020; Bronk Ramsey, 2009a, 2009b). Underlying data: https://doi.org/10.5281/zenodo.4612910; Code: https://doi.org/10.5281/zenodo.4560161 (J. Reich, EXPLO/UBern).

- Oxcal code for Fig. 14: https://doi.org/10.5281/zenodo.4560172

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CRediT authorship contribution statement

Albert Hafner: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - original draft, Writing - review & editing, Funding acquisition, Project administration. **Johannes Reich:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition, Project administration. **Ariane Ballmer:** Conceptualization, Methodology, Validation, Investigation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition, Project administration. **Matthias Bolliger:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Ferran Antolín:** Investigation. **Mike Charles:** Investigation. **Lea Emmenegger:** Conceptualization, Methodology, Investigation, Funding acquisition. **Josianne Fandré:** Software, Validation, Formal analysis, Investigation. **John Francuz:** Software, Validation, Formal analysis, Investigation. **Erika Gobet:** Project administration. **Marco Hostettler:** Conceptualization, Methodology, Validation, Investigation, Funding acquisition, Project administration. **André F. Lotter:** Investigation. **Andrej Maczkowski:** Software, Validation, Formal analysis, Investigation. **César Morales-Molino:** Investigation. **Goce Naumov:** Investigation, Project administration. **Corinne Stäheli:** Conceptualization, Methodology, Investigation, Funding acquisition. **Sönke Szidat:** Validation, Investigation. **Bojan Taneski:** Investigation, Project administration. **Valentina Todoroska:** Investigation. **Amy Bogaard:** Resources, Funding acquisition, Project administration. **Kostas Kotsakis:** Funding acquisition, Project administration. **Willy Tinner:** Resources, Funding acquisition, Project administration.

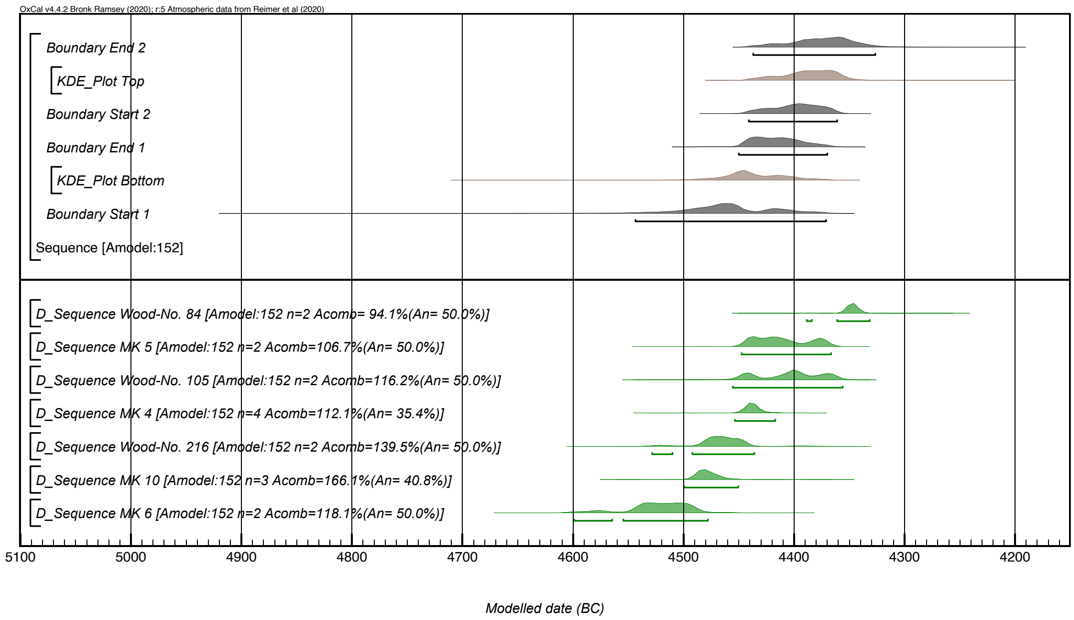

Fig. 14. Ploča Mičov Grad. Comparison of the modeled radiocarbon data from the 5th millennium BC. Green = results of the wood wiggle matching; brown = kernel density estimation plots of the 'top' and the 'bottom' of the organic layer. Modeled with OxCal v4.4.2 (Reimer et al., 2020; Bronk Ramsey, 2009a, 2009b; Bronk Ramsey et al., 2001). Underlying data: https://doi.org/10.5281/zenodo.4613033; https://doi.org/10.5281/zenodo.4612910; Code: https://doi.org/10.5281/zenodo.4560172 (J. Reich, EXPLO/UBern). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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