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 Ploća Mićov 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 Ploća Mićov 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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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
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 Ploca Micov Grad at Gradiste 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 Moraca 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...
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

| 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   | MK-AL     | 358             | 693             | 289         | 36.4 (N-S) | 16.8 (E-W) | 55.5           | 88             | 3,920 km\(^2\) (*) |
|           | 20° 45' E   |           |                 |                 |             |         |         |                 |                | Lake Ohrid sub-watershed: 1,400 km\(^2\) |
| Great Prespa | 40° 54' N | MK-AL     | 259             | 849             | 54          | 34.0 (N-S) | 10.0 (E-W) | 3              | 111 for both Prespa lakes | 3,920 km\(^2\) (*) |
|           | 21° 02' E   | MK-AL-GR  |                 |                 |             |         |         |                 |                | Lake Prespa sub-watershed: 2,520 km\(^2\) |
| Small Prespa | 40° 46' N  | AL-GR     | 47              | 853             | 7           | 10.6 (N-S) | 6.6 (E-W) | 0.3            |                | 3,920 km\(^2\) (*) |
|           | 21° 06' E   | AL-GR     |                 |                 |             |         |         |                 |                | Lake Prespa sub-watershed: 2,520 km\(^2\) |
| Skadar    | 42° 10' N   | AL-MK     | 350–470         | 7               | 9 (44)     | 48 (NW-SE) | 14 (NE-SW) | 1.9            | 168            | 5,500 km\(^2\) |
|           | 19° 19' E   | AL-MK     |                 |                 |             |         |         |                 |                |               |

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; Panagiotopoulou et al., 2014; Matzinger et al., 2006; International Lake Environment Committee Foundation, n.d.). (A. Hafner, EXPLO/UBern).

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), Plljë e Pusit (2287 m) in the Mali i Thâtë mountains and Magaro (2255 m) in the adjacent Galicica 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 Reshpis (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 Tushemishit (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 Galicica and Mali i Thâtë (Fig. 3). Environmental isotopic analysis has demonstrated that 37–42 and 52–54% of water emerging from the St. Naum and Tushemishit 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 archaeological 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 (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: Giakoulis, 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; Srdoc 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 Mićov Grad

One of the best-known lakeshore sites in the southwestern Balkans is situated at Ploča Mićov Grad (also known as ‘Bay of Bones’) at Gradiste...
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 Gradiste peninsula (Kuzman, 2013). Underwater archeological investigations at Ploča Mićov Grad started in 1997, after the site’s official discovery by professional diver Milutin ‘Mićo’ 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 m². 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 Mićov 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.
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 Micov 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 m² (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/m².

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.
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 Micov 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 information possible, the obtained dendrochronological and radiocarbon measurements underwent statistical analysis.

The tree-ring width (TRW) measuring was carried out on a measuring table under a binocular microscope with the software Dendroplus (Ruoff, unpublished) and PASTS (Version 5.0.610, SCIEM). The dendrochronological analysis was performed also with Dendroplus, which identifies cross-dating positions 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% NaClO2 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 14C dated on the Mini Carbon Dating System (MICADAS) AMS (Szidat et al., 2014). 14C 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

| 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 of deciduous oak types. In the modern-day arboreal flora of the Galicica mountains five different deciduous oak species are abundant (Quercus trojana, Q. fraintettso, 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 stumps, 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 Junipers, 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 (Junipers excelsa and J. foetidissima). Based on today’s ecology of these species and their distribution on Galicica both could have been used at the site as a building material, with J. foetidissima 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/m² (Hafner and Suter, 2000; Leuzinger, 2000; Hafner, 1992). Thus, the density of almost 7 piles/m² suggests that the remains originate from numerous settlement phases and that only a few piles of the sampled 40 m² 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 ≥ 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 Placa Mioc 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
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 Ploća Mićov Grad at Gradiste 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),
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 Ploća Micov 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 archaeological 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 Ploća Micov Grad will aim at the investigation of further wooden remains in order to consolidate, specify and expand the existing data, in particular
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 Mićov 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 Mićov 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:

- Ploca_2018_radiocarbon_raw_data_macrofossil_samples.xlsx

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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. 11. Ploča Mićov 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.)
Fig. 12. Ploča Mićov 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.)
Fig. 13. Ploča Mícov 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.4560172 (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, Visualization, 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. Matthäus 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. Gocce Naumov: Investigation, Project administration. Corinne Stäheli: Conceptualization, Methodology, Investigation, Funding acquisition. Sonke Sziat: Validation, Investigation. Bojan Taneski: Investigation, Project administration. Valentina Todoroska: Investigation. Amy Boggaard: Resources, Funding acquisition, Project administration. Konstantinos Kotsakis: Funding acquisition, Project administration. Willy Tinner: Resources, Funding acquisition, Project administration.
Fig. 14. Ploća Mićov 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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References

Akkenik, Ü., Yaman, B., 2012. Wood anatomy of Eastern Mediterranean species. Kessel Publishing House, Remagen-Oberwinter.

Albrecht, C., Wilke, T., 2008. Ancient Lake Ohrid: biodiversity and evolution. Hydrobiologia 615 (1), 103–140. https://doi.org/10.1007/s10750-008-9558-y

Allen, S.E., Gjipali, L., 2014. New Light on the Early Neolithic Period in Albania: The Southern Albania Neolithic Archaeological Project. In: Gjipali, L., Perzhiwa, L. (Eds.), Proceedings of the International Congress of Albanian Archaeological Studies: 65th Anniversary of Albanian Archaeology, pp. 107–119.

Amatja, S., Anovski, T., Benische, R., Eftimi, R., Gourcy, L.L., Kola, L., Leontiadis, I., Micevski, E., Stamos, A., Zoto, J., 2007. Tracer methods used to verify the hypothesis of Cvijic about the underground connection between Prespa and Ohrid Lake. Environ. Geol. 51 (5), 749–753. https://doi.org/10.1007/s00254-006-6388-9.

Andoni, E., Hassa, E., Gjipali, L., 2017. Neolithic settlements on the western bank of Lake Ohrid: Pogradec and Liu 3, in: New Archaeological Discoveries in the Albanian Regions. Proceedings of the International Conference, Tiranà 30–31 January 2017. Tiranà, pp. 123–140.

Antolini, F., Bužek, R., Jacomet, S., Navarrette, V., Sana, M., 2014. An integrated perspective on farming in the early Neolithic lakeshore site La Draga (Banyoles, Spain). Environ. Archaeol. 19, 241–255. https://doi.org/10.1080/17496111.2014.926915.

Baillie, M.G.L., Pilcher, J.R., 1973. A Simple Crossdating Program for Tree-Ring Research

Bayliss, A., 2007. Bayesian buildings: an introduction for the numerically challenged. Vernacular Architect. 38 (1), 75–86. https://doi.org/10.17732/verna.38.175819

Bleicher, N., Walder, F., Gut, U., Bolliger, M., 2020. The Zurich method for sapwood estimation. Dendrochronologia 64, 125776. https://doi.org/10.1016/j.dendro.2020.125776.

Bronk Ramsey, C., 2009a. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51 (1), 123–147. https://doi.org/10.1017/S0033822209003770.

Bronk Ramsey, C., 2009b. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (3), 1023–1045. https://doi.org/10.1017/S0033822209003493.

Bronk Ramsey, C., 2009b. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337–366. https://doi.org/10.1017/S0033822209003865.

Bronk Ramsey, C., van der Plicht, J., Weninger, B., 2001. ‘Wiggle Matching’ radiocarbon dates. Radiocarbon 43 (2A), 381–389. https://doi.org/10.1080/003382201082848.

Butriman, A., 1998. Bizirul baseino ir Zemai i auk tumos akmens amziaus tyrin jim apzvalga. Lietuvos archeologija 15, 107–131.

Charniaux-Carriou, M.M., 2007. Bone and Horn Articles at the Settlements of Kryvina Peat Bog (Southern Albania, Neolithic Lakeside Settlements (6th–4th 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.)

Chrysostomou, P., Jagoulis, T., Mavromatis, K., 2015. Human impacts on Karst aquifers of Albania. Environ. Earth Sci. 74 (5), 1809–1833. https://doi.org/10.1007/s12665-017-5110-3.

Fouache, E., Desruelles, S., Magny, M., Bordon, A., Oberweiler, C., Cousseau, C., Touchais, G., Lera, P., Lezine, A.M., Fadin, L., Roger, R. 2010. Palaeo-geographical reconstructions of Lake Maliq (Korca Basin, Albania) between 14,000 BP and 2000 BP. J. Archaeol. Sci. 37 (3), 525–535. https://doi.org/10.1016/j.jas.2009.10.017.
zwischen 3900 und 3400 v. Chr. In: O’Neill, A., Pyzel, J. (Eds.), Siedlungsstrukturen im Neolithikum – Zwischen Regel und Ausnahme. Welt und Erde Verlag, Kerpen-Loogh (Eifel), pp. 131–153. https://doi.org/10.7892/boris.137935.

Szidat, S., Salazar, G.A., Vogel, E., Battaglia, M., Wacker, L., Synal, H.-A., Türler, A., 2014. 14C analysis and sample preparation at the new bern laboratory for the analysis of radiocarbon with AMS (LARA). Radiocarbon 56 (2), 561–566. https://doi.org/10.2458/56.17457.

Todoroska, V., 2017. Archaeological Research at the underwater archaeological site Vrbnik in Lake Ohrid (research 2015 and 2017). Arheološki Informator 1, 17–22.

Touchais, G., Fouache, É., 2007. La dynamique des occupation de bord de lacs dans le Sud-Ouest des Balkans: L’Exemple de Sovjan, bassin de Korçë (Albanie), in: Richard, H., Magny, M., Mordant, C. (Eds.), Environnements et Cultures à l’âge Du Bronze En Europe Occidentale. Paris, pp. 375–386.

Valastro, S., Davis, E.M., Varela, A.G., 1977. University of Texas At Austin Radiocarbon Dates XI. Radiocarbon 19 (2), 280–325. https://doi.org/10.1017/S0033822200003581.

van der Schriek, T., Giannakopoulos, C., 2017. Determining the causes for the dramatic recent fall of Lake Prespa (southwest Balkans). Hydrol. Sci. J. 62 (7), 1131–1148. https://doi.org/10.1080/02666667.2017.1309042.

Virtanen, K., 2006. Esialgne aruanne Koorküla Valgjärve allveearheoloogiliset uurimised. National Heritage Board, Helsinki.

Wagner, B., Wille, T., Francke, A., Albrecht, C., Baumgarten, H., Bertini, A., Comboutreux-Nebout, N., Cvetkoska, A., D’Addabbo, M., Donders, T.H., Föll, K., Giaccio, B., Grazhdani, A., Hauffe, T., Holtvoeth, J., Joannin, S., Jovanovska, E., Just, J., Kouli, K., Koutsodendris, A., Kranetl, S., Lacey, J.H., Leicher, N., Leng, M.J., Levkov, Z., Lindhorst, K., Masi, A., Mercuri, A.M., Nomade, S., Nowaczyk, N., Panagioutopoulos, K., Peyron, O., Reed, J.M., Regattieri, E., Sadori, L., Sagnotti, L., Stellbrink, B., Sulz便io, R., Tofilowska, S., Torri, P., Vogel, H., Wagner, T., Wagner-Cremer, F., Wolf, G.A., Wonik, T., Zanchetta, G., Zhang, X.S., 2017. The environmental and evolutionary history of Lake Ohrid (FYROM/Albania): interim results from the SCOPSCO deep drilling project. Biogeosciences 14, 2033–2054. https://doi.org/10.5194/bg-14-2033-2017.

Westphal, T., Tegel, W., Heusner, K.-U., Lera, P., Rittershofer, K.-F., 2010. Erste dendrochronologische Datierungen historischer Hölzer in Albanien. Archaeologischer Anzeiger 2, 75–95.