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Zambratija: A 6000-year-old pile-dwelling submerged under the Adriatic Sea

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ABSTRACT

This thesis attempts to reconcile questions of human adaptations and interactions with changing climate events in the past, by using archaeological and environmental evidence from the submerged pile-dwelling in Zambratija Bay, Northwest Adriatic Sea. Discovered in 2008, Zambratija revealed stratified evidence of human activities in a paleo-landscape that was once terrestrial but is now submerged three metres under water. Due to the findings of wooden piles protruding out of the seabed alongside a platform of freshwater peat, all located on the outer edges of a submerged karstic sinkhole filled with sediments, the site was preliminary determined as a lacustrine pile-dwelling. Wooden piles and peat were accompanied by pottery typologically appropriated to local prehistory, which was later supported with radiocarbon dates implying the Late Neolithic period, around 4200 BC. The piles indicated an architectural resemblance to a building tradition known as the prehistoric pile-dwellings around the Alps, a UNESCO-protected network of 111 archaeological sites located across the glacier lakes in today's Austria, France, Germany, Italy, Slovenia and Switzerland, which was in almost continuous use for more than 3000 years from the Late Neolithic to the Iron Age. Due to the specific anaerobic conditions which allowed for the preservation of organic material, these now submerged lacustrine settlements represent some of the most significant and well-researched archaeological sites in European prehistory. In addition to the submerged material culture found in Zambratija, the proximity of the site to the current Adriatic shoreline provided an indication of former sea-levels and a means to assess the local environmental history. The radiocarbon dates implied that the site was in use during the most recent global geological period, also known as the Holocene. The Holocene started around 9650 BC, when interdisciplinary records start showing a considerable increase of human impact to the environment, an interaction that is still ongoing and present in most contemporary climate change debates.

Considering the assumptions and issues drawn from the preliminary research, Zambratija Bay located submerged under the Adriatic Sea some 100 kilometres south of the Alpine lakes, represented an unexpected and unique challenge to the archaeological discipline and was therefore chosen to be the case study for the research presented in this thesis. The interdisciplinary PhD fieldwork was organised and performed on site in 2017, followed by further laboratory and desk-based work. The presented results, derived from 3 seabed sediment cores and 11 wooden pile samples from Zambratija Bay, answered relevant questions with not only local, but also broader implications regarding submerged archaeological research, European and World prehistory and modern-day climate change issues. As an addition to the original results, the thesis also suggests a methodological concept provisionally called Archaeology of the Core, which is based on applying basic archaeological excavation and post-excavation methods to seabed core samples.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed..

Date 23 September 2019

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Mojoj obitelji.

To my family.

CHAPTER 1: INTRODUCTION

This thesis is an interdisciplinary analysis of the climatic and socio-economic changes that occurred after, and were influenced by, the most recent rapid melting of the Earth's polar ice sheets. Based on new environmental and archaeological evidence collected from a submerged Early Copper Age pile-dwelling on the North-eastern Adriatic Sea, the thesis adds new and original knowledge to the disciplines regarding past and present adaptations to climate change. The case study is located in Zambratija Bay, Croatia (**Figure 1**) and today lies three metres under water, providing valuable archaeological and environmental evidence not only of the marine transgression caused by the ice melt, but also a significant new insight into the social networking and cultural interactions between the prehistoric populations of the Northern Adriatic and Alpine regions.

Figure 1 The location of Zambratija Bay (marked with a yellow star) in the Adriatic Basin.

Due to a combination of cultural and natural factors, which will be discussed in Chapter 3 and Chapter 4 in the thesis, the submerged site in Zambratija Bay represents a case study with overlapping environmental and socio-economic circumstances briefly described above. It is located on the most northern peak of the Istria Peninsula, approaching the end of the Adriatic Sea and the Gulf of Venice and Trieste. This makes the locale both part of the Alpine and Adriatic regions geographically. It provides an interesting study area suitable for the investigation of prehistoric contact and trade between the two (Verdonkschot 2014:40). Underwater archaeological investigations in the bay between 2008 and 2015 (Benjamin et al. 2011a; Koncani Uhač 2008, 2009; Koncani Uhač and Čuka 2015) revealed a unique instance of a prehistoric pile-dwelling originally constructed over a freshwater or marshland environment that is today submerged three metres under water. According to the archaeological, environmental and geophysical evidence collected prior to this thesis research and one radiocarbon date range between 4230–3980 Cal BC (Koncani Uhač and Čuka 2015:28) human activity in the pile-dwelling occurred either continuously or with occupational hiatuses at some point between the Late Neolithic and Early Bronze Age (Koncani Uhač and Čuka 2015:44). The mentioned evidence consisted of hundreds of wooden piles protruding out of the seabed situated around organic peat, all in the near vicinity of a submerged karstic sinkhole filled with sediments (Benjamin et al. 2011a; Koncani Uhač 2008, 2009; Koncani Uhač and Čuka 2015). Furthermore, large amounts of pottery, lithics and other types of archaeological remains were scattered around the piles and the peat. Some of the found pottery showed a typological resemblance to the Eastern Adriatic Early Copper Age Nakovana Culture (Koncani Uhač and Čuka 2015:36), and the preserved organic remains indicated an architectural resemblance to prehistoric building traditions common around the glacier lakes in the Alps (Koncani Uhač and Čuka 2015:43), both contemporary to the 4230–3980 Cal BC timeframe (Menotti 2004c). Taking all the collected information into account, it is evident that the significance of the Zambratija Bay site is reaching much further than North-eastern Adriatic boundaries. The chain of events leading to the development of the paleo-landscape, the building of the pile-dwelling and its final abandonment is relevant not only to submerged but also continental European and world prehistory and, as presented in this thesis, to contemporary climate change debates.

Research questions, aims and objectives

The three underwater sites in Zambratija Bay (discussed below) indicate a chronological timescale of local sea-level change from around 4000 BC–100 AD, with one radiocarbon dated wooden architectural element found in situ in a submerged freshwater landscape, show a prehistoric cultural and environmental connection to the Alps. Zambratija Bay therefore represents an ideal case study for providing interdisciplinary empirical evidence showing the interconnected nature of the relationships between natural and cultural complex systems, seen worldwide as triggers for some of the most significant events in human history, such as first hominid migrations out of Africa (Flemming et al. 2003), neolithisation which is also sometimes known as the 'Neolithic revolution' (Forenbaher and Miracle 2005), or the first population of Australia (Ward and Veth 2017). In the Northern Adriatic, it seems to have been significantly related to sea-level change, which will be tested in Zambratija by examining the resilience of the population that occupied the pile-dwelling.

By using the data provided by 2008–2015 investigations, the thesis incorporates the results from a series of environmental and archaeological fieldwork activities undertaken in 2017. The fieldwork research resulted in the collection of seven seabed sediment cores and 20 waterlogged wood samples, supported with nine new radiocarbon dates. The following research questions were therefore designed to explore these topics as well as the known issues relevant to the disciplines of Submerged Prehistoric Archaeology of the Continental Shelves and Wetland Archaeology. The questions will be addressed in the thesis by using research methods adopted from environmental sciences, applied to underwater archaeology and discussed through the theoretical lens of Climate Change Archaeology.

1. How did the physical environment evolve at Zambratija Bay during the Early and Middle Holocene, with special reference to sea-level changes?

2. What affect did the environmental changes have on the people living at the prehistoric pile-dwelling in Zambratija Bay and on the taphonomy and preservation of the archaeological site left behind?

3. With consideration for the site's chronology, spanning the Late Neolithic to the Bronze Age, what socio-economic developments are observable at the Zambratija Bay site relative to the broader Alpine Adriatic archaeological record(s)?

In order to answer these questions, a series of aims and objectives were devised into physical environmental and cultural/archaeological themes. Considering a broad range of topics related to chronological ordering, as well as cultural migration and occupational patterns in regional archaeology, the thesis focuses on significantly enhancing and connecting previous and new prehistoric archaeological and environmental records with new original data.

Environmental aim and objectives

The first aim of this project was to calculate local sea level at the time of settlement with consideration for possibilities for the rapid climate and sea-level change to have impacted on local prehistoric populations. This aim was achieved by completing two objectives: 1) to undertake a retrospective reconstruction of past sea levels by analysing the existing sea-level data for the Northern Adriatic Sea. This data is based on publications with radiocarbon dates from sediment core layers with different environmental and geological proxies, as well as from coastal archaeological remains that serve as past sea-level markers

(Antonioli et al. 2007; Antonioli et al. 2009; Benjamin et al. 2017; Furlani et al. 2014; Lambeck et al. 2004a; Šegota and Filipčić 1991). 2) To reconstruct the local sea-level and environmental changes in Zambratija through the analysis of environmental and cultural proxies from core sediments collected during original fieldwork in 2017. Selected layers with sea-level proxies were then radiocarbon dated, thereby rendering environmental changes apparent in real time. The results, seen in the form of a local sea-level curve and transgression model, provided an environmental background for an archaeological interpretation of the site, which is rationalised with the cultural aims and objectives.

Cultural aim and objectives

The second aim was to determine the cultural connections to known prehistoric cultural complexes in the Eastern Adriatic and Alpine glacier lake regions, during the time of the Zambratija Bay settlement occupation. This aim was achieved by completing three objectives (3–5) concerning the material culture from the settlement. Objective 3) was therefore to create a comparative analysis between the previously published pottery found in Zambratija Bay (Benjamin et al. 2011a; Koncani Uhač 2009; Koncani Uhač and Čuka 2015), and the sites in the Northern Adriatic with comparable pottery styles found in contexts with similar radiocarbon date ranges. Objective 4) focused on the results of the underwater archaeological surveys conducted during the fieldwork in 2017 and the dendrochronological and xylological analysis of the collected piles. The underwater survey was performed on a selected area of the site with more than 20 piles, making it possible to discuss potential patterns of pile placement. The piles themselves became comparable objects, forming a baseline for the architectural features to be the focus of further study. The dendrochronological results also reinforced the results from the radiocarbon determinations. The results of this part of the research are visible in the form of a georeferenced photomosaic of the bay including the survey area layered over the results from previous preliminary investigations of the site.

Bringing together the physical environmental and cultural components of Zambratija Bay, a focus is then placed on mapping the peak periods of cultural occupation with the evolving coast to better understand the human-environmental interactions and relationships. Therefore, the final objective 5) was to integrate the 4000 BC Alpine Adriatic reconstructed shoreline and landscape, showing the then-contemporary Northern Adriatic sites with Nakovana style pottery and Alpine pile-dwellings. This objective was achieved by creating a series of maps of the Northern Adriatic Sea and Alpine glacier lakes region. The maps illustrate how the prehistoric sites with identified relevant material culture were contemporary to the Zambratija Bay pile-dwelling in its environmental context. This was done by GIS software and the result led to examination of the different relationships and prehistoric cultural connections to the Zambratija settlement from around Alpine and Adriatic Europe.

Objectives 1 and 3 were addressed through a review of published literature. Objectives 2 and 4 included an interdisciplinary component, where methods traditionally employed by environmental sciences (i.e. using sensitive sea-level proxies from radiocarbon dated cultural layers and wood analysis) were used to answer archaeological research questions. Objective 5 included results from all previous four objectives by combining old and new data into a synthesised visual representation of cultural connections during times of rapid climate change, thus providing the study with a map and baseline for archaeological discussion.

Research background

Underwater archaeological research of the 20th century Northern Adriatic Sea, specifically concerning the Istrian Peninsula, has primarily focused on shipwrecks and architectural remains from Roman antiquity and later periods. This trend started to change at the beginning of the 21st century with the rise of global interest in submerged landscapes and prehistory. Benjamin and Bonsall (2009) conducted one of the first archaeological studies on the submerged Slovenian coast, which is geographically part of the northern Istrian Peninsula, in 2005 (**Figure 2**) (Benjamin and Bonsall 2009). They were interested in the early and middle Holocene sea-level changes and submerged shorelines of the area and performed a diver-based survey that resulted in the discovery of archaeological features and artefacts ranging in age from prehistory to the nineteenth century. Combining empirical data with local paleo-environmental and sea-level reconstructions, they argued that the 6500–5000 BC coastline around Piran Point, which is located seven kilometres north of Zambratija Bay lies submerged 10–20 metres below the modern-day sea-level (Benjamin and Bonsall 2009:171).

Image removed due to copyright.

Figure 2 The location of Zambratija Bay (marked with a black star) in relation to Piran Point (Modified after Benjamin and Bonsall (2009)).

In 2008, the Croatian Ministry of Culture requested an archaeological prospection of the Zambratija Bay and its immediate shore. Archaeologists from the Archaeological Museum of Istria in Pula, Croatia, conducted a preliminary survey of the seabed (Koncani Uhač 2008), their task to investigate whether the construction works on the elongation of an existing embankment endangered a nearby ancient Roman Villa (Bolšec-Ferri 2007:418). The archaeologists then performed an underwater excavation around the existing embankment and surveyed the entire bay. During that survey, they found three new underwater archaeological sites: a submerged Roman road, the remains of a laced boat from the Bronze Age, and an area with a dense concentration of with wooden piles protruding out of the surrounding seabed (**Figure 3**) (Koncani Uhač 2009; Koncani Uhač and Čuka 2015; Koncani Uhač and Uhač 2012). Due to several factors briefly presented in the next few paragraphs (and more thoroughly in Chapters 2, 3 and 4), the site was identified as a submerged prehistoric pile-dwelling (Benjamin et al. 2011a; Koncani Uhač 2009; Koncani Uhač and Čuka 2015).

Image removed due to copyright.

Figure 3 A photograph of Unit 1 during the initial 2008 excavation campaign. Image source: Koncani Uhač and Čuka (2015).

The site was found at an average depth of 3 m below mean sea-level (MSL). It was initially recognised as 34 vertically placed wooden piles which surrounded an area covered with peat approximately 30 x 67 m in size (Koncani Uhač 2009:265; Koncani Uhač and Čuka 2015:27). Three underwater archaeological campaigns occurred on the presumed settlement between 2008 and 2015, which resulted in the excavation of five 1 x 1 m test units. From these units, archaeologists collected samples of ceramic fragments, lithics and other stone artefacts, botanical and faunal remains, and wood for identification analysis. Based on the typology of the pottery, they came to the conclusion that the fragments belonged to the Terminal Neolithic and early Copper Age, a period which roughly covers a timespan between 4000–3000 BC (Benjamin et al. 2011a:197; Koncani Uhač 2009:266; Koncani Uhač and Čuka 2015:42).

Preliminary surveys show that the site lies on the outskirts of a natural depression, and that the number of marked piles in situ is growing with each survey (currently exceeding 100). A radiocarbon date from one of the wooden piles revealed a calibrated age of 4230–4200 and 4170–3980 Cal BC (95% probability, 2 Sigma, Beta-296187) (**Figure 4**) connecting the relative chronology of the pottery with its known absolute dates (Koncani Uhač and Čuka 2015).

Image removed due to copyright.

Figure 4 Radiocarbon age report by Beta Analytic Radiocarbon Dating Laboratory of a wooden sample taken from a pile in Unit 1 (Koncani Uhač and Čuka 2015).

The presence of peat, wooden piles, and prehistoric pottery indicated an unexpected connection to the UNESCO World Heritage listed prehistoric pile-dwellings near Alpine glacier lakes in Austria, France, Germany, Italy, Switzerland and Slovenia (Menotti 2015b). This combination of cultural and environmental historical circumstance makes Zambratija Bay a significant site for central European and Mediterranean prehistoric archaeology, as well as world heritage. The results presented in this study will impact and provide new, interdisciplinary and empirical perspectives to the disciplines of Prehistoric Archaeology of the Continental Shelves, Wetland Archaeology and the Climate Change Archaeology.

Geomorphological setting

Zambratija Bay is located in the Adriatic Sea, which is a small semi-closed sea with a total of 1246 islands along its eastern (Croatian) border (Duplančić Leder et al. 2004:5) and a large number of shallow basins between them (Šegota and Filipčić 1991:150). The most prominent characteristic of the Northern Adriatic Sea is its relatively shallow bathymetry, which is influenced by a gently sloping (0.02°) continental shelf (Martorelli et al. 2014:175) (**Figure 5**).

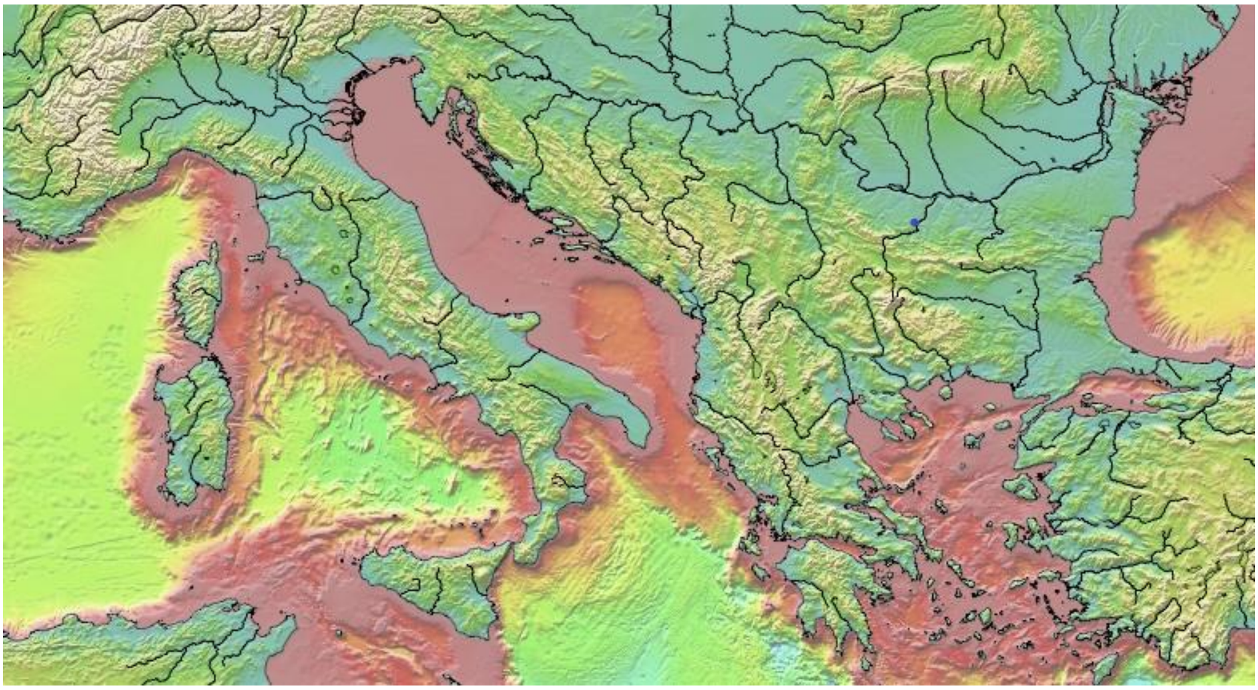

Figure 5 Seabed topography of the Adriatic Basin (Modified after Scripps Institute of Oceanography, University of California San Diego Global Topography interactive map[1]).

In the past, these characteristics enhanced the role of other environment-changing local factors, such as sedimentation deposited by the river Po at the northernmost end of the basin (Martorelli et al. 2014:177). Given these factors, the changes in sea-level resulted in site-specific impacts on the landscape and its inhabitants on both a regional and local scale. The sea-level rise along the Adriatic coast was rapid, with a mean rate of 10 mm/yr until about 5000 BC (Benjamin et al. 2017:14), after which it slowly progressed to its current elevation. According to calculations based on a large number of past sea-level markers, the Relative

[1] https://topex.ucsd.edu/WWW_html/mar_topo.html

Sea-Level (RSL) here changed at up to -2.08±0.60 m over the past 2000 years (Antonioli et al. 2007; Antonioli et al. 2009). The sea-level change data accumulated from archaeological markers can serve as a good indicator of the mean rate for the 5000-year-long gap between the 5000 BC mark and classical Roman antiquity.

One of the most evident characteristics of the Zambratija site is that its settlement was submerged over time due to the post-glacial marine transgression. The Holocene, or the post-glacial epoch, started approximately 9650 BC, and is ongoing. Early and Middle Holocene were periods in which cultural changes were significantly influenced by those in the environment, therefore making them archaeologically interesting for investigating the dynamics between climate change and human adaptations to relatively fast-changing natural surroundings (Van de Noort 2011). Post-glacial Holocene marine transgression and landscape evolution and their impact on prehistoric coastal societies has been a growing topic in the archaeological community for the last decade, particularly the study of prehistoric archaeology of the continental shelves (Bailey and Flemming 2008; Bailey et al. 2017b; Benjamin et al. 2011a; Flatman and Evans 2014; Flemming et al. 2017). The origin of the development of the discipline can be traced back to the 1981 interdisciplinary Symposium on Quaternary coastlines and Prehistoric archaeology (Masters and Flemming 1983b). Since its beginning, the prehistoric archaeology of the continental shelves has been a collaborative science which included a number of different, equally important and cross-referential methods and approaches, most often as a combination of archaeology, geology, oceanography and environmental sciences (Bailey et al. 2017b; Flatman and Evans 2014; Masters and Flemming 1983b). Known today under several terms, such as *Archaeology of the Continental Shelves* (Bailey and Flemming 2008) or *Submerged Prehistory* (Benjamin et al. 2011b), it developed in many different directions (Bailey et al. 2017b; Benjamin et al. 2011b; Evans et al. 2014), resulting in the systematic and cross-referenced worldwide examination of submerged landscapes.

Archaeological setting

The radiocarbon date from Zambratija, was produced from a sample that was collected at a depth of 3 m below MSL (Koncani Uhač 2009:266; Koncani Uhač and Čuka 2015:28). This confirmed that the age of the site alone indicated a considerable significance, as it was an unusually early radiocarbon date for a pile-dwelling (Menotti 2015b:25) (**Figure 6**), but also for being associated with the cultural transition from the late Neolithic to the Early Copper Age. All of which was found on the submerged seabed of the Adriatic Sea. A part of the ceramic assemblage from Zambratija belongs to the Nakovana cultural style of pottery, which was named after the Nakovana coastal cave on the Pelješac Peninsula in Southern Croatia (Forenbaher 1999–2000; Forenbaher and Kaiser 2003; Koncani Uhač and Čuka 2015). The 4230–3980 BC date and the typological characteristics of the found ceramics, placed Zambratija around the middle of the Nakovana cave radiocarbon dates, where the oldest was determined to have been circa 5000 BC and the youngest 3200 BC (Forenbaher et al. 2013:592). The Early Copper Age in the Eastern Adriatic is poorly understood as compared with other post-Mesolithic periods. This is principally due to the fact that the Early Copper Age was mostly defined by specific styles of pottery, without many reliable radiocarbon dates. This led to difficulties in the attempts to establish a more precise definition if the transition, because the pottery styles of the Early Copper Age are similar to those of the Late Neolithic. As for the Eastern Adriatic coast in these periods, pottery shapes and decorations are often classified as Nakovana culture, which is, rarely present in the Northern Adriatic (Forenbaher et al. 2013).

Image removed due to copyright.

Figure 6 A simplified Alpine pile-dwelling phenomenon timeline interrupted with occupational hiatuses and the Zambratija radiocarbon date range (marked with a black star). Image source: Menotti (2015b) modified by K. Jerbić.

Forenbaher et al. (2013) collected data from known excavations and synthesised them in a table and a map (**Figure 7**), providing a valuable and critically evaluated source for radiocarbon dates which are associated with material culture. In Istria, only five radiocarbon dates (**Figure 7:3–7**) are known to be associated with layers containing Copper Age ceramics, and two of those come from unreliable contexts. The three remaining samples come from Novačka cave (**Figure 7:4**), which provided two dates, and a single date from Pupićina cave (**Figure 7:5**).

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Figure 7 A map by Forenbaher et al. (2013) showing the radiocarbon dated Eastern Adriatic Neolithic open-air (white) and cave sites (black).

The Novačka cave ceramics, which was also attributed to the Early Copper Age Nakovana style, falls around 3900 BC. The ceramics attributed to the Late Copper Age-Early Bronze Age transitional period, known as Cetina style from Pupićina cave, was found in stratigraphic layers dated to around 2500 BC (Forenbaher et al. 2013).

Koncani and Čuka (2015) provide a recent overview of a selected collection of Nakovana style pottery as well as other known prehistoric cultural complexes found in Zambratija (Chapter 2), and in combination with the radiocarbon date, concluded that the settlement was most active at circa 4200 BC, which is mostly known as the beginning of the Copper Age (Koncani Uhač and Čuka 2015). Considering these chronological and regional contexts, it seems that Zambratija represents either a multilayered settlement or one that has been used intermittently through multiple periods, starting as early as Late Neolithic, and ending in the Late Bronze Age (Koncani Uhač and Čuka 2015). According to the Forenbaher et al. (2013) study, the latest known Neolithic dates in the Eastern Adriatic fall around 4000 BC, and the Early Copper Age dates are spread through the entire span of the fourth millennium BC, with Nakovana pottery appearing between 4000 and 3500 BC. Therefore, by synthesising all reliable recent peer-reviewed sources it is possible to conclude that, even though the transition from the Neolithic to the Copper Age on the Eastern Adriatic coast is still obscure, it most likely happened at the beginning of the fourth millennium BC (Forenbaher 1999–2000:375; Forenbaher et al. 2013:604). This consequently suggests that the radiocarbon date from Zambratija indicates the potential for the evidence from Zambratija to contribute to these discussions.

The peat found on site is an organic material deposited in a brackish wetland environment, therefore indicating a freshwater type of landscape prior to sea-level rise (Roberts 1998). The phenomenon of building architecture in and around lacustrine environments started in the Neolithic period approximately 4300 BC and was in use until 700 BC (Menotti 2004a:210), and its origins most likely lie in the Mediterranean region (Menotti 2004b:2). This assumption is based on the finds of the tetraploid naked wheat or 'lake-dwelling wheat', on Early Neolithic sites in Spain, and Italy (Menotti 2004b:2). The discovery and study of the pile-dwellings in the Alps in the 19th century represent the historically significant start of underwater archaeological explorations (Hafner 2004; Menotti 2015b). The preliminary date from Zambratija makes it seem like this is one of the earliest prehistoric representatives of people living in a pile-dwelling settlement, with an additional distinctive possibility of being a maritime outpost of a traditionally lacustrine type of settlement, compared to the Alpine sites. The case of Zambratija therefore calls for additional radiometric and dendrochronological dates, as well as a palaeoenvironmental study, all of which was performed during this research and demonstrated in the following chapters. The new data will help determine the nature of the settlement, its inhabitants and their interaction with the fast-changing environment and neighbouring cultural groups.

Submerged marine Prehistoric pile-dwelling settlements have yet to be found or studied in the Adriatic coastal region. Neolithic and Copper Age occupational sites in the Adriatic are well known, however most commonly in the form of caves (Čuka 2009; Jerbić Percan 2011; Komšo 2008), or occasionally as open air sites (Komšo 2004, 2007). In the Bronze Age, occupational sites have transformed to hillforts, with sporadic finds in caves (Buršić-Matijašić 2012; Buršić-Matijašić and Žerić 2013; Čuka 2009; Hänsel et al. 2005). The closest freshwater pile-dwellings to Zambratija Bay are on the lakes in Italy (Marzatico 2004), Austria (Ruttkay et al. 2004) and the Slovenian marshlands to the north-west (Velušček 2004), and on the southeast Cetina (Marović 2002:234; Milošević 1999; Smith et al. 2006:172-173) and northeast Sava rivers (Marović 2002:234; Potrebica 2003:217). In order to address the role of Zambratija Bay in the context of coastal settlement patterns of the Late Neolithic/Early Copper Age Adriatic, and culturally connect the settlement to the Alpine pile-dwellings, it is necessary to put this site onto a geographical and cultural map of the 4000 BC map of the Istrian Peninsula and its hinterland, starting with an overview of material culture and other archaeologically significant data collected in Zambratija Bay so far.

A brief history of Croatian archaeology and the first attempts of sea-level research

The Istrian Peninsula is today a part of Croatia, and the preliminary research was conducted by Croatian institutions and archaeologists under the administration of the Croatian Ministry of Culture. Therefore, this research was conducted and executed under the historical and cultural legacy of Croatian archaeological scholarly and scientific work. The territory of modern Croatia was a part of many different cultural circles and influences throughout history, which were all developed through centuries of migrations and socio-economic and political situations. This thesis is debating a part of prehistory where the ethnic background of the populations is unknown and does not represent a relevant factor in the archaeological discussion. As other prehistoric sites worldwide, the scientific advantage of Zambratija is that it represents a historically significant example relevant for the understanding of a human population's adaptation to their surroundings on a global scale. Nevertheless, it is important to understand the complexity of the region and the historical background of the people and institutions with an interest in local archaeology in recent history, and are considered, in one way or another, pioneers in the field. Therefore, a very short overview of the developments concerning cultural heritage and archaeology with a highlight on the history of sea-level research relevant to modern Croatia is presented here not only as a historical background, but also as a critical reflection.

The beginnings of archaeological scholarly work and cultural heritage management in Croatia

Archaeology has been an object of scientific interest for more than a century in Croatia, often following the contemporary European archaeological scholarly trends and topics. A famous example is Dragutin Gorjanović Kramberger (1856–1936), who used stratigraphy, X-ray technology and fluorine content as his scientific methods while researching the Neanderthal site in Krapina (Novaković 2011). However, the interest in human remains and past civilisations and behaviour in these territories has been an interest of previous scholars and explorers, and can be traced back to the 18th century, with the Italian scientist Vitaliano Donati of Padova (Donati 1750). He wrote about the coastal geology of the Adriatic in 1750, and was one of the very first people to notice the phenomenon of submerged architectural remains in the seas around Pula, Istria (Petrić 2001). One of the many historically crucial moments in history of this land was marked by the fact that in the times of the early Roman administration, the Istrian peninsula was a part of the *X* Italian region (*Veneto et Histria*), and the coastal towns were holding important roles as harbours.

Today's Dalmatian coast, the province *Dalmatia* in Latin (Novaković 2011), served as a gateway to the inner parts of the empire, and many coastal towns that were formed in these areas are still living today, in many cases holding the same names, 2000 years later. Therefore, the earliest attempts to protect cultural heritage were in these areas, because of the many visible architectural remains of the Roman times. In 1802, the first collection of monuments from the Roman period was formed in the Temple of Augustus in Pula, and in 1820, the Archaeological Museum was opened in Split (Novaković 2011). The first archaeological courses in Croatia were held at the University of Zagreb in 1878 by Isidor Kršnjavi, which led to the formation of discipline-specific curriculum in 1896 with Dr Josip Brunšmid as chair, and the second archaeological programme was started in Zadar, in 1957 (Novaković 2011). Both developed into well-established archaeology departments that are still active and evolving today. Also, 1878 saw the establishment of the Croatian Archaeological Society, and the first publication of the archaeological bulletin at the Archaeological Museum of Split. The following year, the Archaeological Society published their first issue, and one of the papers discussed ancient Roman anchors (Ljubić 1879). These examples represent only a few of the many cases where archaeology was recognised as cultural heritage. It all cumulated under the Austro-Hungarian administration, with the establishment of the Public Heritage Protection Service in Zagreb, which was under the auspices of the Ministry of Culture, and was spread around the Croatian territory under 20 regional branches with professional archaeologists (Novaković 2011) (**Figure 8**).

Image removed due to copyright.

Figure 8 A map of Croatia showing the 20 current Public Heritage Protection Service branches under the auspices of the Ministry of Culture (Modified after Wievegh (2010)).

First attempts at reconstructing past sea levels

The phenomenon of sea-level change was noticed back in the 18th century with Vitaliano Donati (Donati 1750), and was followed by Alberto Fortis (Fortis 1774), who noticed similarities in the submerged architectural remains across the Dalmatian coast. In 1901, the Istrian conservator Anton Gnirs talked about the submerged parts of a Roman Villa Rustica. He was fascinated with the sea-level phenomenon and synthesised it in a study of archaeological sea-level markers throughout the entire Eastern Adriatic coast (Gnirs 1908; Petrić 2001). Together with the work of geologist Nikola Andrijašević (Andrijašević 1910), who also noticed the connection between the submerged architectural remains and the environmental changes, represent the first scientific studies of sea-level change in Croatia (Petrić 2001; Radić Rossi 2012a; Vilibić et al. 2017). Even though the earliest mentions of diving and salvage of wrecked ship cargo can be traced back to the fifteenth century, the first attempt of formal underwater archaeological investigations in Croatia were held by Don Frane Bulić (Bulić 1899; Bulić 1900) in the waters off Kaštela Bay in the village of Vranjic in 1899 (Petrić 2001; Radić Rossi 2008, 2012a). There, a number of ancient Roman *sarcophagi* were found on the seabed, which were documented by archaeologists (**Figure 9**) with the help of hired professional divers (Petrić 2001; Radić Rossi 2012a).

Image removed due to copyright.

Figure 9 Original drawings from 1899 of the submerged Roman *sarcophagi* by Frane Bulić. Image source: Petrić (2001).

Local development of maritime archaeology as an academic discipline

The interest in underwater archaeology was scarce, but present and contemporary with the archaeological literature of the 20th century. In 1953, Mladen Nikolanci talks about artefacts and heritage found in the waters of Dalmatia (Nikolanci 1953). Later, in 1968, the *Conference on Underwater Archaeology Problems* was held in Zagreb, and the term *hydroarchaeology* was introduced to the Croatian archaeological community by Štefan Mlakar (Radić Rossi 2012b). In 1970, Nenad Cambi published "A Handbook for Hydroarchaeological exploration", as a handbook for divers (Cambi 1970). In 1972, Ivan Mirnik writes about "The first hydroarchaeological notes" in Croatia in the magazine for fishing and marine sports "More" (Eng. "The Sea") (Mirnik 1972), and in 1973 Ksenija Radulić discusses the "Problems in our hydroarchaeology" (Radić Rossi 2012b). These early attempts of defining underwater archaeology, as well as the first investigations was noticed even by Keith Muckelroy (1974) who states "…considerable progress has been made in Yugoslavian waters since 1969, when a well-regulated system was established based on 'working teams' in every major coastal town by the Office for the Protection of Monuments (Zagreb)…", admirably citing the non-translated work of Dasen Vrsalović from 1974 (**Figure 10**) (Muckelroy 1978).

— (1976). The fourth century wreck at Yassi Ada; an interim report on the hull. *I.J.N.A.*, **5**, 115–31.
Visquis, A. G. (1973). Premier inventaire du mobilier de l'épave des jarres à Agay. *C.A.S.*, **2**, 157–67.
Vrsalovic, D. (1974). *Istrazivanja i zastita podmorskih archeoloskih spomenika u SR Hrvatskoj*. Republicki Zavod za zastitu spomenika kulcture, Zagreb.

Figure 10 Keith Muckelroy citing Dasen Vrsalović in his book Maritime Archaeology (1978) (Photo: K. Jerbić).

Vrsalović in 1979 writes his doctoral thesis on the topic of underwater archaeological investigations of the Eastern Adriatic, as a contribution to the trade paths and economic circumstances of the Classical Antiquity Adriatic Sea, synthesising the development of underwater archaeology in Croatia from the 1950s up to that point (Petrić 2001; Radić Rossi 2012b). Vrsalović died at the age of 53 in 1981, as he was carrying the honourable position of President of the Croatian Archaeological Society. His dissertation was published *post mortem* as a book in 2011 (Vrsalović 2011). After many years of underwater archaeological investigations, the survival of the global crisis of the identity of underwater archaeology in the 1980s (Radić Rossi 2012b), and the unfortunate political events in the 1990s, Croatia ratified the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage on December 1 2004 (Rodrigues 2005).

There is archaeology under the shipwrecks

Even though sea-level change was an interest amongst local scholars over the last century, few contemporary underwater archaeologists took notice of the topic. That has started to change, and the new trend can be traced to the underwater prehistoric archaeological sites that emerged in the last decade (Bekić 2017; Bekić et al. 2011; Bekić et al. 2015; Benjamin et al. 2011a; Benjamin and Črešnar 2009; Čelhar et al. 2017). New literature and interdisciplinary international trends concerning submerged prehistoric landscapes and other topics related to the archaeology of the continental shelves have also influenced these changes. While the topic has been noticed in Croatia, an organised large-scale research is still to be undertaken (Bekić et al. 2015; Benjamin et al. 2011a; Čelhar et al. 2017; Koncani Uhač 2009; Radić Rossi 2008, 2012a; Radić Rossi and Cukrov 2017).

This thesis provides a timely and valuable contribution to the regional records and debates and serve to open this under-represented focus of underwater exploration in the Eastern Adriatic. There remain considerable gaps in knowledge however, it is an intention of this thesis that the research in Zambratija will be held as a positive example of multidisciplinary international scientific collaboration and an original contribution to central European and submerged landscape archaeology. It is the author's intention that this will be the first of many such sites to be systematically studied and brought to light to both the local and international research communities. Zambratija represents an exceptional opportunity to investigate past human interactions with fast-changing environments, and, more specifically, cultural adaptation pathways to the Early Holocene climate and sea-level variations. Taking into consideration the preliminary research results (Chapter 2), local environmental history (Chapter 3) and known cultural occurrences around the time of the settlement's occupation (Chapter 4), this thesis considers a combination of archaeological disciplines and theories relevant to the site (Chapter 5) as a research framework to select a set of appropriate interdisciplinary methods (Chapter 6). The results of these methods (Chapter 7) were then used as a tool to answer archaeological questions significant for the understanding of past and present relationships between cultures and the environment (Chapter 8), contributing scientific value to submerged archaeology with Zambratija Bay as a case study, making it an equal participant in contemporary climate change debates (Chapter 9).

CHAPTER 2: A HISTORY OF RESEARCH IN ZAMBRATIJA BAY 2008–2015

The unusually dense concentration and the diversity of underwater and terrestrial sites found in and around Zambratija Bay has prompted several investigation campaigns from the site's discovery in 2008 to the last excavations by the Archaeological Museum of Istria in Pula (AMI) in 2015. As an employee of AMI's Prehistory Department between 2012 and 2014, and in 2015 as a contracted diver-archaeologist and archaeological illustrator, the author participated in some of these investigations[2] (**Figure 11**).

Figure 11 The author diving on the submerged prehistoric site in Zambratija Bay during the 2014 archaeological investigations (Photo: I. Koncani Uhač).

[2] This involvement offered an empirical perspective on the complexity and significance, as well as to the probable theoretical, methodological and financial limitations of possible further investigations of the site. The museum experience and access to the original data presented below, led to the initial development of the project and served as the fieldwork guidelines and research framework building blocks of this thesis, which was commenced in March 2016 at Flinders University in Adelaide, South Australia.

Data presented in this chapter with permission from all the collaborators, is organised here as a guide through all the known archaeologically significant aspects of the site, starting with the site discovery and the timeline of all investigations prior to the commencement of the research for the purposes of this thesis. It is based on the documents, photographs and fieldwork diaries made available to the author by personal communication, as well as the most recent publication by Koncani Uhač and Čuka (2015) which focused on the pottery obtained on site during the investigations between 2008 and 2015. The first segment of this chapter will show all the visual representations of the bay as well as the results of the radiocarbon dating analysis. After that, an overview of the typologically determined pottery found on site will serve as a guideline for the segment following afterword, which will be an overview of the stratigraphical contexts from the seabed surface and the five excavated units. The data presented below will later be combined in the discussion with the results from new fieldwork and laboratory analyses collected for the purposes of the thesis.

Site discovery

In the fishing village of Zambratija, in Zambratija Bay near Umag on the northern Croatian Adriatic coast, construction works on the elongation of the existing port embankment during 2008 endangered the nearby ancient coastal Roman Villa. Following current Croatian cultural heritage legislation and procedures, the local branch of the Croatian Ministry of Culture in Pula (KOPU), covering the territory of the Istrian Peninsula (**marked as KOPU on Figure 8**) requested an archaeological prospection of the bay and its immediate shore before the continuation of the construction works. Since the villa was located on the foreshore and endangered by tidal movement, the Ministry also requested an underwater archaeological survey of the bay, a task appointed to the nearest established underwater archaeological team working for the Archaeological Museum of Istria in Pula. With the help of Mr Christian Petretich, an amateur SCUBA diver familiar with the local history and folklore, the archaeologists performed an underwater excavation around the embankment area and surveyed the entire bay, where they found a submerged Roman embankment, the remains of a Bronze Age boat built in a laced technique, and an area covered in peat with wooden piles that protruded from the surrounding seabed (Koncani Uhač 2009:267; Koncani Uhač and Uhač 2012:534). Underwater archaeological investigations started immediately after the site's discovery in September 2008. Since there were two more underwater sites recognised in the bay, the initial archaeological campaign was an investigation of all three sites, resulting in the excavation of six units and a small collection of finds from the seabed (Koncani Uhač 2008, 2009). Unit number 6 was excavated inside the submerged settlement in a location with a high concentration of wooden piles, revealing an undisturbed cultural layer containing prehistoric pottery, superimposed by a layer of peat and wood. The first site survey (**Appendix I**) was also conducted in 2008, documenting all the excavated units, peat platform and 34 wooden piles protruding from the seabed on the north-western ridges of what was later identified as a submerged karstic sinkhole (Benjamin et al. 2011a:195; Koncani Uhač 2008:397, 2009:265). Although this unit was initially marked with the number 6, a more recent publication dedicated to the analysis of the pottery found on the site refers to it as Unit 1 of the submerged prehistoric settlement (Koncani Uhač and Čuka 2015), a convention continued in this thesis (**Figure 12**).

Image removed due to copyright.

Figure 12 The position of the peat platform (6) and units (1–5) excavated on the submerged prehistoric pile-dwelling in Zambratija Bay between 2008 and 2015. The green dots indicate clusters of georeferenced piles protruding from the seabed. The 2001 attribution to Unit 2 is a typing mistake (Image: Koncani Uhač and Čuka 2015).

One wooden pile was completely excavated from Unit 1, revealing traces of wood shaping technology, with a tapered base to allow for ease of placement into the natural ground (**Figure 13**). As seen in Figure 15, the deteriorated end on the left was protruding from the seabed, while the end on the right still has visible traces of wood technology where it has been sharpened in order to be pushed into the sediment. The pile was then stored in the AMI laboratory until 2011, when a small sample taken from its surface was sent for radiocarbon dating, revealing an age of 5260 ± 30 BP, calibrated to 4230–3980 Cal BC (Beta-296187) (**Figure 14**) (Koncani Uhač and Čuka 2015:28).

Image removed due to copyright.

Figure 13 A wooden pile taken from the seabed in Unit 1 (Photo: M. Čuka).

Lab Reference	Uncalibrated ^{14}C Age	Calibrated Age	Probability	Location	Year	Sample description
Beta-296187	5260 ± 30 BP	4230–3980 Cal BC	95%	Unit 1, Layer 02	2008	Wood

Figure 14 The initial radiocarbon date from Zambratija Bay (Koncani Uhač and Čuka 2015).

Further excavations and surveys followed in 2011, for the purposes of defining and marking more piles (**Figure 12 in green**) as well as determining the outer limitations of the settlement. Unit 2 (**Figure 12:2**) was positioned on the western edges of the submerged sinkhole and the peat platform, and it did not contain any determinable archaeological remains. In 2012, as requested by AMI, an underwater surveying company (Harpha Sea d.o.o. from Koper, Slovenia), conducted a bathymetric survey of the bay (**Figure 15**). The hydrographic survey resulted in a recorded relief of the seabed with its elevations across the bay, providing the data necessary to reconstruct Zambratija's submerged paleo-landscape (Koncani Uhač and Čuka 2015:30). A submerged karstic sinkhole was clearly recognisable in this data. The hydrographic data was later overlayed with the geodetic survey revealing the previously recorded wooden piles, which were clearly located around the outer, elevated edges of the submerged feature.

The last archaeological excavation campaign at the Zambratija submerged settlement, before the research undertaken for the purposes of the present study, took place in 2014, when three more units (Unit 3, 4 and 5) (**Figure 12:3, 4, 5**) were excavated on different parts of the submerged sinkhole to further determine the site's archaeological and environmental stratigraphy, as well as to record additional piles. This was also the year when the author participated in the archaeological research of the site. Out of the three units, only the layers from Unit 5 contained typologically determinable archaeological remains (Koncani Uhač and Čuka 2015:33).

Image removed due to copyright.

Figure 15 A bathymetric image of Zambratija Bay showing the submerged relief. The square marks the position of the Roman Villa and the embankment, which were the initial reason for an archaeological prospection of the bay. The circle marks the position of the submerged karstic sinkhole. Image used and modified by the author with permission from the Archaeological Museum of Istria in Pula (AMI).

During the time between 2008 and 2015, additional archaeological investigations were conducted with a focus on the other two underwater sites found in Zambratija Bay. The remains of a Bronze Age wooden boat (**Figure 16**) were documented and investigated in multiple occasions between 2008 and 2013 (Boetto et al. 2015; Koncani Uhač et al. 2017a; Koncani Uhač and Uhač 2012), eventually resulting in an exhibition (Koncani Uhač et al. 2017a) and a partial reconstruction of the boat. Two units were excavated on the sides of the submerged Roman road in 2015 (**Figure 17**). During that campaign, all three sites were documented with drone aerial photographs which resulted with a photomosaic of the bay (**Figure 18**).

Image removed due to copyright.

Figure 16 The Bronze Age boat found in Zambratija Bay (Photo: AMI).

Image removed due to copyright.

Figure 17 Submerged roman road located in the near vicinity of the submerged prehistoric site in Zambratija Bay (Photo: I. Koncani Uhač).

Figure 18 A photomosaic of the underwater archaeological sites in Zambratija Bay: Bronze Age boat (1), Roman Road (2) and peat platform (3). (Photo: J. Benjamin, modified by K. Jerbić).

As presented above, the 2008–2015 surveys conducted on the site led to three different sets of data—a bathymetric map (**Figure 15**), georeferenced positions of archaeological and environmental features (**Appendix I**), and aerial photographs with which to create a photomosaic (**Figure 18**). For the purposes of this thesis, these datasets have been digitally overlayed to complement and cross-reference each other. The results were then used to better understand the geomorphological and environmental properties of the bay, and as a spatial reference for all excavated units, marked wooden piles and the peat platform. These datasets and the published archaeological material culture from the site, presented in the next section, form the foundational data of this thesis.

Artefact typology and comparative age determinations

A total of 727 ceramic fragments were collected from around the site and in archaeological units, all showing typological resemblance to already known prehistoric fragments in the Istrian region, out of which 294 were determined as parts of vessels, such as rims and handles (Koncani Uhač and Čuka 2015:35). Out of those 294, 29 fragments were recognised as material culture attributed and compared to known prehistoric complexes in the Istrian Peninsula, ranging from the Late Neolithic/Early Copper Age to the Bronze Age (Koncani Uhač and Čuka 2015). The age of material culture determined here was presumed by comparative correlation of the Zambratija fragments to typological similarities found at other archaeological sites, where stratigraphically closed contexts and reliable radiocarbon determinations provided dates. These correlations were drawn through a review of literature regarding archaeological research on the Istrian Peninsula. According to the researched literature, the Late Neolithic/Early Copper Age–Bronze Age range on the Istrian Peninsula covers a timespan between 4252 Cal BC (Forenbaher et al. 2013:592; Jerbić Percan 2011:7) and 901 Cal BC (Hänsel et al. 2005:22). Although representing a large 3000-year timeframe, a part of the Zambratija ceramic assemblage from contextualised layers in units 1 and 5 show a resemblance to a recognisable style called Nakovana-style, discussed in more detail in Chapter 4, which in the Eastern Adriatic represents the end of Neolithic and the start of Early Copper Age (Forenbaher 1999–2000). On the Istrian Peninsula, Nakovana-style pottery is found in contextualised layers covering a radiocarbon age range between 4252–4048 and 3959–3797 Cal BC (Forenbaher et al. 2013:592). Together with the 4230–3980 Cal BC radiocarbon date from Zambratija, the Nakovana-style ceramics set the beginning of occupation of the submerged settlement to the Early Copper Age.

Other traces of material culture, such as 45 knapped flint tools excavated from Unit 5 (Koncani Uhač et al. 2017b) (**Figure 19**), and stone artefacts such as grinding stones and whetstones scattered around the seabed (Koncani Uhač and Čuka 2015:33) (**Figure 20**) were also documented, but have not yet been published[3]. Other types of archaeologically significant finds included terrestrial and aquatic faunal bones, and botanical remains, which have also not yet been analysed in more detail (Koncani Uhač and Čuka 2015:28; Koncani Uhač et al. 2017b).

[3] The typological determinations presented in the thesis were obtained through personal communication with Darko Komšo, and have so far only been published as a part of a conference poster by Koncani Uhač, I., K. Jerbić, M. Čuka and D. Komšo 2017b *Investgating Prehistory - A Multidimensional Approach to a Submerged Prehistoric Site in Croatia*. Nicosia, Cyprus.

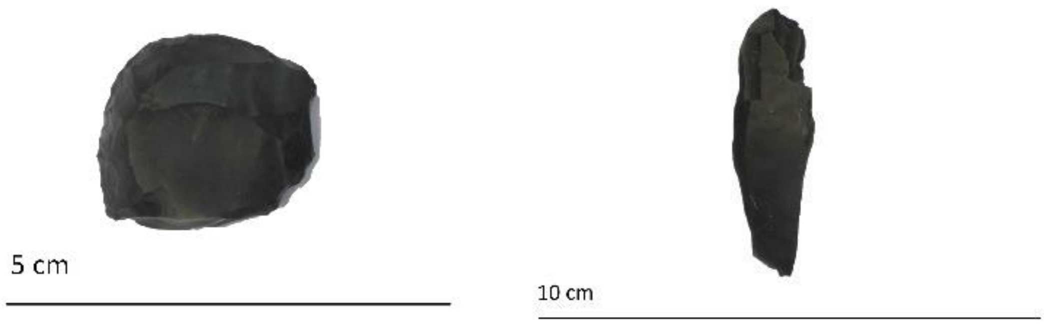

Figure 19 A chert scraper (left) and blade (right) found in Unit 5 Layer 02 (Photos: M. Čuka, modified by K. Jerbić).

Figure 20 A fragment of a grinding stone on the seabed in Zambratija Bay (Photo: J. Benjamin)

The ceramic fragments are presented here as photographs and as drawings. In the section below which is describing the typological characteristics, such as surface rendering (polished, brushed or plain), colour and decoration, fragments are presented as photographs. In the following section, which is describing the stratigraphic contexts, the fragments are presented as drawings, in order to include them in the drawings of the stratigraphical contexts later in the chapter.

General Neolithic to Bronze Age determination 1: Brushed surface ceramics

A total of 13 determinable fragments of the Zambratija pottery assemblage is decorated or stylised with brushed surface decoration on the outer and/or inner side of the wall (**Figure 21**).Three were a part of the surface find assemblage (**Figure 21:1–3**), five were found in Layer 02 of Unit 1 (**Figure 21:4–8**) and five were found in Layer 02 of Unit 5 (**Figure 21:9–13**). The intensity of the surface brushing technique varies from sherds with a dense or sparse distribution of 'streaked' lines, ranging from those more firmly impressed and clearly visible to those that can hardly be seen. The pottery fabrication contains visible specks of quartzite and the brush strokes are irregular in their density and the force of surface impression. The impressions appear to have been executed with a brush or an object that could leave a similar trace. This style of surface treatment is often described as resembling wicker baskets (Buršić-Matijašić 1994:251). Out of the 13 fragments, eight are overlaid with further decorations, effectively making the brushed surface a background (**Figure 21:1, 3, 4, 8, 9, 11–13**), which is a regular stylistic addition to brushed surface ceramics on other known sites (Buršić-Matijašić 1994:247).

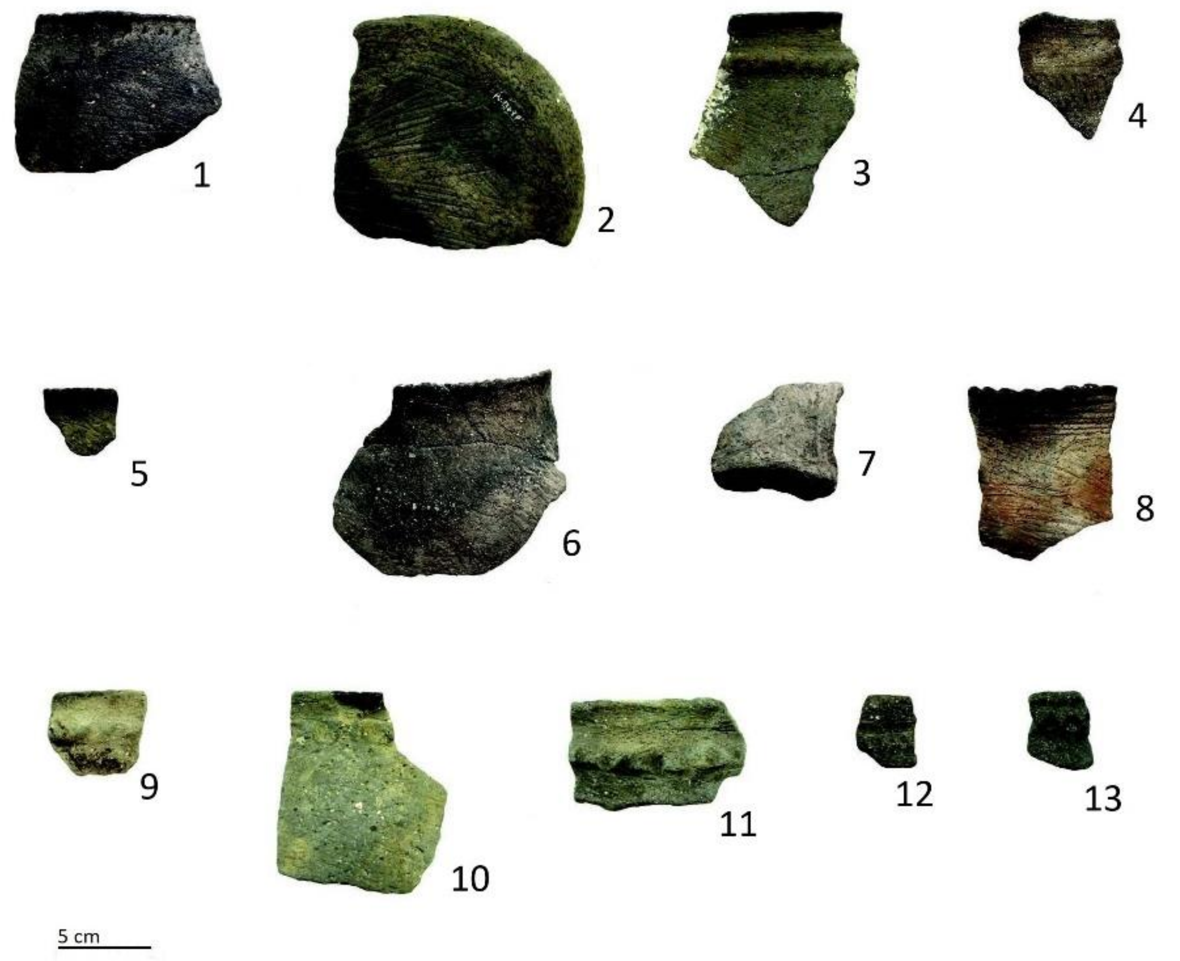

Figure 21 Brushed surface pottery found in Zambratija Bay from the seabed surface (1–3), Layer 02 in Unit 1 (4–8) and Layer 02 in Unit 5 (9–13) (Modified after Koncani Uhač and Čuka (2015)).

In Istria, comparable brushed surface ceramic fragments similar to those from Zambratija were also found in Jačmica (Jerbić Percan 2011), and Srbani (Čuka 2009) caves, as well as the open-air site of Sveti Mihovil (Zlatunić 2007) where they have been attributed to a range of prehistoric periods from the Neolithic to the Middle Bronze Age. The lack of presence in the periods following the Middel Bronze Age makes brushed surface ceramics a low resolution, but certain indicator of prehistory in stratigraphic contexts (Buršić-Matijašić 1994).

General Neolithic to Early Bronze Age determination 2: Ceramic funnels with perforated walls

The pottery assemblage included several dark grey and black funnels with perforated walls, identified as strainers or sieves (**Figure 22**). These fragments were found in Unit 1, Layer 02 (**Figure 22:1, 2**), and Unit 5, Layers 01 (**Figure 22:3**) and 02 (**Figure 22:4, 5**).

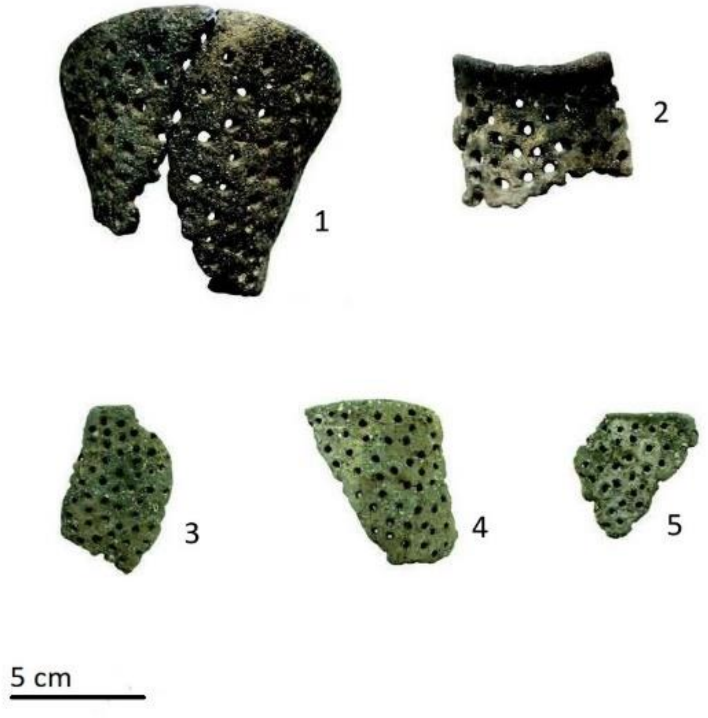

Figure 22 Fragments of black and dark grey ceramic funnels with perforated walls from Layer 02 in Unit 1 (1, 2), Layer 01 in Unit 5 (3) and Layer 02 in Unit 5 (4, 5). Fragments 4 and 5 were a part of the same vessel, which can be visible in the drawing presented on Figure 37:7 (Modified after Koncani Uhač and Čuka (2015)).

The strainers are considered as parts of sets for milk processing for making cheese, and/or for straining beverages produced by soaking and fermenting grains, fruit or milk (Evershed et al. 2008; McClure et al. 2018:2). Similar strainers were also found locally in the Neolithic layers of the Laganiši cave, in Middle and Late Bronze Age context of the Vaganačka cave (Koncani Uhač and Čuka 2015) and at Sveti Mihovil (Zlatunić 2007, 2008), where they were dated to the Bronze Age. The nature of the strainers and association with the process of making cheese (McClure et al. 2018:2) and beverages, together with the finds of grinding stones and whetstones indicates the nature of the site being closely connected with the domestication and use of plants (Hamon 2008) and animals (Evershed et al. 2008).

General determination to prehistory with probable attribution to Early Copper Age: Ceramic spindle whorls

Four round, flat ceramic circular objects with a hole in the middle were identified as spindle whorls (**Figure 23**), which were most likely parts of spindles that served to achieve fast and stable rotation in the process of textile production (Barber 1992:51; Hulina et al. 2011:152). Two were found on the seabed surface (**Figure 23:1, 2**), and two in Unit 5 (**Figure 23:3, 4**). Comparable fragments were found on the Javorika-Gromače open-air site (Vitasović 1999), Laganiši cave (Komšo 2008) and Pupićina cave (Forenbaher and Kaiser 2006; Hulina et al. 2011:150), where they unfortunately all appear in disturbed layers ranging from the Early Copper Age to the Bronze Age. However, spindle whirls were found in contexts containing the Early Copper Age Nakovana-style ceramics (see below) in Vela spila on Korčula island in southern Dalmatia (Čečuk and Radić 2005:227).

Figure 23 Ceramic spindle whorls found in Zambratija Bay on the seabed (1, 2) and in Unit 5 (3, 4) (Modified after Koncani Uhač and Čuka (2015)).

Late Neolithic/Early Copper Age determination: Nakovana-style

Amongst the typologically identifiable pieces found on the seabed surface, as well as in contextualised layers of Unit 1 and Unit 5 (**Figure 24**), were three decorative and three functional fragments attributed to the Nakovana-style pottery with comparable fragments found in layers containing ceramics from the Neolithic to the Bronze Age in Istria. The presumed origins and development of the Nakovana-style pottery, which is a Late Neolithic/Early Copper Age cultural complex found on the Eastern Adriatic (Forenbaher 1999–2000), will be discussed further in depth in Chapter 4. The decorative fragments consist of black bowls with a polished, shiny surface whose preserved shape lines indicated rounded bellies, slightly constricted necks and flared rims. Their outer wall surfaces were decorated with very discrete and sophisticated vertical channelled lines that vary in length and width (**Figure 24:1–3**). The fragments with functional typological determination consist of sub-surface lugs (**Figure 24:4–6**). Both of these stylistic and functional characteristics are well-known Nakovana-style features that have been found in contextualised Early Copper Age layers across the Eastern Adriatic, including Istria (Forenbaher 1999–2000:373).

Figure 24 Ceramic fragments from Zambratija determined as Nakovana-style pottery from the seabed surface (1), Layer 02 in Unit 1 (2, 3) and Layers 01 (4,5) and 02 (6) in Unit 5 (Modified after Koncani Uhač and Čuka (2015)).

In Istria, fragments with decorative and functional traits attributed to the Late Neolithic/Early Copper Age were found in the cave sites at Laganiši (Komšo 2008:11), Jačmica (Jerbić Percan 2011:20), Novačka and Pupićina (Forenbaher and Kaiser 2006:186), as well as the open air sites at Javorika-Gromače (Vitasović 1999:30) Kargadur (Čuka 2009:19; Komšo 2007:260) and Sveti Mihovil (Zlatunić 2008) (**Figure 25**). Three of these sites, Jačmica and Pupićina caves, had Nakovana-style pottery in contextualised stratigraphic contexts covering a radiocarbon dated range between 4252–4048 Cal BC, 4229–3800 Cal BC and 3959–3797 Cal BC respectively (Forenbaher et al. 2013:592).

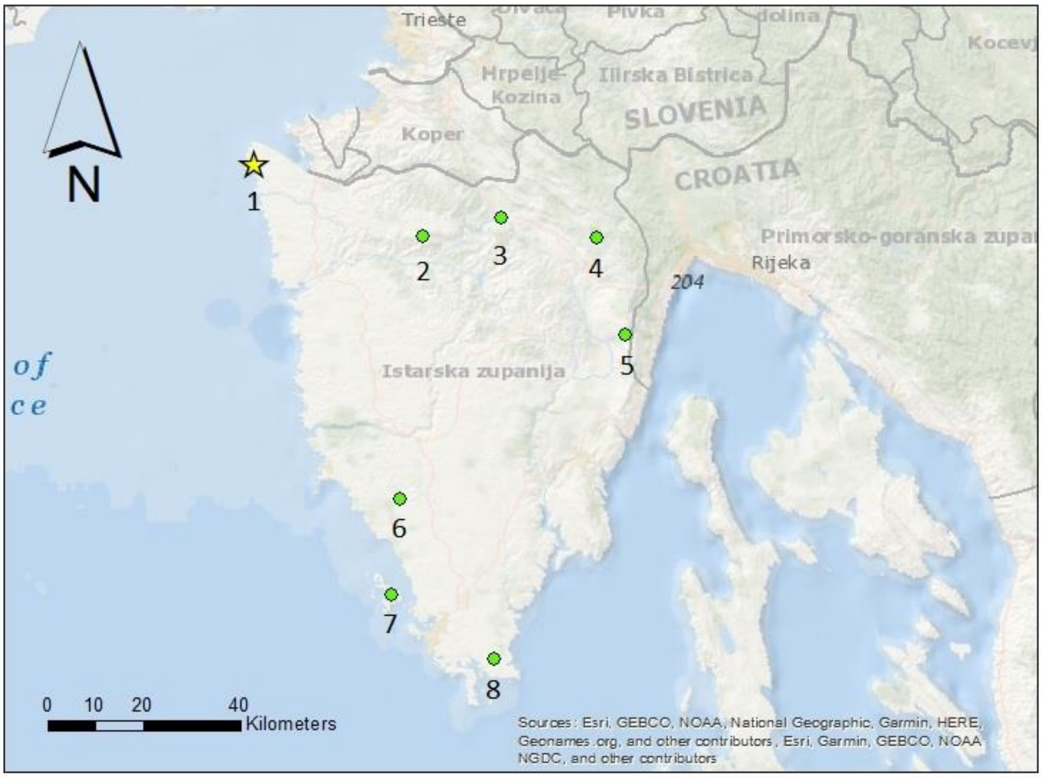

Figure 25 The location of Zambratija Bay (1) in relation to the known sites with stratigraphic contexts containing Nakovana-style pottery on the Istrian Peninsula: caves Laganiši (2), Jačmica (3), Novačka (4) and Pupićina (5); open air sites Sveti Mihovil (6), Javorika-Gromače (7) and Kargadur (8).

Bronze Age determination: triangular handle

Part of the ceramic assemblage from Zambratija can typologically be attributed to the Bronze Age. The aforementioned five fragments of strainers come from a context that dates beyond the Bronze Age and they represent a general proxy for a wider range of prehistory. One surface find, however, although without supporting context, is highly recognisable as a definite representative of the Istrian Bronze Age and together with evidence presented below indicates likely scenarios. The seabed surface finds in Zambratija may have been carried there by erosion from the nearby Bronze Age Romanija hillfort (Buršić-Matijašić 2007; Marchesetti 1903), or from an unknown Bronze Age site nearby. It is also possible that the settlement was in use, with occupational hiatuses, for an extended period of time, such is the case with a large number of pile-dwellings around the Alpine lakes (Menotti 2004a:210). This hypothesis can also be supported by the finding of the Bronze Age boat in the vicinity of the submerged site (Boetto et al. 2015; Koncani Uhač et al. 2017a; Koncani Uhač and Uhač 2012), which has been radiocarbon dated to 1120–930 Cal BC (Koncani Uhač and Uhač 2012:534). Potential future investigations should therefore incorporate the broader terrestrial areas around the settlement to check the validity of these hypotheses.

The surface find from Zambratija was recognised as a Bronze Age triangular handle (**Figure 26**), with 541 similar comparable specimens found on the Monkodonja hillfort, typologically attributed to the Bronze Age (Buršić-Matijašić 1998:66-68) which in Istria roughly covers a 1900–900 Cal BC timeframe (Buršić-Matijašić 1998:34). This timeframe was confirmed in Monkodonja with 18 Bronze Age radiocarbon dates ranging in age from 2135–1922 to 1040–901 Cal BC (Hänsel et al. 2005), and partially overlaps with the aforementioned radiocarbon date from wood sampled from the Bronze Age boat.

Figure 26 Bronze Age triangular handle found on the seabed surface in Zambratija Bay (Modified after Koncani Uhač and Čuka (2015)).

An overview of known environmental and archaeological contexts

During the investigations of the submerged prehistoric site, archaeologists recovered material culture and archaeologically significant environmental finds. The material culture can be categorised into the permanently in situ remains consisted of a peat platform and wooden piles, and the movable small remains consisted of ceramic and stone artefacts, as well as the paleo-botanical and paleozoological remains found scattered around the seabed and in the layered contexts of the excavated units. The scattered seabed finds were collected for preliminary typological determination, after which the data was used to determine suitable positions for archaeological units (Koncani Uhač 2008:397, 2009:266). This practice was stopped after 2011 due to the vast number of artefacts, terrestrial faunal bones and botanical remains without archaeological context (Koncani Uhač 2017 pers. comm.). Nevertheless, they represented a valuable dataset for preliminary typological attribution of the site to prehistory and were the primary reason for the instigation of a series of systematic underwater archaeological investigations and surveys.

Seabed surface – peat platform, wooden piles and pottery

The peat platform (**Figure 27**) is located above a clay seabed surface (**Figure 28**) and covers an area of around 30 by 67 metres, oriented roughly northeast–southwest. The original digital drawings (**Appendix I**) indicate that the upper surface of the peat is at around -2.70 MSL and placed on a seabed surface at around -3.20 MSL. Although the preserved shape is irregular, it indicates a relatively rectangular form spreading across the north-western shallow edges around the submerged sinkhole. Clay plaster fragments was found around the peat platform, and together with the architectural distribution of the surrounding wooden piles implied that these remains might represent dwellings (Koncani Uhač and Čuka 2015:27). So far, 100 wooden piles, identified either as superficially protruding or excavated in the units, were marked on the site. According to digital data, their preserved heights appear from -2.98 to -3.12 MSL.

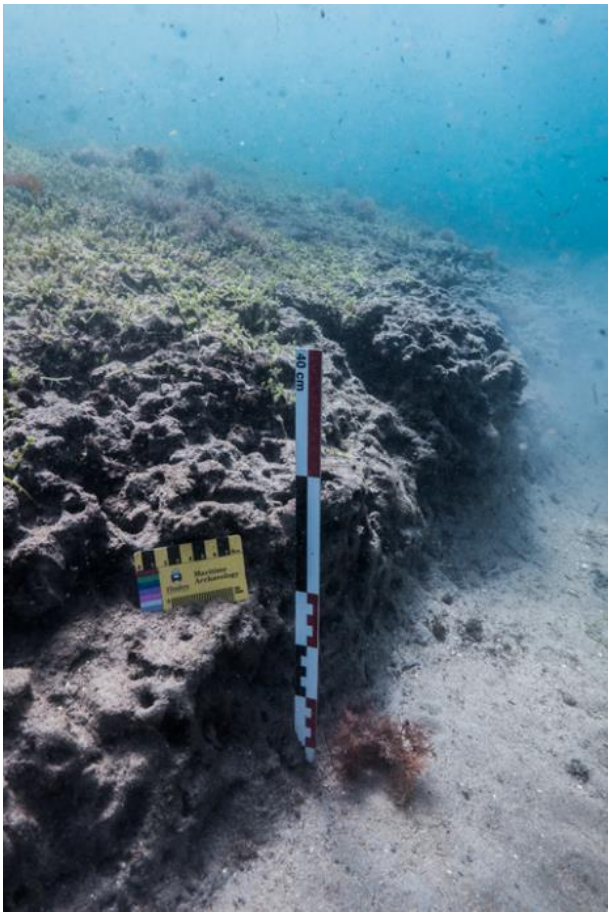

Figure 27 The submerged peat (Photo: J. Benjamin).

A single pile that was taken out for analysis at the time was identified as oak (*Quercus L.*) (Koncani Uhač and Čuka 2015:27). All piles marked to date are located around the outer edges of the submerged sinkhole that is naturally protected from the open sea with limestone ridges locally known under the toponyms 'Škoj' and 'Zanestra' shallows (Koncani Uhač and Čuka 2015:27).

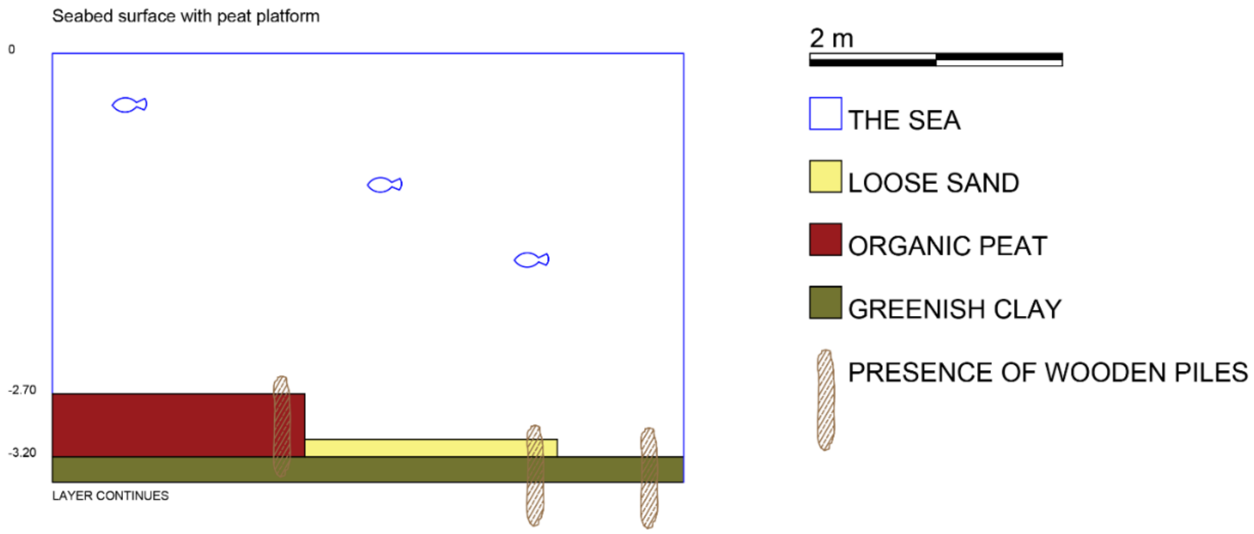

Figure 28 A schematic representation of the seabed surface around the peat platform.

Out of the ceramic surface finds and based on cross-referencing with other known sites presented in the sections above, seven (**Figure 29**) could be typologically referenced to other known prehistoric sites on the Istrian Peninsula, based on their shape, function or decoration.

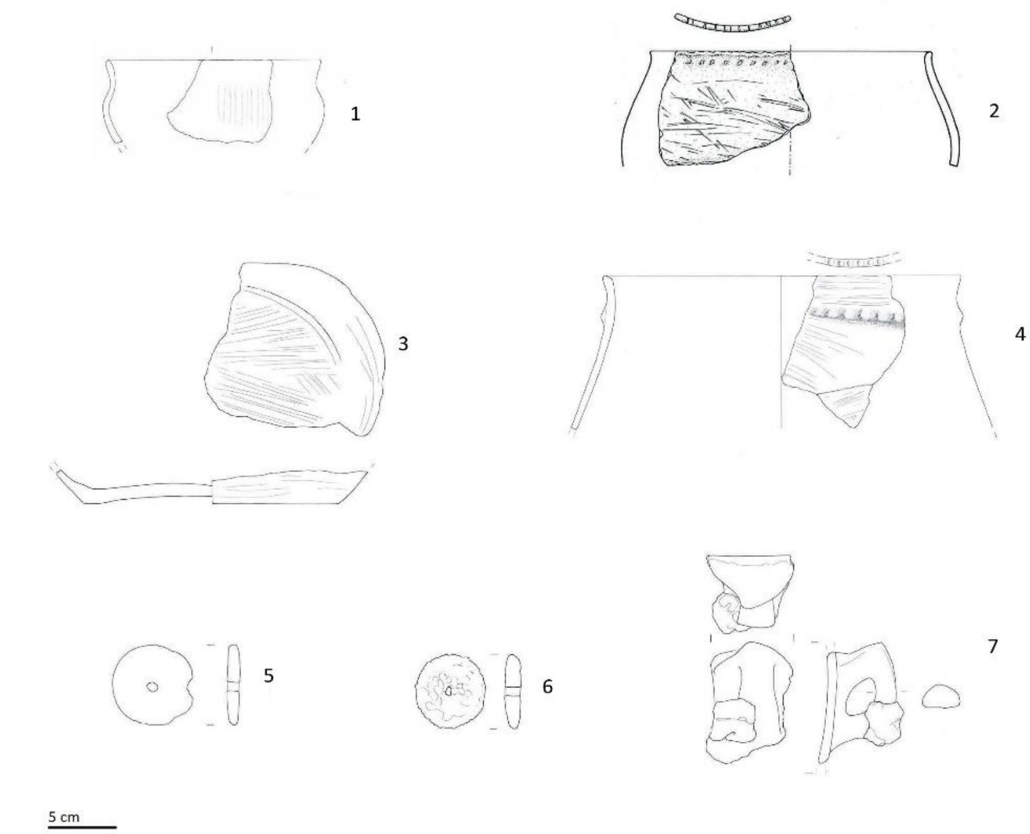

Figure 29 Typologically determinable surface ceramic finds from Zambratija Bay: Nakovana-style (1), brushed surface ceramic fragments (2–4), spindle whorls (5–6), Bronze Age handle (7) (Modified after Koncani Uhač and Čuka (2015)).

Typologically, the oldest individual ceramic found on the surface of seabed is classified as a Nakovana-style fragment (**Figure 29:1**). The discovery of two ceramic spindle whorls (**Figure 29:5–6**) indicate a definite attribution to prehistory and represent probable Copper Age proxies. Three brushed-surface ceramic fragments (**Figure 29:2–4**) indicate a timespan between the Late Neolithic and Early Bronze Age (Koncani Uhač and Čuka 2015:41), and the one triangular handle (**Figure 29:7**) shows that the settlement persisted as late as the Middle Bronze Age (Koncani Uhač and Čuka 2015:37). With regard to the remaining surface finds, the archaeologists recognised terrestrial faunal remains, bones and antler, as well as grinding stones, which are known to be used in Europe since the Early Neolithic (Hamon 2008).

Unit 1

Unit 1 of the submerged prehistoric site, originally named as Unit 6 of the Zambratija Bay sites (Koncani Uhač 2008:398, 2009:265) but later on referred to as Unit 1 of the Zambratija Bay submerged pile-dwelling site (explained in detail on page 21–22) (Koncani Uhač and Čuka 2015:29), was excavated during the first archaeological campaign, which was conducted to investigate and confirm the three newly discovered underwater sites. The unit was placed in an area with a dense concentration of wooden piles, on the eastern edges of the submerged sinkhole. The initial dimensions were two by two metres, but due to time restrictions of the excavation permit and large amounts of archaeological finds, it was reduced to two by one metres in size to maintain the quality of the investigation (Benjamin et al. 2011a:195; Koncani Uhač and Čuka 2015:29).

The vertical stratigraphy of the unit (**Figure 30**) begins with a topmost layer of loose sand and seagrass with visible wooden piles protruding on its surface at a depth of -2.36 m MSL. This layer is marked in the image as Layer 1. At the depth of -2.50 m MSL, a muddy grey layer occurred between and around the piles, which were still firmly placed in the subsurface. This new layer, marked as Layer 2, was composed of compact grey, silty sediment, and contained small stones, shells, animal bones and pottery. Nine typologically identifiable fragments of pottery were found in Layer 2 (**Figure 31**). They were all similar in shape and form compared to the fragments found on the surface. These were found, however, in an archaeologically and geologically documented context. Two of the fragments belonged to the black, shiny, channelled 'Nakovana-style' pottery, attributed to the Late Neolithic/Early Eneolithic period (**Figure 31:1–2**). They were situated with five fragments of brushed-surface pottery (**Figure 31:3–7**), with typological analogies on the Istrian Peninsula mostly attributed to the period between the Early Neolithic to the Early Bronze Age. Two fragments of perforated funnels were also found (**Figure 31:8–9**), with comparable fragments found in layers containing ceramics from the Neolithic to the Bronze Age in Istria. This layer also revealed several other wooden piles, one of which was removed from the sediment for wood species and radiocarbon analyses. Layer 2 has been investigated to its lower level, where a layer of peat and wood emerged at a depth of -3.09 m MSL, marked as Layer 3, where the excavations ended (Benjamin et al. 2011a:195; Koncani Uhač and Čuka 2015:31).

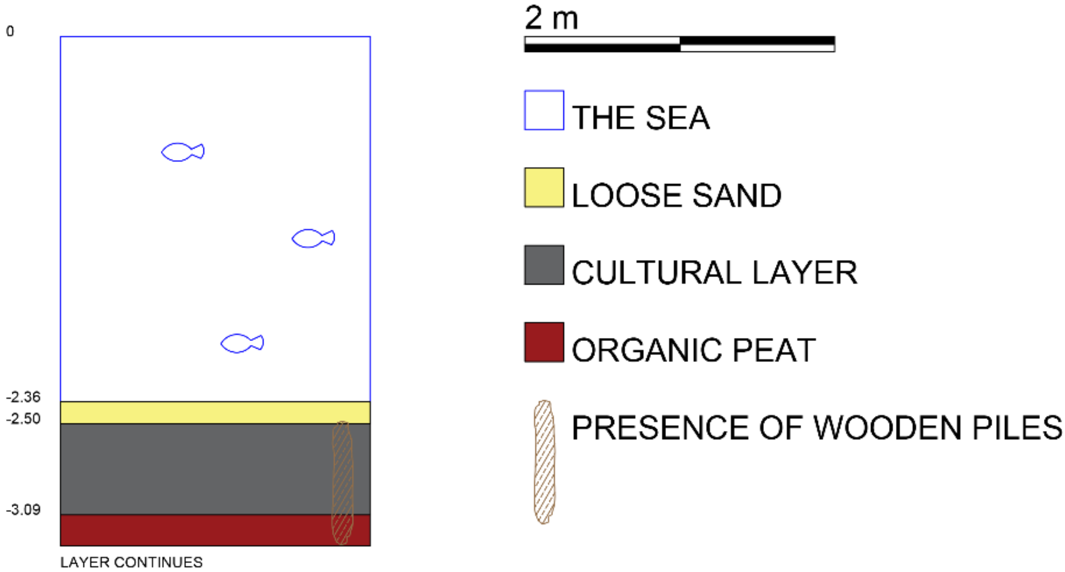

Figure 30 A schematic representation of Unit 1.

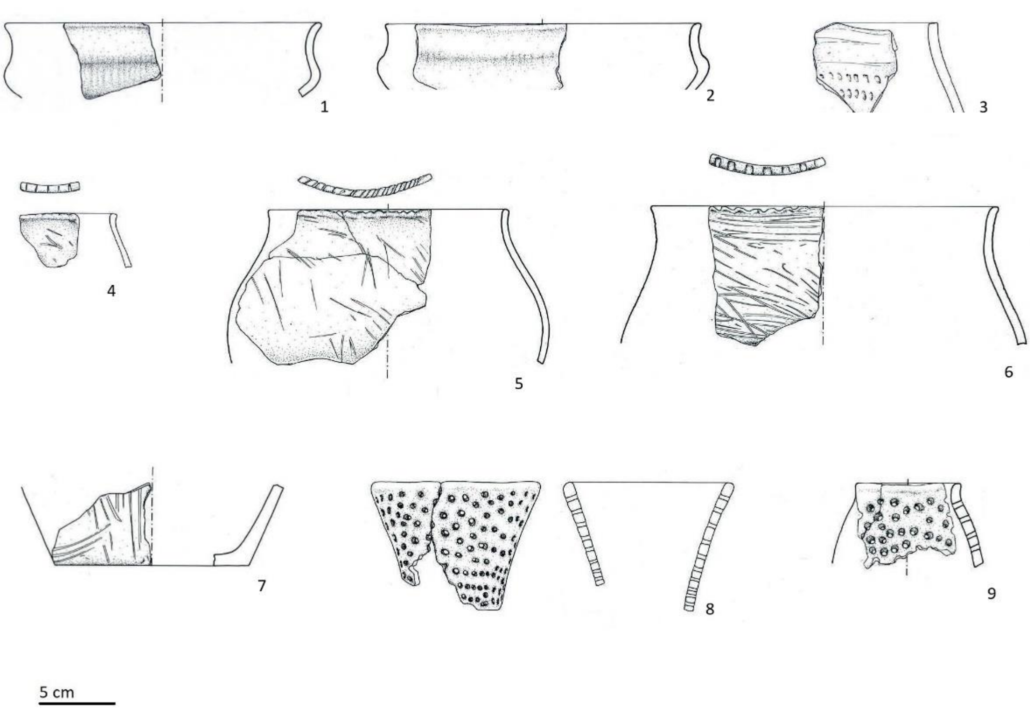

Figure 31 Typologically determinable ceramic fragments from Unit 1 Layer 2. Nakovana-style (1–2), brushed surface ceramic fragments (3–7), perforated funnels (8–9) (Modified after Koncani Uhač and Čuka (2015)).

Unit 2

Unit 2 was strategically positioned on the presumed north-western extent of the settlement to determine the western spatial limitations of the site. The results of this investigation confirmed the initial presumption about the preserved peat platform being an integral part of the Prehistoric pile-dwelling and situated on its outer margins. This conclusion was made based on the horizontal stratigraphy of the site area, now also visible in the high-quality aerial photos. The outer north-western margins of the platform also represent the extents of the spread of wooden piles and scattered archaeological material and mark the beginning of a sandy marine, archaeologically sterile sediment which further continues into deeper waters outside the bay. Unit 2 did reveal a layer of peat underneath the sand, however, making the peat an environmental feature of the bay the extents of which have not yet been determined.

The 0.5 x 0.4 m unit was placed in an area with no visible piles and it did not contain material culture. Its vertical stratigraphy (**Figure 35**) starts at -2.45 m MSL with a thin layer of loose sand and seagrass, marked on the image as Layer 1. A layer of peat marked as Layer 2 was found under the sandy surface, at a depth of -2.55 m MSL. As opposed to Unit 1, Unit 2 did not have a cultural layer between the sandy surface and the peat and was archaeologically sterile. The peat layer stops with a sharp transition at -2.68 m MSL, revealing a greenish-yellow clay sediment, marked as Layer 3, where the excavations ended (Koncani Uhač and Čuka 2015:32).

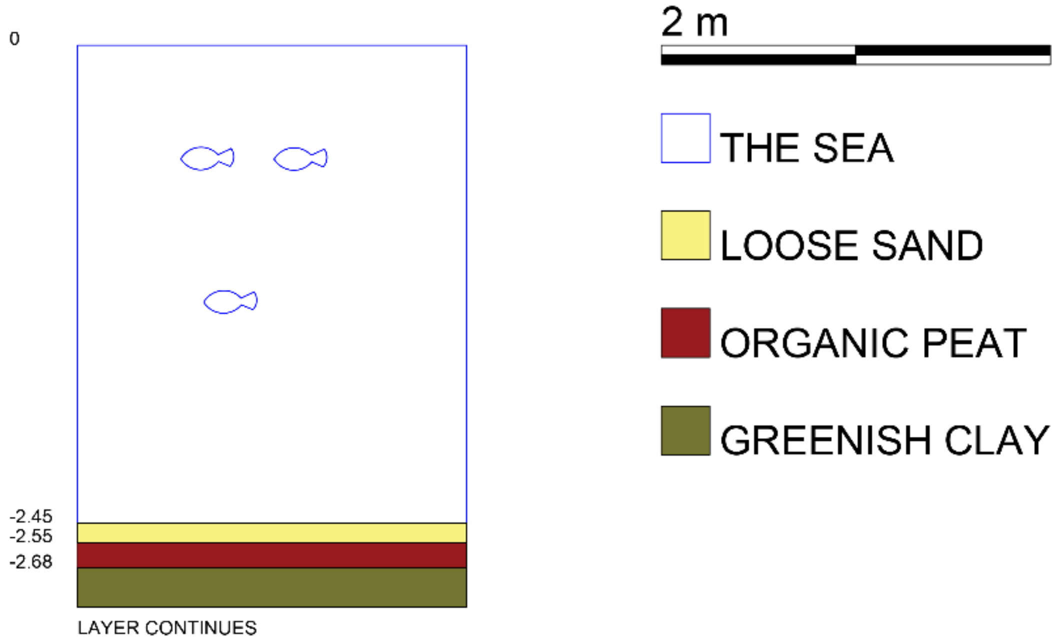

Figure 32 A schematic representation of Unit 2.

Unit 3

Unit 3 was positioned on the north-western edge of the site, placed on the side of the peat platform facing towards the sinkhole. The seabed surface in this area was very densely covered with piles, six of which were inside the unit margins. The original dimensions of Unit 3 were two by two metres, but as in the case of Unit 1, these measurements were gradually reduced as the excavations continued. Therefore, each new layer surface of excavation was reduced by 50% of the size of the previous layer surface, starting with two by two and followed by two by one, one by one and one by 0.5 metres.

The vertical layering (**Figure 33**) started at -2.90 m MSL with a marine sandy surface with the six protruding piles, marked as Layer 1. A cultural layer marked as Layer 2, appeared below at -3.05 m MSL, containing shells, small stones, a bone of a terrestrial animal and a few typologically undeterminable pieces of pottery. This layer stops at -3.20 m MSL, again revealing a layer of organic peat without archaeological remains, marked as Layer 3. The peat layer ends with a sharp transition to a greenish-yellow clay sediment starting at -3.65 m MSL marked as Layer 4. Further investigations were undertaken by following the vertical line of one of the wooden piles pushed deeper into the clay sediments. They found the tapered end of one of the piles at -4.05 m MSL, which marked the end of the unit excavation, but not the end of the clay sediment (Koncani Uhač and Čuka 2015:33).

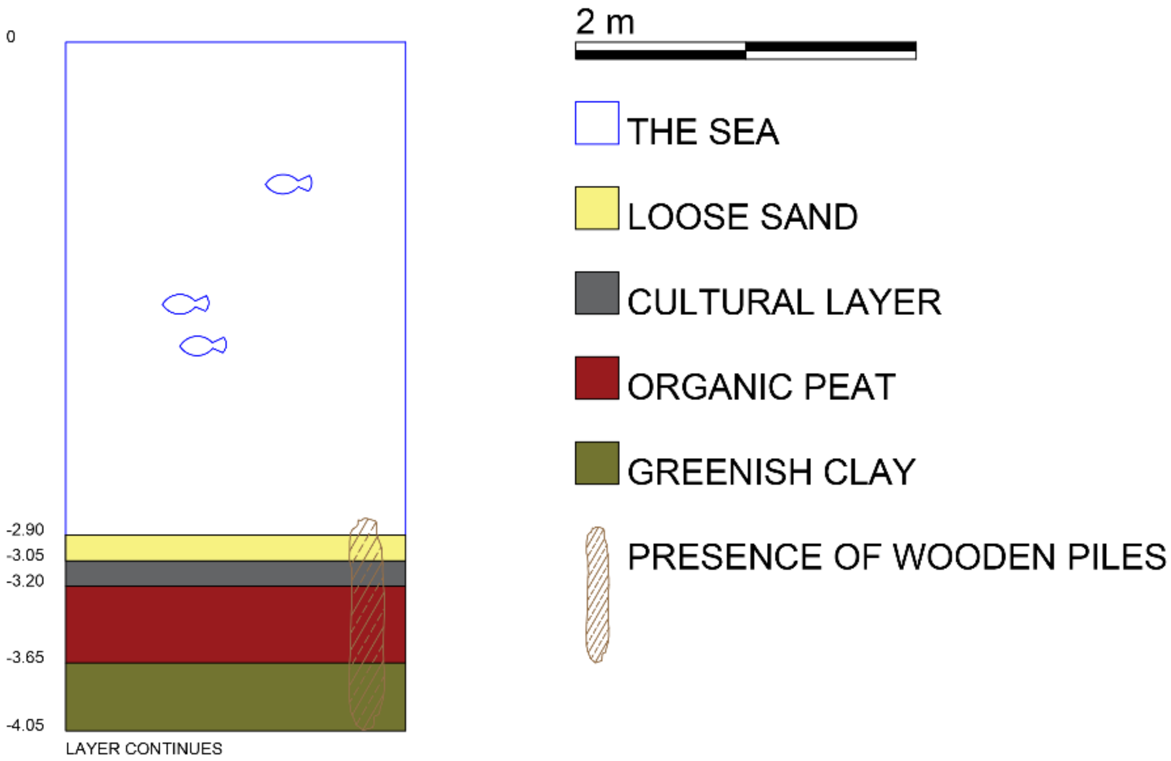

Figure 33 A schematic representation of Unit 3.

Unit 4

Unit 4 was positioned on the southeast side of the site, on the outer edges of the submerged sinkhole and in an area with a large concentration of surface finds. Its dimensions were two by two metres, and other than the finds without archaeological context, no other finds have been excavated from the layers. Only two layers were excavated, with the excavation surface of the lower one reduced to 0.5 by 0.5 metres.

Layer 1 was found at a depth of -2.62 m MSL and composed of loose sandy sediment, with some seagrass, shells and small and medium sized stones. It was also full of loose, non-contextualised archaeological finds which included typologically undeterminable prehistoric pottery, clay plastering, a whetstone and terrestrial animal bones, scattered around the unit area between the wooden piles. Layer 1 ended at -3.0 m MSL, when the stratigraphy changed to a layer of organic peat, called Layer 2. It was excavated until it sharply changed to a layer of greenish-yellow clay, which started at -3.17 m MSL, and that marked the end of the excavation of Unit 4 (**Figure 34**) (Koncani Uhač and Čuka 2015:33).

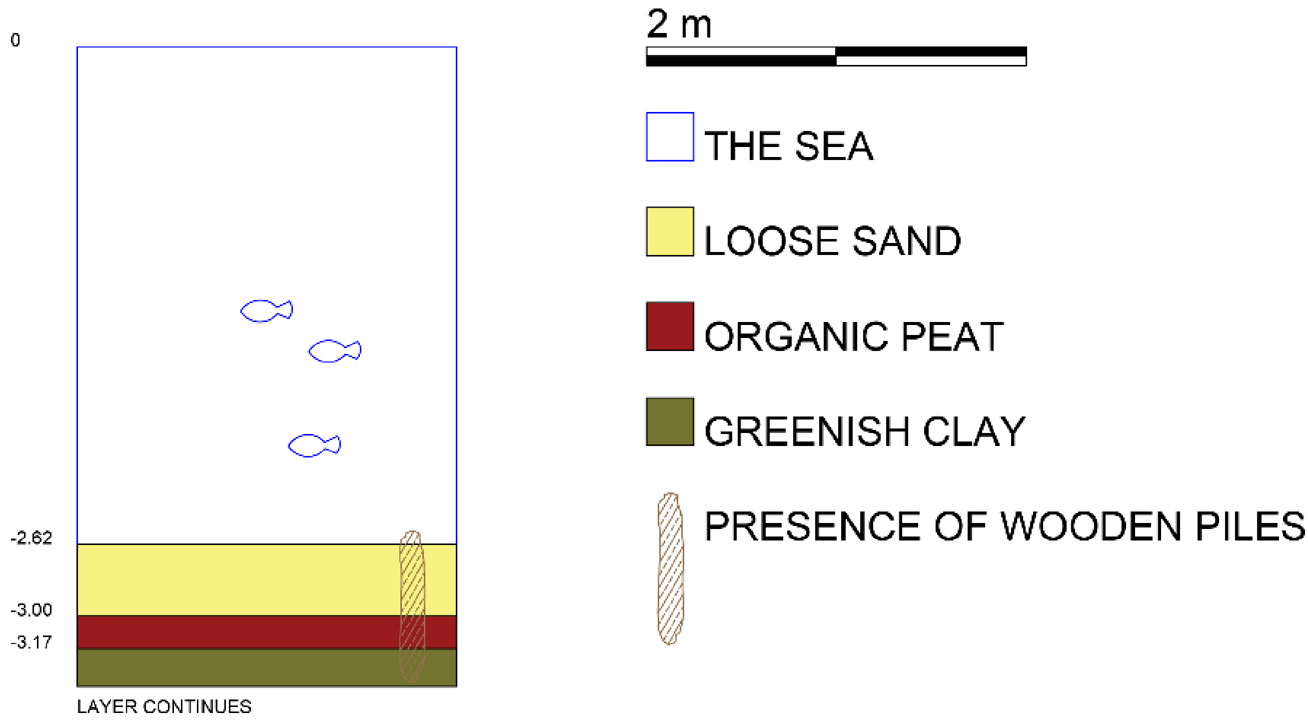

Figure 34 A schematic representation of Unit 4.

Unit 5

The last unit was placed on the southern edge of the submerged sinkhole, and its margins surrounded seven wooden piles, as well as pottery and animal bones scattered around the seabed surface. The excavations started inside a two by two metre area but were later reduced to a one by two metre investigation.

The surface layer, marked as Layer 1, started at -2.74 m MSL, and was composed of sand, seagrass, small stones and ceramics (**Figure 35**). Three typologically determinable pottery fragments were identified in this layer, which were two pieces of black, polished surface pottery sherds with preserved sub-surface lugs and a perforated funnel fragment (**Figure 36**).

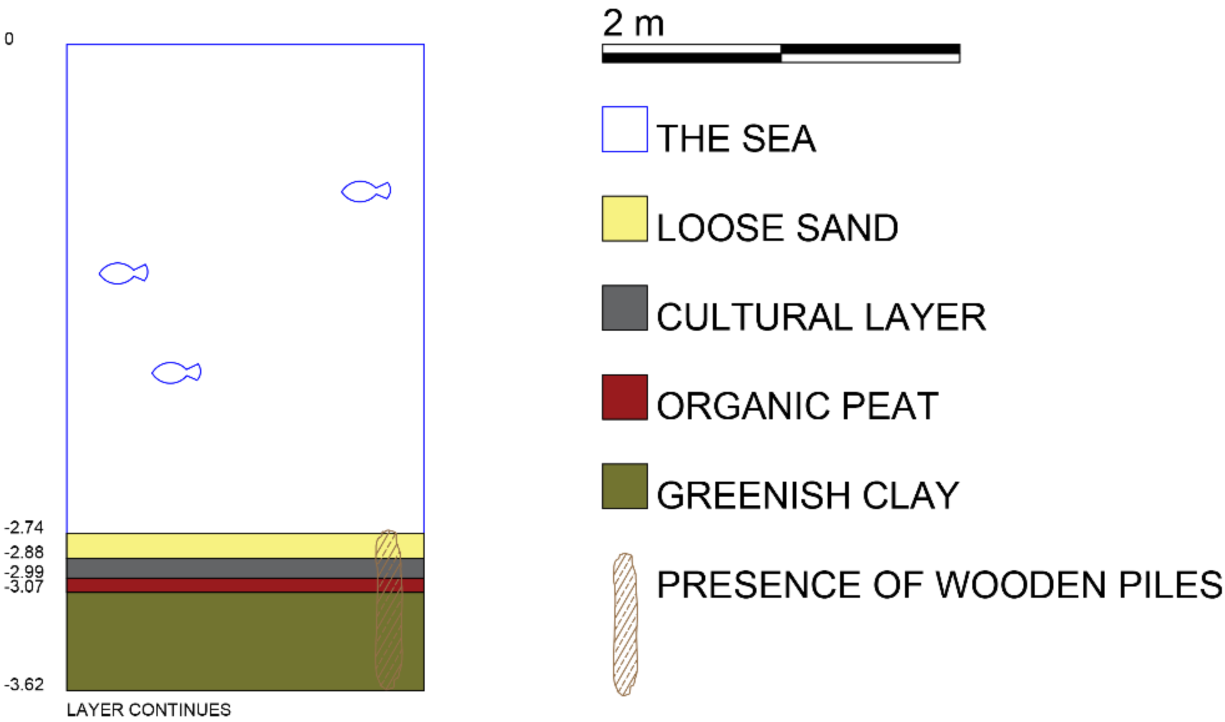

Figure 35 A schematic representation of Unit 5.

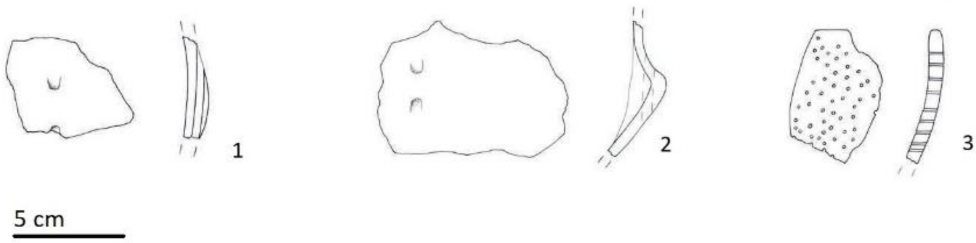

Figure 36 Typologically determinable ceramic fragments from Unit 5 Layer 1. Nakovana-style (1–2), perforated funnel (3).

At -2.88 m MSL, the surface layer was followed by compact silty sediment marked as Layer 2, containing small stones, organic material, animal bones, prehistoric pottery, ceramic plastering and lithics. Ten typologically determinable fragments of pottery were found in this layer (**Figure 37**), of which one was a sub-surface lug (**Figure 37:1**), five were brushed surface fragments (**Figure 37:2–6**), two were parts of one perforated funnel vessel (**Figure 37:7, 8**), and two were spindle whirls (**Figure 37:9–10**).

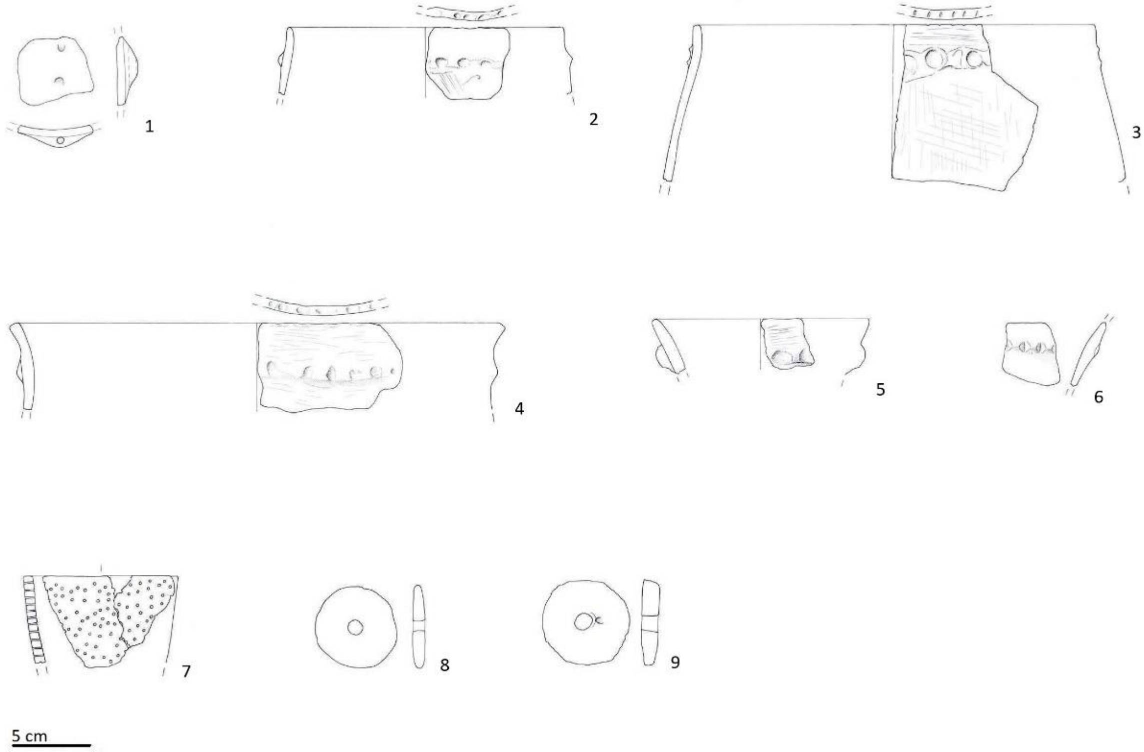

Figure 37 Typologically determinable ceramic fragments from Unit 5 Layer 2. Nakovana-style (1), brushed surface ceramic fragments (2–6), perforated funnel (7), spindle whorls (8–9).

An assemblage consisting of 45 knapped flint tools made from black imported chert, were also found in Layer 2. The lithic assemblage mostly consisted of flakes, and some non-prismatic blades. Typologically, the most common types of recognisable tools were scrapers and sickles, which are traditionally associated intensive vegetation cutting, and are a dominant typological find in the Adriatic settlements from the Neolithic onwards (Kaiser and Forenbaher 2016). According to Darko Komšo, an expert in Istrian prehistory and lithic assemblages (Komšo 2004, 2006, 2007, 2008; Komšo and Vukosavljević 2011), these shapes and tools are all indicative of Copper Age stone tool industry in the Istrian region (Komšo 2017: pers. comm.). This layer stops at -2.99 m MSL with a sharp transition to a compressed, organic peat with decayed plant and animal remains, marked as Layer 3. The peat stops again with a sharp transition to a greenish-yellow clay marked as Layer 4 at -3.07 m MSL, which was investigated to a depth of -3.62 m MSL. This depth marked the tapered end of one of the wooden piles rammed into the clay sediment, which is where the excavations stopped, but the clay sediment continued deeper (Koncani Uhač and Čuka 2015:35).

The results of a botanical analysis of seeds obtained from the peat in Unit 5 showed the presence of the aquatic plants alkali bulrush (*Scirpus maritimus L.*), hairy sedge (*Carex cf. hirta L.*), pondweed (*Potamogeton sp.*) and the water caltrop (*Trapa natans L.*), which are characteristic of natural wetland habitats, or wet meadows (Koncani Uhač and Čuka 2015:28).

A synthesis of known data

According to the presented archaeological and environmental evidence, the now submerged shallows of Zambratija Bay have been inhabited from at least Early Eneolithic to the times of Roman Classical Antiquity. A total of five units were excavated on the seabed in the location of the submerged settlement where a peat platform as well as 100 individual piles were recorded (Koncani Uhač and Čuka 2015:28). A combination of small and large finds, which include pottery, lithics and other stone artefacts such as grinding stones; animal bones, plant macrofossils, wooden piles and peat, together with the typological chronology and the one radiocarbon date, provide enough evidence to infer that this is a submerged Late Neolithic/Early Copper Age pile-dwelling. The bathymetry and photogrammetry show that the settlement was placed over or around the outer edges of a karstic sinkhole filled with sediments, and that there are traces of organic peat in the near vicinity of the site. The peat might have overlapped the extents of the sinkhole, which was naturally protected from environmental disturbances with high limestone ridges that visibly protrude from the sea surface today. It is unclear, however, what the extents were of the peat over which the settlement was presumably built, when the site was occupied and abandoned, and whether any occupational hiatuses occurred. These issues will be addressed in this study by reconstructing the past sea-levels and environmental changes supported by radiocarbon dating, with the expectation of adding new, valuable knowledge into the local and global map of human prehistory 'lost' to rising sea levels.

No similar submerged or terrestrial prehistoric site has been located or studied in the Adriatic region to date, and further investigations of the site will contribute to the existing knowledge of the prehistoric settlement patterns on the Eastern Adriatic coast. So far, indications of prehistoric pile-dwellings have been speculated further south in the coastal Adriatic region on the Cetina river (Marović 2002; Milošević 1999; Smith et al. 2006) and the Pakoštane coast (Bekić et al. 2015; Čelhar et al. 2017; Pešić 2012). The nearest confirmed prehistoric stilt-house settlements to Zambratija are those of the Ljubljansko barje marshlands (Velušček 2004). Traditionally, the occupational sites from the Neolithic and Copper Age in the Adriatic are represented by caves and open air sites; and hillforts during the Bronze Age (Buršić-Matijašić 2012:27), distinguishing Zambratija from other contemporary settlement sites in the Adriatic.

In the Eastern Adriatic Bronze Age, especially on the Istrian Peninsula, settlements were megalithic fortified structures on hilltops, with nearby graveyards that indicate complex social structures (Buršić-Matijašić 1998; Buršić-Matijašić and Žerić 2013). One seabed surface find of a triangular handle from Zambratija has been typologically attributed to the Bronze Age (Koncani Uhač and Čuka 2015:37). Since the find was out of cultural or chronological context, it is less reliable than finds from stratified layers, but it should nevertheless be considered for further archaeological analyses. The fragment does indicate direct or indirect evidence of cultural continuity in the area, which can also be supported with the discovery of a submerged Bronze Age boat built with the lacing technique, some 50 metres from the earlier settlement. Samples taken from the boat yielded a radiocarbon date range between 1120–930 Cal BC (Boetto et al. 2015; Koncani Uhač et al. 2017a; Koncani Uhač and Uhač 2012:534). The nearest prehistoric hillfort fortification to Zambratija is Romanija, with pottery and a bronze spear typologically attributed to the Bronze and Iron Age (Marchesetti 1903); however, the hillfort has been disturbed by military construction in the 20th century and there are no radiocarbon dates to confirm this typological chronological determination (Buršić-Matijašić 2007:433). A crucial contribution to the understanding of possible cultural continuity to the Bronze Age in Zambratija Bay will therefore be radiocarbon dates from the multilayered prehistoric hillfort site of Monkodonja near Rovinj, around 70 km south along the Adriatic coastline (**Figure 38**). A sheep bone and a fragment of a human femur were found there in a 40m deep natural pit located next to the hillfort dry-stone walls. Radiocarbon dating revealed the bones' ages as between 4678 and 4539 Cal BC, and 3907 and 3663 Cal BC respectively (Hänsel et al. 2005:13), making Monkodonja a site that is partially overlapping in occupation with the Zambratija settlement. The hillfort was in its highest cultural peak during the Late Bronze Age period, with the latest radiocarbon date range being 1040–901 Cal BC (Hänsel et al. 2005:21).

Evidence of long-term and short-term occupation in later periods is also present in the bay from the Early Roman Republic period Greek-Italic *amphorae* found near the remains of the Roman maritime *villa* (Gnirs 1908:78), the site that initiated the underwater prospection in 2008 (Bolšec-Ferri 2007; Koncani Uhač 2009). On the southeast shore of the cove lies the remains of the Late Antiquity/Medieval period Sipar fortress (Čučković 2007; Gnirs 1908:78). All these sites make Zambratija a location with potential for not only archaeological, but also sea-level research. Only a few kilometres farther north along the Istrian coast in the Savudrija Bay, the remains of a port from the times of Roman Antiquity from the first century AD (Koncani Uhač and Auriemma 2015:157), with the preserved walking surface was found at around 1 m below present day level (Koncani Uhač and Auriemma 2015:144). The submerged port in Savudrija therefore represents a local sea-level change archaeological marker for the last 2000 years. Such archaeological indicators of past sea-level change are a special characteristic of the Mediterranean Basin, which has been historically significant position as a communication route for millennia (Auriemma and Solinas 2009:134). The remaining ports, harbours, wharfs and other maritime structures such as fish tanks (Florido et al. 2011) have become valuable references for the reconstructions of past sea-levels and coastlines in the interdisciplinary studies of the Holocene sea-level change in the Mediterranean (Antonioli et al. 2007; Antonioli et al. 2009; Lambeck et al. 2004a; Lambeck et al. 2004b), which helped set submerged archaeology and underwater archaeological research into the interdisciplinary science of sea-level change modelling and reconstruction, further discussed in Chapter 3.

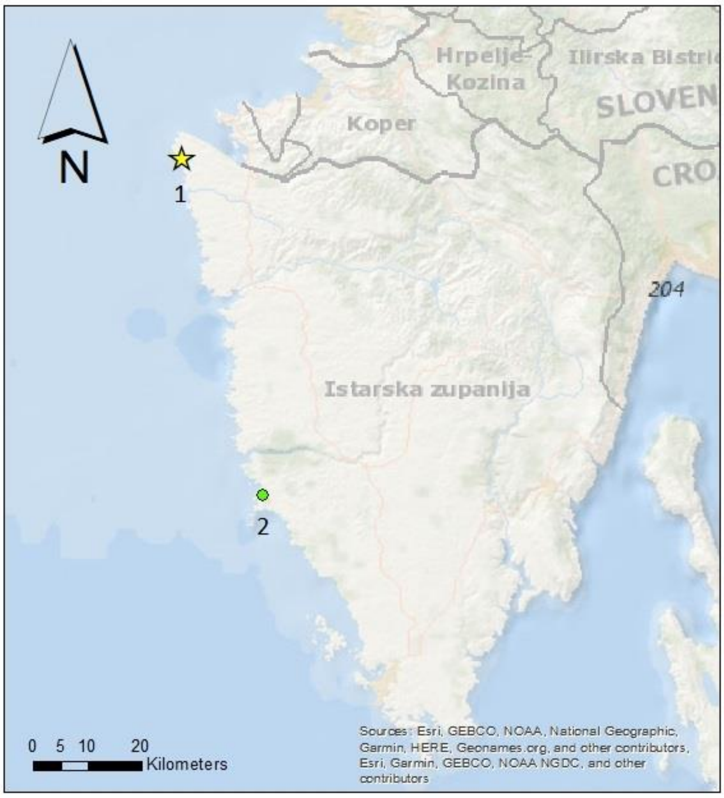

Figure 38 The location of Zambratija Bay (1) in relation to the Monkodonja hillfort (2).

CHAPTER 3: SUBMERGED LANDSCAPES AND PREHISTORIC ARCHAEOLOGY OF THE EASTERN ADRIATIC

Zambratija is an inundated archaeological site with stratified evidence of human activities in a landscape that was once terrestrial but is now submerged three metres under water. The proximity of the site to the current shoreline provides an indication of former sea-levels and a means to assess the local environmental history. Previous paleo-environmental and archaeological research indicates the Mediterranean, and consequently the Adriatic Basin, were affected by changing sea-levels caused by natural glaciation and deglaciation processes (see Antonioli et al. 2007; Benjamin et al. 2017; Lambeck and Purcell 2005; Surić et al. 2014). This thesis attempts to reconcile questions of human adaptations and interactions with changing climate in the past, using the submerged pile-dwelling in Zambratija as a case study. Therefore, in order to understand the climate events that took place before, during and after the occupation and resource exploitation of prehistoric Zambratija Bay, it is important to contextualise the site within its global and local environmental settings, starting with the Quaternary cycles.

Global Quaternary cycles

The Quaternary is the most recent geological period. It began around 2.4 million years ago (Hewitt 2000:907) and is subdivided into the Pleistocene (Greek *pleistos* “most” and *kainos* “new”) and the Holocene (French *holo-* “whole”) epochs (Hafsten 1970). The beginnings of the Holocene are closely connected to the events following the Last Glacial Maximum (LGM) which occurred between around 26,000 (Hughes and Gibbard 2015) and 17,000 BC (Lambeck et al. 2002). After the LGM, a 9000-year period of deglaciation caused global sea-levels to rise, triggering variations in temperature and climates of local and global ecosystems. The Holocene or the “post-glacial epoch” therefore began around 9650 BC (Benjamin et al. 2017:14; Smith et al. 2011:1846) and it represents the current, warm stage in the alternating sequence of Quaternary glacial and interglacial periods (Roberts 1998:56). These glacial/interglacial cyclical periods of freezing and melting of the polar ice sheets caused changes in sea-level and repeatedly altered the Earth’s climate throughout the Quaternary (Lambeck et al. 2002). Since the first known production of tools starting around 3.3 million years ago (Harmand et al. 2015), the cycles represented a critical component in the behaviour of early and modern human populations and how they exploited the continental shelves (Flemming et al. 2003:62). The Pleistocene–Holocene transition marks a significant moment in human history where the anatomically modern humans were already inhabiting all continents except for Antarctica and Greenland (Straus 1996:vii). Shortly after the transition to the Holocene, determined by climate and sea-level stabilisation at around 5000 BC (Smith et al. 2011:1856), archaeological records show intense periods of population migrations and the beginning of farming in the Middle East (Turney and Brown 2007) (**Figure 39**).

Image removed due to copyright.

Figure 39 The locations of sites with the first evidence of Neolithic across Europe, from Turney and Brown (2007). 1 (red) 11,000–9500 BC, 2 (orange) 9500–8000 BC, 3 (yellow) 8000–6400 BC, 4 (purple) 6400–5000 BC, 5 (blue) 5000–3500 BC, 6 (all colours) the spread of Neolithic across Europe from 11,000–3500 BC.

The causes of glacial and interglacial cycles

Although many scientists and scholars in the 19th and 20th centuries contributed to the understanding of the causes of these oscillations (discussed below), a fully comprehensive theoretical explanation of the ice ages is still unknown (Raymo and Huybers 2008). However, a few questions have been answered with the development of an astronomical theory explaining global sedimentary cycles by looking at the changes in the Earth's orbit, also known as the Milankovitch cycles (Imbrie 1982; Milankovitch 1930). In 1837 Louis Agassiz presented a theory supported by fieldwork evidence, stating that by that time the Earth underwent through at least one ice age. His theory was further developed in 1842 by Joseph Adhémar who proposed that intense glaciation takes place during anomalously long winters. In 1860, James Croll added that the glaciation is a consequence of a weaker solar radiation in aphelion, or the point in orbit when the Earth is farthest from the Sun, with longer winters as a consequence (Imbrie 1982:409-409; Raymo and Huybers 2008:284; Roberts 1998:60). It was only in 1930, when mathematician Milutin Milankovitch identified three astronomical cycles, varying in length but overlapping each other and thus creating a complex recurring glaciation-deglaciation pattern in the Northern Hemisphere throughout the Quaternary (Milankovitch 1930).

The three relevant cycles Milankovitch considered were the Earth's orbital eccentricity, axial tilt or obliquity and the precession of the equinoxes (Imbrie 1982:410; Raymo and Huybers 2008:284; Weertman 1976:17). The Milankovitch theory is based on several arguments which rely upon these cycles. According to his calculations, solar radiation is weaker, and a glaciation cycle re-starts at the point of alignment when the spin axis of the Earth is tilted at a sharp angle with respect to the orbit, during a summer aphelion, causing snow and ice to stay frozen throughout the years and eventually forming glaciers (Raymo and Huybers 2008:284) (**Figure 40**).

Cycle	Length in years
Orbital eccentricity	100,000
Axial obliquity	41,000
Precession of the equinoxes	19,000 and 23,000

Figure 40 The three variables in the Milankovitch astronomical cycles and their length according to deep-seabed core data (Modified and simplified after Raymo and Huybers (2008)).

The scientific community encountered a few difficulties when trying to test the hypothesis. Questions were asked by astrophysicists whether the solar radiation variations lasted long enough to produce ice ages (Weertman 1976), climatologists worried that the theory oversimplified causes of glaciation by only looking at orbital forces, excluding other unknown factors (Berger 1988), and geologists found it difficult to collect empirical data to support the theory (Imbrie 1982:413). These problems were adequately addressed with the emergence of radiometric dating methods since the 1950s, as well as the development of geological quantitative methods of investigating stratigraphic sequences of seabed and ice cores in the 1970s (Imbrie 1982:412; Roberts 1998:60). Some supporting evidence for the Milankovitch theory came from Hays et al. (1976), who compared foraminifera deposits in a deep-sea sediment core with the ratio of oxygen isotopes $\delta^{16}O$ and $\delta^{18}O$, which are known as ocean ice accumulation indicators (Raymo and Huybers 2008:284). This and similar corroboration helped revive the Milankovich Earth orbit theory during the 1970s (Berger 1988:632; Imbrie 1982:417). The Milankovitch theory is currently the most widely accepted explanation to help understand the causes of global glaciation and deglaciation processes on a geological timescale. Scholars are conscious of its many limitations (Denton et al. 2010), however, which are expected to be answered with comparative research of the Antarctic and Greenland ice sheets (Raymo and Huybers 2008:285).

Sea-level change definitions, terminology and research methods

This section provides definitions for sea-level change terminology used throughout this thesis, beginning with a naming system for the empirically identified Milankovitch periodical cycles. As presented above, the history of Quaternary global events has been a research topic since the 19th century. This rich research legacy unfortunately resulted in a confusing and complicated time scale by the 1970s (Imbrie 1982:413). Although not perfect, the most widely accepted system in use today is the marine oxygen isotope $\delta^{18}O$ stage (MIS) timescale, which begins in the present with MIS 1 and numerically progresses further back in time (Shackleton 2006). The timescale was first developed by Urey (1947), refined into MIS stages by Emiliani and reintroduced to the scientific community by Shackleton (1967). All three argued that the visible changes in the constitution of the ocean's isotopes, which are a consequence of the variations in glacier volume, can be detected in deep-seabed core sediments. Following that principle, a total of 22 to MIS stages have been identified from the V28-238 equatorial Pacific core (Shackleton and Opdyke 1976), and that database has been constantly developed and updated since its first introduction until today (Imbrie et al. 1984; Lisiecki and Stern 2016). The most recent glacial cycle is represented with five MIS stages, with MIS 1 being the current warm period, or the Holocene, with the previous interglacial peak during MIS 5e approximately 123 kya (Lambeck et al. 2002:200-201). The MIS 5e substage, which occurred between 128,000 and 116,000 years ago, is known as the most recent stage where the global sea-levels were higher than today (Rovere et al. 2016a). During that time, human populations were already migrating throughout African, Asian and European landscapes (Benjamin et al. 2017:10; Flemming et al. 2003).

The cause and effect chain of events clarified by the Milankovitch cycles did not end at global glaciations and deglaciations. Accumulated ice sheets and their continual movements had a significant impact on the Earth's surface, influencing a variety of environmental phenomena which resulted in sea-levels fluctuating over time. The global sea-level curve, which is a visual representation of changing sea-levels through time (**Figure 41**), is continuously updated and geographically fine-tuned with site-specific, local variations influencing sea-levels.

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Figure 41 A simplified global sea-level curve for the last 200,000 years (From Bailey and Flemming (2008)).

The causes of these variations can be broadly described as eustatic, glacio-hydro-isostatic or tectonic, with tectonic being the most difficult to measure. Eustatic changes are global sea-level changes directly caused by the water released or accumulated by the ice sheets, making it a universal sea-level change factor (Fairbanks 1989:637; Fleming et al. 1998:327). The other two factors are local, which is why sea-level curves show different fluctuation intensity and/or direction at individual measuring positions (**Figure 42**). Glacio-hydro-isostatic contributions to sea-level change are a consequence of post-glacial rebound caused by the changes in volume of ice and water load in a specific place (Lambeck and Chappell 2001:681). All other site-specific active or episodic processes that are not eustatic and isostatic, such as geomorphology, sedimentation, ocean temperature, abrupt climatic conditions and catastrophes, the changes in tidal ranges and even human interventions, are considered as tectonic factors (Gehrels and Long 2008; Lambeck et al. 2004b; Lambeck and Purcell 2005; Surić et al. 2014). Taken all of the aforementioned variations into account, the past global sea-level curve shows an amplitude of 120 metres, most of which was below current sea-level over the last 200,000 years (Bailey and Flemming 2008:2154).

The data presented here illustrates how sea-level changes are a complex mixture of astronomical, global and local trends and events, and that in reality, sea-level is not level (Gehrels and Long 2008:16). This is also reflected in terminology, depending on whether the sea-level in question has been assessed and adjusted to local sea-level factors. The Global Mean Sea Level (MSL) is an average calculation of the sea surface level where tidal range, climate conditions and land movements have been included. It is sometimes labelled as Eustatic Sea Level (ESL) which refers to the changes in sea-level caused by eustatic factors on a global scale (Benjamin et al. 2017:4; Rovere et al. 2016b). The term which will be used in this thesis is MSL. The Relative Sea Level (RSL) represents a local sea-level that has not been corrected for any sea-level factors, or the level as observed from the coastline at a certain point in time (Rovere et al. 2016b; Smith et al. 2011:1846). RSL is mostly referred to when investigating past sea-levels and the affect they had on the continental shelves and coastal communities in the past, which is done through the investigation of paleo-environmental sea-level indicators, or proxies (Antonioli et al. 2009; Furlani et al. 2014; Gearey et al. 2017).

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Figure 42 Local sea-level change variations through time and space (Lambeck and Chappell 2001:681).

In environmental sciences, proxies are known as sensitive indicators of phenomena in the past observed through the application of uniformitarianism, or an assumption that past events can be explained through present-day processes (Reitz and Shackley 2012:3; Roberts 1998:257). The most commonly observed proxies for the Holocene sea-level change are landscape features such as tidal notches (Furlani et al. 2014), submerged caves (Radić Rossi and Cukrov 2017), fossils (Ward et al. 2006:215) and depositional indicators such as foraminifera (Massey et al. 2006; Shaw et al. 2016). A unique characteristic of the Holocene marine transgression reconstruction is the use of archaeological RSL indicators, such as shell middens (Bailey and Flemming 2008:2155), or coastal buildings (Doneus et al. 2015).

Some authors state that the Early Holocene sea-level rise provides knowledge of crucial importance for managing the effects of future climate change (Törnqvist and Hijma 2012:601; Turney and Brown 2007:2036). A similar principle to uniformitarianism can be applied to modern environmental debates, by using the reconstructions of past marine transgression patterns, or predictive models. Predictive models are created by a mathematical analysis of the existing multiproxy sea-level data supported with radiocarbon dates (Lambeck and Purcell 2005). Satellite measurements showed that global sea-level rise rate between 1993 and 2003 was 3.1 mm/year, which is significantly higher than the 20th century average of 1.7 mm/year. Although there were similar 10-year periods with a higher rate than average in the 20th century, it is still clear that sea-level rise is a contemporary global occurrence (Gehrels and Long 2008:12). Analyses showed that an estimated 400 million people are populating the world's immediate 10 metre above MSL coastline (Van de Noort 2013:1), and that 70% of the world's beaches are withdrawing due to rising sea-levels (Stocchi and Spada 2009:56), therefore making adaptations to climate change and sea-level rise a global concern. The combination of archaeological research with the investigation of past climate and sea-level change has become a crucial element in the current climate change debates (Van de Noort 2013:1). This does not suggest a literal application of uniformitarianism to future human populations. Archaeological research can, however, help recognise elements of cognitive adaptive models from the past which can then be applied in the planning of adjustment elements for modern communities to successfully assimilate into contemporary extreme climate events (Van de Noort 2013:19).

Post-LGM climate and sea-level rise in the Mediterranean

During the last glacial cycle (MIS 1–5), sea-levels were lowest during the LGM period, with global ice volume at around 55 X 10^6 larger than today (Lambeck et al. 2002:203). Studies suggest (Clark et al. 2004; Fairbanks 1989)that the post-LGM deglaciation caused the global MSL to rise by 120 metres (Clark et al. 2004; Fairbanks 1989), with an uplift mean rate of 10 mm/year between 17,000–5000 BC (Benjamin et al. 2017:14). Glacio-isostatic (GIA) models indicate that the rate of sea-level rise significantly decreased around 5000 BC. Most of the ice had melted into the oceans by that time and the global RSL entered a stable period. Since then ocean volumes increased by just a few metres (Vacchi et al. 2016:173). These sea-level changes triggered several catastrophic climate change episodes throughout the Holocene, with consequences effecting global coastal landscapes and environments. These global trends are also seen in the Mediterranean, where sea-levels were rapidly rising until around 5500 BC and then slowly decelerated until around 2000 BC, after which local RSL changes were closely connected to isostatic factors (Vacchi et al. 2016:172). The two most significant sea-level predictive models produced for the post-LGM RSL change in the Mediterranean are the Lambeck and Purcell (2005) and the Stocchi and Spada (2007) studies.

Lambeck and Purcell (2005) calculated a series of predictive post-LGM marine transgression models for the Mediterranean during the 18,000 Cal BC, 10,000 Cal BC and 4,000 Cal BC timeframes (recalculated in **Figure 43** to BC). The study was based on four tectonically stable positions around the Mediterranean Basin – the Carmel coast in Israel, Peloponnesus Peninsula in Greece, Versilia plain in Italy and the Côte d'Azur in France, which made it possible to not only calculate MSL, but also all four RSL variations. As seen in Figure 43, the Northern Adriatic RSL values were shallower than the overall MSL during the 18,000 BC and 10,000 BC timeframes. However, at the 4000 BC mark, Northern Adriatic RSL was slightly lower than the Mediterranean MSL. The latter timeframe coincides with the preliminary Zambratija dates of 4230–3980 Cal BC. The Northern Adriatic environmental data provided for the study was based on a 70-metre core in the Versilia plain in Tuscany (Lambeck and Purcell 2005:1983). The 4000 BC difference between RSL and MSL was explained by isostatic changes caused by the accumulation of ice around the Alps (Lambeck and Purcell 2005:1976). This suggests that the post-LGM sea-level rise was not a streamlined uplift process.

Calculations of sea-level proxy data implied significant increase or decrease in meltwater accumulation, which led scientists to recognise several known global climatic episodes and events which disturbed the Mediterranean Holocene sea-level curve, and consequently had an impact on the contemporary coastal environments and cultural groups (Benjamin et al. 2017:15).

Years BC	Mediterranean MSL	Northern Adriatic RSL
18,000	-142 m	-110 m
10,000	-54 m	-40 m
4000	0 m	Between -4 and -9 m

Figure 43 Post-LGM Mediterranean MSL values with the Northern Adriatic RSL variation (Modified after Lambeck and Purcell (2005)).

Stocchi and Spada (2007) focused on the influence of remote Antarctic ice sheets to the eustatic sea-level rise in the Mediterranean Basin based on three ice-sheet models. They concluded that the total input of melting Antarctic ice to the Mediterranean MSL was 14 metres (Stocchi and Spada 2007:752). Their study was based on sea-level curves from the French, Tyrrhenian, Adriatic, Tunisian and Israeli coasts, where the Adriatic case-study was taken over from the Lambeck and Purcell (2005) paper (Stocchi and Spada 2007:755). By compartmentalising the Mediterranean into so-called "Clark zones" representing similar glacio-isostatic RSL measurements, they argued that the SE Tunisian coast measurements matched the history of Antarctic ice-sheet deglaciation (Stocchi and Spada 2007:742). They did not consider the Alpine ice-sheet melt for the Adriatic Basin but speculated that the combination of that factor with the Adriatic Basin's relatively shallow depths might make their model for that area less accurate (Stocchi and Spada 2007:756).

Holocene climate change episodes in the Northern Hemisphere

In the Early Holocene (9650–5000 BC), global environments underwent several dramatic climate changes caused by a combination of fluctuating temperatures and rapid episodes of sea-level rise. It is estimated that around half of the total Holocene sea-level rise occurred during this short period, with rising sea-level rates as high as 2.5 cm/yr (Törnqvist and Hijma 2012:601). Paleoenvironmental records show that the post-LGM deglaciation was interrupted by the Younger Dryas Event between 10,800–9700 BC, when global sea-level rise slowed down, and the Northern Hemisphere underwent a cooling period (Fairbanks 1989:640; Lambeck et al. 2002:204; Smith et al. 2011:1846). The start of the Holocene was therefore marked with a new warming period after the Younger Dryas Event, when global temperature was rising by approximately 15°C over a 1,500-year period, which ended around 7500 BC. This consequently initiated the continuation of the post-LGM deglaciation process, which particularly affected the deglaciation process of the so-called Fennoscandian, Greenland and Laurentide ice sheets across the Northern Hemisphere. (Dyke et al. 2002; Törnqvist and Hijma 2012:602). The rapid melting of the Laurentide ice sheet led to the formation of proglacial Lake Agassiz, and eventually the lake's abrupt discharge of glacial melt water into the Arctic Ocean after an ice dam formed by the Laurentide Ice Sheet disintegrated. The drainage of the lake shaped what is now Hudson Bay in Canada at around 6470 BC (Smith et al. 2011:1848) and flooded the lowland landscapes of the North Atlantic (Törnqvist and Hijma 2012:602), including Doggerland (Gearey et al. 2017:36) (**Figure 44**). The data gathered from Greenland ice and Atlantic deep sea-bed cores imply that the Laurentide Ice Sheet meltwater was voluminous enough to cool down the ocean temperature, which is supported by evidence of ocean surface freshening and sudden sea-level jumps on both sides of the Atlantic. As a consequence of these incidents, the mean annual temperature in the Northern Hemisphere was lowered by 3.3°C ±1.1°C around 6200 BC, which is known as the 8.2k cold event, also referred to as the 8.2ka, or 8.2kyr event – depending on the timescale naming system referring to kiloyears before present (Törnqvist and Hijma 2012:602). Evidence of climatic effect of the 8.2k event was traced as far as the Mediterranean, where paleoclimatic records from the Aegean Sea showed unusual occurrences of polar winter outbreaks (Mayewski et al. 2004:249). After the 8.2k event, five more rapid Holocene climate change events dated between 4000–3000 BC, 2200–1800 BC, 1500–500 BC, AD 800–1000 and AD 1400–1850 were identified in the vertical chemical composition of Greenland Ice Sheets. Environmental evidence from these periods showed occurrences of cooler climate on the North and South poles and drier climate around the Equator, which was attributed to solar variability (Mayewski et al. 2004). One of the most recent known exchanges of global warming and cooling are also known as the Medieval Warm Period which lasted between calendrical years 800–1300 and was immediately followed by the so-called Little Ice Age, which lasted until around 1870. The reason why these dates are mismatched with the Greenland Ice Sheet records can be explained with the atmospheric ^{14}C record deficiency in the last 1500 ± 500 years (deMenocal 2001:292).

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Figure 44 The melting process of the Fennoscandian (FIS), Greenland (GIS) and Laurentide ice sheets (Törnqvist and Hijma 2012:602).

Holocene sea-level rise in the Alpine Mediterranean

The Alpine Mediterranean region consists of the Tyrrhenian, Sardinia-Corsica and Adriatic tectonic blocks with natural borders outlined with seismic activity. The Adriatic block, also known as the Adria or Apulia microplate, is partially independent and slowly moving away from the large African plate to the south towards the Eurasian plate (Antonioli et al. 2007:2465; Surić et al. 2014:95). This contributes to the variety of eustatic, glacio-hydro-isostatic and tectonic sea-level factors in the region. Even though the Mediterranean Sea was protected from direct Arctic ice melt, sea-level change still occurred due to the global eustatic factor. Over the last 15 years, several small- and large-scale past sea-level change studies were performed throughout the Mediterranean and Adriatic coastline, all of which included the eustatic, glacio-hydro-isostatic and tectonic factors (for example Antonioli et al. 2007; Antonioli et al. 2009; Furlani et al. 2014; Surić et al. 2014). The diversity of glacio-hydro-isostatic and tectonic sea-level effects contributed to localised RSL variations (Lambeck and Purcell 2005; Stocchi and Spada 2009). As an example, according to some of these reconstructions the RSL at the French Mediterranean coast around 2000 BC was around 1.5 metres lower than today (Lambeck and Purcell 2005:1984), whereas at the same time in the Eastern Mediterranean RSL had already reached its present-day levels (Benjamin et al. 2017:18) (**Figure 45**).

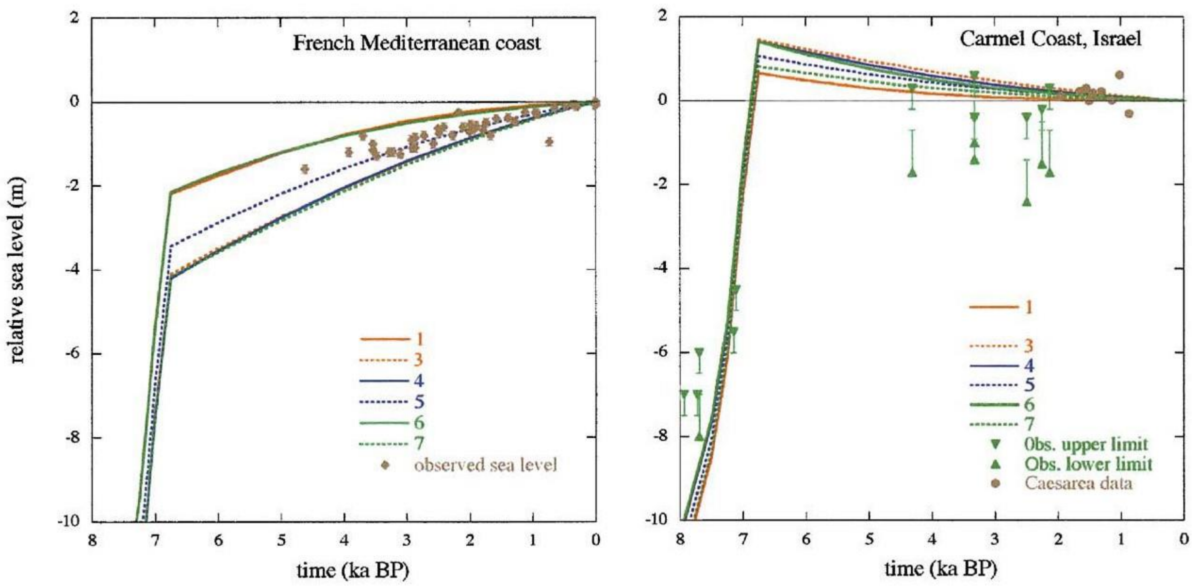

Figure 45 Observed and predicted sea levels for the French Mediterranean and Carmel coast (Modified after Lambeck and Purcell (2005)).

Past sea-level reconstructions for the Middle and Late Holocene Mediterranean are based on geomorphological, biological and archaeological proxies which contributed to the construction of sea-level curves on the French, Italian, Slovenian, Croatian, Greek, Turkish, Lebanese, Israeli, Libyan and Tunisian coastlines. In a recent interdisciplinary overview, Benjamin et al. (2017) gathered sea-level data from these coastlines throughout the late Quaternary, emphasising the importance of including the Late Holocene ice-sheet offload to the sea-level change. They found that in most of the Mediterranean, the Middle and Late Holocene hydro-isostatic factor contributed to the uneven local RSL, and mentioned the possible Alpine glacial meltwater impact on the Northern Adriatic sea-level variations (Benjamin et al. 2017:18).

For their Mediterranean sea-level models study, Lambeck and Purcell (2005) included the glacio-hydro-isostatic calculations for the European ice sheet, which was covering today's Scandinavia, Barents and Kara seas and Northern Eurasia, and ice sheets covering the Arctic, including the aforementioned Laurentide Ice Sheet (Lambeck and Purcell 2005:1973). For the Northern Adriatic 10,000 BC and 4000 BC models they also included the Alpine deglaciation happening at the time, which is of significance to the Zambratija site from many perspective angles. The model shows that a maximum value for the glacio-isostatic uplift derived from the Alpine deglaciation was around 3 metres (Lambeck and Purcell 2005:1974), and an RSL value of around -4–9 metres for the 4000 BC model (Lambeck and Purcell 2005:1983). The 120,000 km^2 Alpine glacier was the largest Southern European post-LGM glacier (**Figure 46**). Since its morphological characteristics were uneven, the deglaciation process was complex and episodic (Keller and Krayss 1993; Monegato et al. 2017; Stocchi et al. 2005:138).

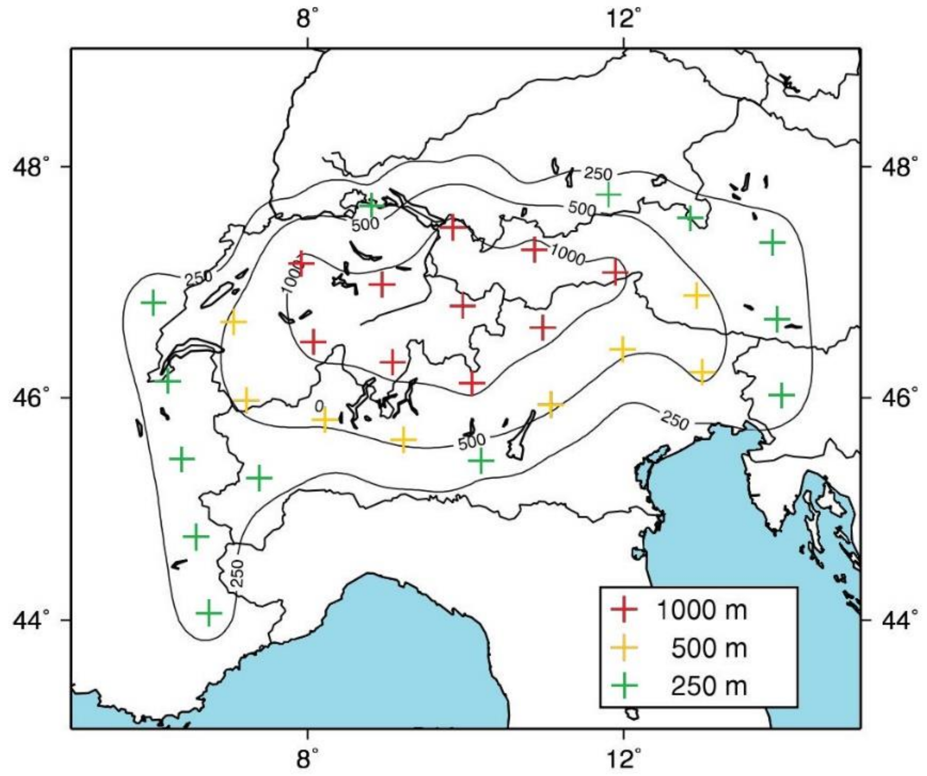

Figure 46 The extents of the Alpine glacier at the LGM. Modified after Stocchi et al. (2005).

The sea-level curve for the Tyrrhenian and Northern Adriatic coast shows the start of a significant water influx from around 16,000–8000 BC, after which the sea-levels slowly grew until around 4200 BC when they align with present-day levels. Particularly interesting are the case studies from Venice and Trieste, both close to Zambratija, which show that the melting of the Alpine glacier moderated the post-glacial rise of Northern Adriatic sea-levels (Stocchi et al. 2005:140), which has been accepted in recent literature as the most prominent hydro-glacio-isostatic sea-level factor in the region (Surić et al. 2014:95).

Holocene sea-level markers and submerged landscapes of the Adriatic Basin – environmental data

The Lambeck and Purcell (2005) study of the Adriatic was based on one core in the Versilia plain in Northern Italy but due to the increased intensity of sea-level investigations between 2004 and 2014, the database for the Late Holocene Adriatic sea-level curve has been updated with a larger number of radiocarbon dated environmental and archaeological markers (Antonioli et al. 2007; Antonioli et al. 2009; Furlani et al. 2014). The combination of natural factors, such as rocky limestone coast with a low tidal range, a large number of submerged karstic caves; and being located on the crossroads of cultural activity throughout millennia, makes the Adriatic an ideal location for the investigation of sea-level changes (Surić et al. 2014:93).

Local geomorphology and tectonics

The Adriatic Basin is a small and geographically isolated, tectonically active part of the Mediterranean (Antonioli et al. 2007:2464). Most of the Eastern Adriatic coast is composed of carbonates, making it a part of the Eastern Dinaric karst that formed throughout the Lower Trias until the Lower Eocene geological eras. The karst and started to get saturated by flysch deposits during Lower and Middle Eocene (Antonioli et al. 2007:2465; Surić et al. 2014:95). Seismic measurements in the basin showed deformations related to motion dynamics, suggesting that the Adria plate is a partially or perhaps even a completely independent plate, progressively distancing away from the African one in a rotating counterclockwise movement. It has been suggested and supported by calculations that the movement speed is 2.0 ± 0.2 millimetres per year, the result of which is seen in the thrusting and crustal thickening of the southern Alps (Antonioli et al. 2007:2465). The complicated karstic system with the Adria microplate pushing towards the Alps makes the Adriatic Basin a tectonically complex location for the reconstruction of Holocene sea-level rise. According to archaeological and geomorphological Late Holocene sea-level markers in the Northern Adriatic, RSL changed there up to -2.08 ± 0.60 metres, with a tectonic lowering of 1.5–1.6 metres in the last 2000 years (Antonioli et al. 2007:2484).

A prominent characteristic of the Northern Adriatic is its relatively shallow bathymetry occurring on a gently sloping (0.02°) continental shelf (Martorelli et al. 2014; Surić et al. 2014:95). Its numerous islands and shallow basins coupled with the large Istrian Peninsula located at the head of the Adriatic (Šegota and Filipčić 1991) tend to augment the impact of changing environmental dynamics, such as the sedimentation provided by the river Po (Martorelli et al. 2014; Surić et al. 2014:95). It is a region of microtidal conditions with average tidal range amplitude around 30 cm, which is episodically influenced by the cold north-eastern and warm south-eastern wind, with increases of sea-level up to 1.6 metres above MSL (Surić et al. 2014:95).

Geomorphological sea-level markers

Although not useful for absolute dating purposes (Surić et al. 2014:95), tidal marine notches represent valuable relative indicators for coastal tectonic movement (**Figure 47**). They are described as bio-erosional landscape features, typically limestone sea cliffs whose peaks are adjusted to the MSL (Furlani et al. 2014:37). In the Northern Adriatic the submerged tidal notches were found as deep as -19 m MSL, but most of them are noticeable in shallow waters (Surić et al. 2014:97) and have been attributed to the Roman Age.

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Figure 47 A tidal notch near Dubrovnik (Modified after Surić et al. 2014).

A submerged tidal notch in the Gulf of Rijeka at -0.5 to 1.0 m MSL had deformations attributed to an AD 361 earthquake (Benac et al. 2004), which were then cross-referenced with several archaeological sites (Antonioli et al. 2007:2469-2473). In a snorkelling study of submerged tidal notches around the Istrian Peninsula, researchersnoticed an important link between the notch erosion intensity and submerged freshwater springs (Furlani et al. 2014). This suggested that the submerged tidal notches previously attributed exclusively to bio-erosion should be re-assessed. A similar conclusion was made based on the investigations on tectonic movements in the Eastern Adriatic. Surić et al. (2014) argue that predispositions for the development of a tidal notch requires tectonic stability, however the Eastern Adriatic showed evidence of multiple significant tectonic sea-level factors, such as the Alpine glacier melting, which had a significant impact on the local tectonic uplift (Surić et al. 2014:99). Faivre et al. (2011) investigated the sea-level changes of the Western Istrian Peninsula coastline since 2856 BC, with the aim to reveal the origin of the submerged tidal notch which spreads from the Gulf of Trieste to the Velebit mountain. The evidence, which was compared to the Lambeck and Purcell (2005) and Antonioli et al. (2007) studies, showed the existence of a shallow marine environment there until around AD 1450, when the sedimentation changed to layers of terrestrial origin, today partially submerged. This made it possible to date the formation of the local submerged tidal notch between the calendrical years AD 1000–1500, after which the Western Istrian coastline was inundated with fluvial sediments from the nearby river and the notch subsided due to tectonics (Faivre et al. 2011:141). The current discussion is looking at whether the modern-day increased sea-level rise has had an impact on the disappearance of tidal notches, with studies both supporting and rejecting this hypothesis (Benjamin et al. 2017:5).

Unlike tidal notches, submerged speleological objects represent a less controversial past sea-level marker due to the nature of their formation. There are more than 140 submerged caves on the Eastern Adriatic coast (Surić et al. 2014), some of which have already been used as past sea-level indicators by radiometric dating of speleothems. After being submerged, they become incrusted with marine organisms which form thick marine crusts, which can be sampled for dating (Lambeck et al. 2004a:1569). Stalagmites are speleological rock formations made by water dripping from the ceiling to the floor and can therefore only be formed above sea-level. According to the Uranium series age of two submerged stalagmites found at a depth of -14.5 and -18.8 m MSL on the Northern Adriatic Krk island, the MIS 5.1 MSL should have been much higher than that of the calculated global eustatic MSL curve (Surić et al. 2014:98). Evidence of more recent sea-level change was found on Lošinj Island in the partially submerged Medvjeđa Cave. The cave can only be entered today through a ceiling crack into a small chamber, with the original entrance floor of the main chamber being -10.0 m MSL (Šegota and Filipčić 1991:164), making it also a potential archaeological sea-level marker. A stalagmite from Medvjeđa Cave submerged -0.45 m MSL showed a radiocarbon range of 620±63 years BP, revealing that the stalagmite peak must have still been above sea-level around AD 1330 (Šegota and Filipčić 1991:152). Similar archaeological potential can be seen in the submerged Y Cave on the Central Dalmatian Dugi Otok Island. The 6-metre-high entrance lies at -12.0 m MSL. Diving surveys recorded a total cave length of 87 metres, and it contains evidence of freshwater springs. According to current sea-level calculations, the cave was inundated sometime in the 6th millennium BC, making it inhabitable for Late Palaeolithic, and Mesolithic populations (Benjamin et al. 2011a:202; Benjamin and Črešnar 2009:62). Anchialine caves are another type of speleological sea-level marker. Anchialine caves have freshwater layers floating above seawater, a phenomenon that also only appears above sea-level. Submerged anchialine caves in the Adriatic islands do not only represent a geomorphological sea-level marker, but also demonstrate archaeological potential, which has been confirmed with recent research showing traces of human interventions (Radić Rossi and Cukrov 2017).

Submerged karstic depressions along the Eastern Adriatic, such as the one taken from the 72-metre-deep Lošinj Bay provide records of re-occurring Quaternary marine transgressions. Filled with depositional sediments accumulated during multiple sea-level fluctuations, these submerged deep depressions represent valuable resources for reconstructing sedimentary stratigraphic and chronological sequences based on geochemical and biological proxies (Benjamin et al. 2017:5-6).

Depositional sea-level markers

Due to its very protected, almost land-locked position which made it possible to preserve sediments containing detailed environmental record of the Holocene climatic and environmental variations, the Adriatic Basin is an almost ideal case study for sea-level change investigations (Piva et al. 2008:153). In addition, the Po river delta infused the Northern Adriatic seabed with terrestrial and freshwater sediments, creating coast-specific environments such as estuaries, deltas, salt marshes and lagoons. Areas of extensive sediment accumulation contain remains of fossilised microorganisms which, when they were alive, were sensitive to factors such as depth, salinity and temperature of the aquatic environment they inhabited. These characteristics make microfossils reliable proxies for past sea-level and climate change reconstructions. Some of the most useful depositional sea-level microfossil markers include salt-marsh foraminifera, testate amoebae and ostracods (Benjamin et al. 2017:5). Due to these ideal circumstances, many sea-level studies of the Adriatic which included depositional markers as one of chosen research methods have been performed, re-evaluated and/or used as available data (Abelli et al. 2016; Antonioli et al. 2007; Antonioli et al. 2009; Felja et al. 2015; Lambeck et al. 2004a; Piva et al. 2008; Shaw et al. 2016).

Both archaeology and environmental sciences study sediments as physical structural background for the study of cultural or natural material deposition through time. Evidence of a submerged freshwater environment, as well as of anthropological landscape exploitation, make Zambratija a rare case where sediments can be researched from multiple viewpoints. That way, investigations can give answers to research questions regarding past climate change and its impact to human and environmental systems, empirically supported from the same vertical stratigraphic sequences. A diverse variety of foraminifera, a common depositional sea-level marker, were found in the seabed cores used for this research. The author performed a basic statistical analysis of the foraminifera microfossils, which were referenced and compared with the most recent scientific research of the Adriatic foraminifera (Ćosović et al. 2006; Ćosović et al. 2011; Felja et al. 2015; Shaw et al. 2016).

Submerged landscapes

After the LGM, around 20 million km^2 of the Earth's territory was inundated by the rising sea (Harff et al. 2016b:1), leaving landscapes and natural habitats abandoned by their terrestrial flora, fauna and human populations. These submerged Quaternary landscapes are now being investigated by collaborative marine research. Existing records are updated with new available proxy data. Archaeologists worldwide are drawn to these investigations for a variety of reasons, not only to find submerged archaeological sites, but also to reconstruct the ecosystems which the hunter-gatherer populations were inhabiting and exploiting, as well as to find possible land bridges and passages used to occupy new territories (Flemming et al. 2003; Gearey et al. 2017; Harff et al. 2016a; Lewis Johnson and Stright 1992; Masters and Flemming 1983b). Some of those bridges are known in the Mediterranean and represent crucial knowledge for the understanding of prehistoric migratory routes between Africa and Europe. For example, according to paleoenvironmental and bathymetric data, the Maltese Islands were connected to present-day Sicily between 18,000 and 12,000 BC (Foglini et al. 2016:91), and the Europe–Sicily bridge in the Strait of Messina, which is today 81 metres deep, was dry land for at least 500 years between 19,500 and 18,000 BC (Antonioli et al. 2016:111).

Submerged landscapes of the Croatian Adriatic have been investigated as a part of the LoLADRIA (Lost Landscapes of the Eastern Adriatic Shelf) research project funded by the Croatian Science Foundation.

The multidisciplinary team was led by the Croatian Geological Survey (CGS), and it included multiple coring campaigns across the Adriatic, where they used micropaleonthological and geochemical proxies for sea-level and paleo-environmental reconstructions of Holocene submerged landscapes (Brunović et al. 2015; CGS 2018). A recent multidisciplinary study of Middle and Late Holocene paleoenvironment in the Mirna River valley, located around 20 kilometres south from Zambratija, showed that the river delta formation changed on multiple occasions in the last 7000 years. As a consequence, landscapes changed constantly, which had a significant impact on the local human populations. This can also be seen in the archaeological evidence (Felja et al. 2015).

Archaeological evidence of sea-level change in the Adriatic Basin

Archaeological sea-level markers are most accurate when the time of their origin is known, and when they are in close connection with remains of fixed tidal bioindicators, such as barnacles. This, however, is only applicable to near coast or partially submerged archaeological structures, such as ancient harbours (Henderson et al. 2011) or fish tanks (Florido et al. 2011), which limits the Mediterranean sites to the last 3000 years (Benjamin et al. 2017:19; Morhange and Marriner 2015:146). Evidence of prehistoric exploitation of inundated landscapes that were once terrestrial are rare for Palaeolithic sites, although not entirely unknown (Cliquet et al. 2011; Werz et al. 2014), after which they occur far more frequently in the Mesolithic (Hansson et al. 2016; Larsson 1983; Lübke et al. 2011; Nymoen and Skar 2011; Uldum et al. 2017), and Neolithic (Cassen et al. 2011; Flemming 1983a; Galili and Rosen 2011; Geddes et al. 1983; Gifford 1983; Wreschner 1983). Conversely, there are few Bronze Age submerged sites (Flemming 1983b). As far as the nature of the submerged cultural heritage, a variety of submerged or drowned archaeological sites and finds have been used as archaeological sea-level markers worldwide. These include extinct land animal bones and material culture found in marine dredging (Stanford et al. 2014), as well as submerged settlements (Galili et al. 2017a; Wreschner 1983), prehistoric fishing fences (Leineweber et al. 2011), ancient burials (Bulić 1900; Uldum 2011), submerged cave drawings (Clottes et al. 1992), shell middens (Bailey 1983) and many more.

The archaeological investigation of submerged prehistoric landscapes and cultural sites developed into its own discipline at the end of the 20th century, which will be discussed in greater detail in Chapter 5. However, sea-level change did not stop, and archaeological indicators for it exist from later periods such as the ancient harbours mentioned above, as well as evidence of previous RSL on ancient nearshore city walls and constructions. For example, the southern city gate of ancient Osor on the island of Cres, Croatia, which was formed as a Roman Colony in the 1st century AD, are now positioned at -0.60–0.80 m RSL, depending on the tide. Considering that the gates were at least 1 metre above RSL at the time of building, the gate position today roughly indicates a sea-level uplift of up to +1.80 metres in the last 2000 years (Šegota and Filipčić 1991:155).

Archaeological and historical evidence for sea-level change is seen on the island of Mljet, Croatia. Historical sources say that in 1490, the channel between the island's brackish lake and the Adriatic Sea had to be lowered, so that the existing mill built on the channel could continue functioning. The consequences of this action led to a significant influx of sea water into the lake, with drastic changes apparent in the lake sedimentation. By 1950, the channel was inundated, making it possible to roughly estimate a +0.6 metre RSL uplift during those 460 years (Šegota and Filipčić 1991:152).

As discussed in Chapter 1, a fascination with sea-level change on the Adriatic coast and how it can be confirmed with archaeological evidence began with 19th and early 20th century academics and scholars. The first synthesis of known archaeological and geological sea-level markers for the Eastern Adriatic coast was done by Šegota and Filipčić (1991). They gathered historical, archaeological and geological data from 27 (17 archaeological and 10 geological) coastal and submerged sites, ranging in age from 7300 BC to AD 1700, and in RSL depth from -0.45 to -28.0 metres from the Gulf of Trieste in the North, to Mljet Island in the South (Šegota and Filipčić 1991:152). According to their calculations, which were synthesised on a comparative sea-level curve showing the global MSL line with the 27 positions (**Figure 48**), the Holocene marine transgression development can be archaeologically and geologically traced in the Adriatic from the Late Neolithic to the Late Iron Age (**Figure 49**).

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Figure 48 The Adriatic sea-level curve according to the 27 markers reviewed by Šegota and Filipčić (1991).

Archaeological era	Years BP	Years BC	RSL
Early Neolithic	7950–6750	6000–4800	-18.8–13.5 m
Middle Neolithic	6750–5450	4800–3500	-13.5–9.0 m
Late Neolithic	5450–4550	3500–2600	-9.0–6.5 m
Copper Age	4550–3950	2600–2000	-6.5–5.0 m
Bronze Age	3950–2850	2000–900	-5.0–3.1 m
Iron Age	2850–2050	900–100	-3.1–1.96 m

Figure 49 Sea-level change throughout archaeological eras in the Eastern Adriatic coast, according to Šegota and Filipčić (1991).

It is important to emphasise that even though the chronological determinations of archaeological eras in **Figure 49** represent a simplistic and outdated timeline based on available academic literature at the time, due to the large volume of the collected dataset and the quality of the analysis, that research is still considered pioneering work by including archaeology and modern-day sea-level studies in Croatia. Therefore, Figure 51 serves only as a demonstration of historical work and will not be used further in the thesis. An updated table and sea-level curve with recent scientific sea-level archaeological and geological data from interdisciplinary international research from the last 15 years is presented later.

21st century interdisciplinary investigations of sea-level change in the Adriatic

Over the past two decades, there has been an increase in using environmental and archaeological indicators to assess sea-level change in the Adriatic Sea. The archaeological sites used as sea-level references were from Roman or pre-Roman times, except for one Bronze Age site (Auriemma and Solinas 2009:143) (discussed below). Lambeck et al. (2004a) compared the upper surface of quay paving stones in the 1st century AD Roman town of Aquileia with current sea-levels to conclude the sea had risen more than 0.8 m in the last 2000 years (Lambeck et al. 2004a:1580). A combination of geomorphological and archaeological site data compiled from AD ~100 indicate Holocene sea-levels increased in the north-eastern Adriatic since that time by -1.80 ± 0.60 to -1.50 ± 0.60 metres (Antonioli et al. 2007:2467). Those sea-level increases were corroborated by a later study that assessed 127 archaeological sites in the northern Adriatic (Antonioli et al. 2009:109).

Auriemma and Solinas (2009) provided a review of the so-far known archaeological sea-level markers with examples from the Italian coastline, including the Adriatic. They systematically divided the types of archaeological sea-level markers to fishponds, harbour structures, coastal buildings, coastal quarries, hydraulic systems, prehistoric settlements and caves, paleo-beaches and beached wrecks. The list also includes an interdisciplinary discussion on various reliability factors, such as the links between the functional features of piers and barnacle growth, as well as relative and absolute chronologies (Auriemma and Solinas 2009:144). For the Adriatic, they also included a partially submerged Bronze Age settlement of Torre Guaceto near Brindisi, with visible architectural features from -0.5 to -2.5 metres RSL (Auriemma and Solinas 2009:143).

Further data for the Holocene sea-level change in the Adriatic has been added with a small-scale interdisciplinary study on the Classical Antiquity port of Issa on the island of Vis, where the RSL for 2400 BC has been calculated to -199 ± 25 m (Faivre et al. 2010). Classical Antiquity fish tanks have also been added to the sea-level change studies of the Adriatic, and calculations showed that the average sea-level has been rising at a 0.63–0.83 mm/year since the Roman times (Florido et al. 2011). The most recent assessment of the Holocene sea-level change for 917 environmental and archaeological Western Mediterranean sites, included 200 locations which were divided into seven areas across the Croatian, Italian and Slovenian Adriatic coasts on both sides of the Adriatic Basin (Vacchi et al. 2016). All studies mentioned so far have been used for this assessment, which represents the first study of the Mediterranean Holocene sea-level change by establishing index points, or RSL indicators, and marine and terrestrial limiting points, in its methodology. In order to qualify as an RSL index point, the sea-level indicator is required to have a known location, calibrated age and elevation relative to MSL at the time, and these are usually biological, lagoonal and beach rock sea-level indicators. The indicators that do not have all the necessary requirements are used as marine limiting points. Terrestrial limiting points include coastal or submerged archaeological sites and subaerial and freshwater environments (Vacchi et al. 2016:177). The result of this methodological classification is a sea-level curve with RSL index points which fall below terrestrial and above marine limiting points. The sea-level calculation results of all 200 Adriatic locations from the Vacchi et al. (2016) study is presented in **Figure 50**.

Location	IP	LP	BP	BC/AD	RSL
Venice/Friuli lagoons	49	9	9700	7700 BC	-23.5 m
			7500	5500 BC	-9.3±0.8 m
			6600	4600 BC	-5.5±0.8 m
			5500	3500 BC	-3.0 m
			4000	2000 BC	-1–2 m
			2500	500 BC	-1.4±0.7 m
			600	1400 AD	-0.4±0.6 m
			300	1700 AD	-0.3 m
North-eastern Adriatic	28	6	10,900	8900 BC	-28.0 m
			10,000–9,600	8000–7600 BC	-28.0–23.0 m
			9600	7600 BC	-22±1.2 m
			5000	3000 BC	-2.9±1.0 m
(Trieste)			3100	1100 BC	0.1±0.8 m
(Istria)					-1.29±1.1 m
			2000	0	-1.75±1.4 m
			1900	100 AD	-1.0±1.1 m
			1500	500 AD	~-0.5
North-western Adriatic	40	9	12,900	10,900 BC	-53.0±0.9 m
			12,200	10,200 BC	-43.0 m
			10,000	8000 BC	-23.3±0.8 m
			9200	7200 BC	-20.0±0.8 m
			8200	6200 BC	-15.1±1.5 m
			7100	5100 BC	-8.3±1.5 m
			6000	4000 BC	-7.6±0.8 m
			5000–4500	3000–2500 BC	-4.6–4.1 m
			1700–1200	300–800 AD	~-2.8 m stillstand
			800	1200 AD	-2.5±0.7 m
Mid-eastern Adriatic	23	1	2600	600 BC	-1.5±0.3 m
			1900	100 AD	-1.1±0.3 m
			1400–1100	600–900 AD	-0.7±0.3 m
			600–200	1400–1800 AD	-0.3±0.3 m
Mid-western Adriatic	3	3	10,400	8400 BC	-18.6 m
			7700	5700 BC	-11±0.6–7.4±1.1 m
			2500	500 BC	-3.0 m
Northern Apulia	16	3	7700	5700 BC	-14.0 m
			6800	4800 BC	-6.0 m
			4400	2400 BC	-2.2±1.0 m
			2600–today	600 BC–today	Within ~2 m MSL
Southern Apulia	4	6	5500	3500 BC	-4.0±0.5 m
			4000	2000 BC	-3.4±0.5 m
			3000	1000 BC	~-2.5 m
			2000	0	-2.2±0.7 m
			1000	1000 AD	-1.6±1.0 m

Figure 50 Post-LGM RSL calculations for the Adriatic Sea based on 163 index points (IP) and 37 marine and terrestrial limiting points (LP) (200 sea-level indicators in total), according to Vacchi et al. (2016). Since it represents the most recent overview of the Holocene sea-level change in the Adriatic, this study will be used as the sea-level reference for the Adriatic Sea throughout the thesis.

Submerged prehistoric archaeology in Croatia

The site in Zambratija Bay represents one of only a few submerged prehistoric archaeological sites investigated on the Eastern Adriatic Coast. These sites have been noticed and investigated by archaeologists since the late 1970s, but only a few were published with radiocarbon dates from stratigraphic contexts. Even though the knowledge is scarce and, in most cases, stratigraphically and contextually unreliable, an up-to-date overview will be listed here with available typological affiliations, radiocarbon dates, context and reference.

Although in situ submerged Palaeolithic and Mesolithic sites have not been confirmed, there are a few indications of their existence. Possibly the oldest one is in Resnik near Kaštel Štafilić (**Figure 51:2**), where stone tool artefacts typologically determined to the Mousterian Lithic Industry with evidence of the so-called Levallois stone-knapping method, both associated with Neanderthal populations, were found on the seabed surface at around -4.0 m MSL (Karavanić et al. 2014:34). The site is situated near the terrestrial Mujina Cave, which is the only Dalmatian cave with an undisturbed and contextualised stratigraphy, with Mousterian layers radiocarbon dated to around 43,000–37,000 BC (Karavanić et al. 2014:32).

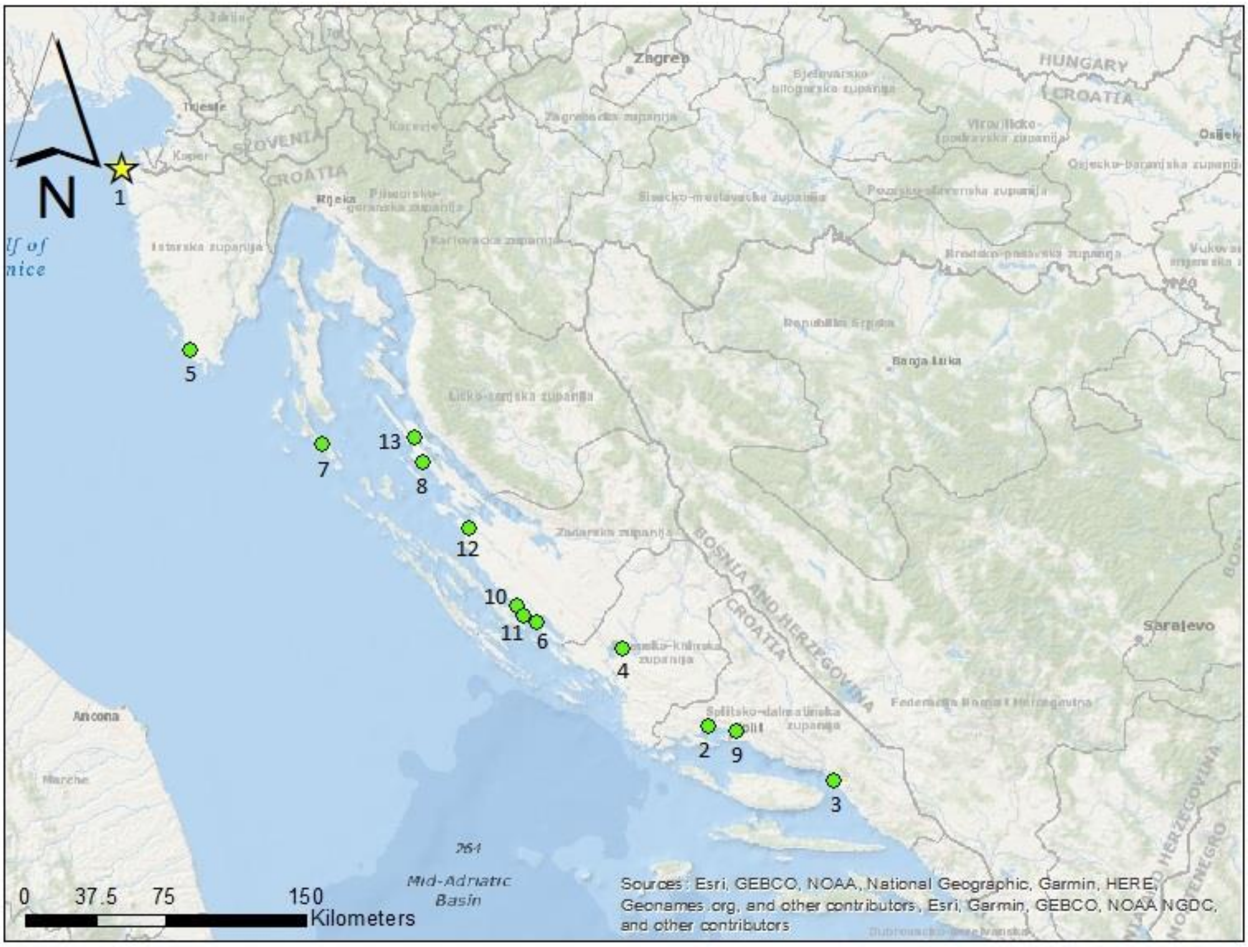

Figure 51 Submerged archaeology in Croatia: Zambratija Bay (1), Resnik (2), Baška Voda (3), Stipanac (4), Veruda (5), Janice/Babuljaš/Sv. Justina/Veliki Školj (6), Mali Lošinj (7), Šimuni (8), Vranjic (9), Ričul (10), Oštarija (11), Nin (12), Caska (13).

In Baška Voda (**Figure 51:3**), non-archaeologist divers rescued six stone tool artefacts after an accidental dredging of the seabed by a boat engine. They claimed to have found the lithics at around -5.0–6.0 m MSL, in seabed layers around 30–40 centimetres deep. According to the divers, the position of the dredge was around 50 metres away from the Baška Voda harbour shoreline (Benjamin et al. 2011a:199; Benjamin and Črešnar 2009:59).

Stone artefacts attributed to the Upper Palaeolithic were collected from the seabed around the islet of Stipanac in Prokljansko Lake near Skradin (Benjamin and Črešnar 2009:58; Karavanić et al. 2014:35) (**Figure 51:4**). The lithics, as well as prehistoric pottery sherds, were found scattered on the seabed at around -3.0 m MSL. The paleo-shoreline of the Stipanac islet is currently positioned approximately -3.0 m MSL and is connected to the nearby Školj Peninsula by a submerged embankment, ranging in depth from -1.5–3.0 m MSL. The submerged embankment represents one of the islet-to-shore late prehistoric sites in the Zadar archipelago (discussed below) (Brusić 1977:57).

A reliable example of found stone tools attributed to the Neolithic is from a dredging campaign for deepening the Veruda Bay Marina in Pula (**Figure 51:5**), which lays at around -2.0 metres MSL. The dredged sediments were deposited on land and inspected by archaeologists and they contained stone artefacts, including volcanic rock stone axes and chert tools dating from the Neolithic to the Early Bronze Age (Benjamin et al. 2011a:197).

Discovered in 2011, the Janice site was the first submerged Neolithic site found in Croatia. Archaeologists found evidence of a prehistoric settlement on the seabed of Janice Beach while conducting an underwater excavation of the Roman harbour of Pakoštane near Zadar (**Figure 51:6**). Wooden material, prehistoric stone tools, and prehistoric pottery were located ~4.5 m below MSL (Bekić et al. 2011). The following year, two excavation units revealed sediment layers containing pottery, chert and wooden finds, as well as bones, pits and charcoal (Pešić 2012). According to the most recent publication on the Janice site (Bekić et al. 2015), the site is located at a depth of -5–6 m MSL. Five wooden elements – four vertical piles and one horizontal plank, were found in the excavation units, however authors warn that the stratigraphy might have been disturbed due to tidal exposure. An abundance of pottery, chert tools and three obsidian tools, as well as land animal bones, and one radiocarbon date from a wooden pile with an age range of 4681–4539 BC show that the site was in use during the Neolithic and Eneolithic periods (Bekić et al. 2015:9). Authors speculated that this might have been a maritime pile-dwelling, however this hypothesis has not been supported with further paleo-environmental evidence. The settlement might have been protected by, or culturally connected to, a nearby unique submerged formation composed of shells, from where two radiocarbon dates revealed an age range of 4994±30 BP and 4874±24 BP (Bekić et al. 2015:17)[4]. The

[4] Inconsistency following the original publication of radiocarbon age dates, where one is listed as a Cal BC range and two as BP. The date cannot be calibrated correctly without knowing the material of the sample, which has not been provided in the publication.

Eneolithic pottery from Janice shows typological similarities with prehistoric pottery dredged from sediments beneath a Medieval wooden shipwreck, found at a depth of -5.0 m MSL near the islet of Palacol/Oruda near Mali Lošinj (Bekić et al. 2015:14; Benjamin et al. 2011a:198) (**Figure 51:7**). One more islet in the Pakoštane area, Babuljaš (**Figure 51:6**), revealed submerged layers with prehistoric pottery, which was overlayed with a 5th century AD Roman shipwreck cargo at a depth of around -5.0 m MSL. The pottery and lithic artefacts dated from the Neolithic to the Bronze Age. The artefacts, including a flint projectile point, were found in 20–50 cm thick seabed layers, but were likely not in situ (Pešić 2013, 2015, 2016).

Underwater investigations of the Šimuni harbour (**Figure 51:8**) revealed what might be an in situ submerged Bronze Age settlement. At a depth of around -2–3 m MSL, archaeologists found 40 wooden piles protruding out of the seabed, 10–30 cm in diameter and organised in a linear formation. A large number of prehistoric pottery sherds typologically attributed to the Urnfield Culture Complex, which is dated from the 14th to the 12th century BC, were found scattered on the seabed surface. It seems probable that this might be a prehistoric maritime pile-dwelling or harbour, however this assumption needs to be further explored with systematic excavations and radiocarbon dates (Bekić 2017). A cultural continuity from Bronze to Iron Age can be seen in the stratigraphy of the Vranjic harbour in Kaštela Bay (**Figure 53:9**), where stratigraphic layers with prehistoric pottery have been radiocarbon dated to the 16th and 15th century BC (Radić Rossi 2008:500).

The aforementioned complex site of Stipanac (**Figure 51:4**) consisted of a submerged prehistoric settlement on an islet connected to the nearby shore with a stone slab embankment. Stipanac formed part of a collection of late prehistoric sites in the Zadar archipelago and was first recorded by Brusić (1977). A similar settlement pattern and organisation can be recognised on the islet of Ričul near Turanj (**Figure 51:10**), Oštarija/Kumentić islet near Biograd na Moru (**Figure 51:11**), Sv. Justina and Veliki Školj islets in front of Pakoštane (**Figure 53:6**) and on the islet in the Bay of Nin (**Figure 51:12**) (Benjamin et al. 2011a:198; Brusić 1977).

The islet Ričul near Turanj (**Figure 51:10**) is connected to the nearby shore by a submerged embankment, surrounded with scattered pieces of prehistoric pottery. The embankment stops at a point where the islet's submerged paleo-shoreline starts at a depth of around -2.0–3.0 m MSL. The stratigraphy of the shoreline revealed dark sediments beneath the sandy surface layers containing pottery, bones, shells and a partially submerged stone slab pavement. A Bronze Age urn containing the bones of a child was found on the terrestrial part of the islet (Brusić 1977:54). Recent archaeological investigations show that the submerged stone embankment structure lies on a seabed that is around -3–4 metres deep, and its highest stones are at -2.2 m MSL. It is 125 metres long and supported by wooden piles rammed into the seabed. Remains of the prehistoric settlement are seen on the Ričul islet shoreline, which was artificially expanded towards the sea. Excavated sediments contained Middle Bronze Age pottery, land animal bones and antler, as well as pits and seeds (Čelhar et al. 2017). Three published radiocarbon dates obtained from wooden piles “from different positions at the site” (Čelhar et al. 2017:31), unfortunately without a mentioned elevation or stratigraphical context in relation to MSL, revealed an age between 1500 and 1300 years BC, or Middle Bronze Age (Čelhar et al. 2017:24). Settlements on the islets of Oštarija/Kumentić (**Figure 51:11**), Sv. Justina and Veliki Školj (**Figure 51:6**) were excavated in the 1970s and all showed similarities in their architectural construction. Drywall embankments or natural bridges, that are now submerged, connected the settlements to the nearby shore during times of habitation. Submerged cultural layers contained high concentrations of prehistoric pottery which Brusić explained, although without reference, with a -2.5–3.0 metre sea-level rise since the prehistoric times (Brusić 1977:56). The final settlement in the group is on the islet in the Bay of Nin (**Figure 51:12**). Cultural continuity from the 1st millennium BC Liburni Illyrian tribe to the times of Roman Antiquity can be seen in the archaeological finds, especially visible in the Roman age bridge that connected the islet to the shore, which was built over the older, drywall embankment (Brusić 1977:58).

Due to historical and cultural reasons, records of submerged prehistoric sites in the Croatian Adriatic differ in their nature of collection and quality of information. Such data though is crucial for the reconstruction of past sea-levels. Natural and cultural environments are best represented through quantitative assessment, reference to MSL, and appropriate selection and citing of radiometric dating samples. Improved recording and interpretation practices using an interdisciplinary approach may provide superior methods to assess these types of sites in the future.

As a relatively new discipline, submerged archaeology, and in this case submerged Prehistory in the Adriatic Basin is currently showing great possibilities for a wide range of high-quality investigations. As an almost land-locked and relatively isolated basin, it offers a unique record of different climate, sea-level and cultural changes through time, that were mirroring contemporary global occurrences. In order to maximise the value of that record, the research building blocks of the discipline should be based on a combination of archaeological, environmental and physical science research methods. Small, but significant steps have already been made in that direction, such as in the case of Caska (**Figure 51:13**), where an interdisciplinary team of researchers addressed the ‘enigmatic’ Adriatic tidal notch problem (Marriner et al. 2014), and in the exploration of submerged anchialine caves (Radić Rossi and Cukrov 2017). Submerged archaeology is sometimes considered to be a financially unsustainable discipline (Bailey 2014:294), however these examples demonstrate how a small-scale research, executed according to high methodological standards, can be beneficial to sea-level change sciences, as well as to human populations which are today living in an fast changing environmentally and culturally complex world. Archaeological evidence shows that in the time when Zambratija was occupied, human populations in Europe were faced with similar kinds of changes, which will be discussed in the next chapter.

CHAPTER 4: CULTURAL GROUPS IN THE ADRIATIC AND ALPINE REGIONS AFTER NEOLITHISATION

Building on the concepts introduced in Chapter 2 of this thesis, the typological analysis of the Zambratija pottery was culturally ascribed to local cultural groups and styles from the Late Neolithic to the Early Bronze Age. This relative chronology was further supported with one radiocarbon date from a wooden pile from Zambratija revealing an age of 4230–3980 Cal BC (Koncani Uhač and Čuka 2015), confirming that the site was contemporary to the Eastern Adriatic Late Neolithic Hvar culture, and Early Copper Age Nakovana-style pottery from the Jačmica, Novačka and Pupićina stratified cave sites (Forenbaher et al. 2013:592). The presence of wooden piles driven into the organic, submerged freshwater sediments, indicated that Zambratija was a prehistoric pile-dwelling similar to those around the Alpine lakes, an architectural innovation which started in the Early Neolithic and lasted for around 3500 years, until the Early Bronze Age (Menotti 2015a). The nearest Alpine pile-dwellings to the Eastern Adriatic are situated in Austria (Ruttkay et al. 2004) (**Figure 52:1**), Italy (Marzatico 2004) (**Figure 52:2**) and Slovenia (Velušček 2004) (**Figure 52:3**) with the earliest known settlements there aligning with the preliminary date from Zambratija. Iron Age riverine pile-dwellings have been recorded on Cetina (Marović 2002:234; Milošević 1999; Smith et al. 2006:172-173) (**Figure 52:4**) and Sava rivers (Marović 2002:234; Potrebica 2003:217) (**Figure 52:5**).

The Late Neolithic represents a final stage of a global cultural transformation. This transformation started with the Mesolithic/Neolithic transition, from the nomadic hunter-gatherer to the sedentary agropastoral lifestyle. Since it was first described by Vere Gordon Childe in his book *Man Makes Himself* (Childe 1936; Willis and Bennett 1994:326), this new lifestyle trend which came to Europe from Southwest Asia, also known as neolithisation, has been a topic of discussion in the European prehistoric archaeology throughout the 20th century (for example Biagi et al. 1993; Hole 1984; Peretto et al. 2004; Starnini et al. 2018; Willis and Bennett 1994). In order to contextualise the known cultural occurrences that preceded and proceeded the submerged settlement in Zambratija, an overview of regional and surrounding socio-economic circumstances from the Early Neolithic to the Early Bonze Age will be presented next, starting with the neolithisation of the Eastern Adriatic coast.

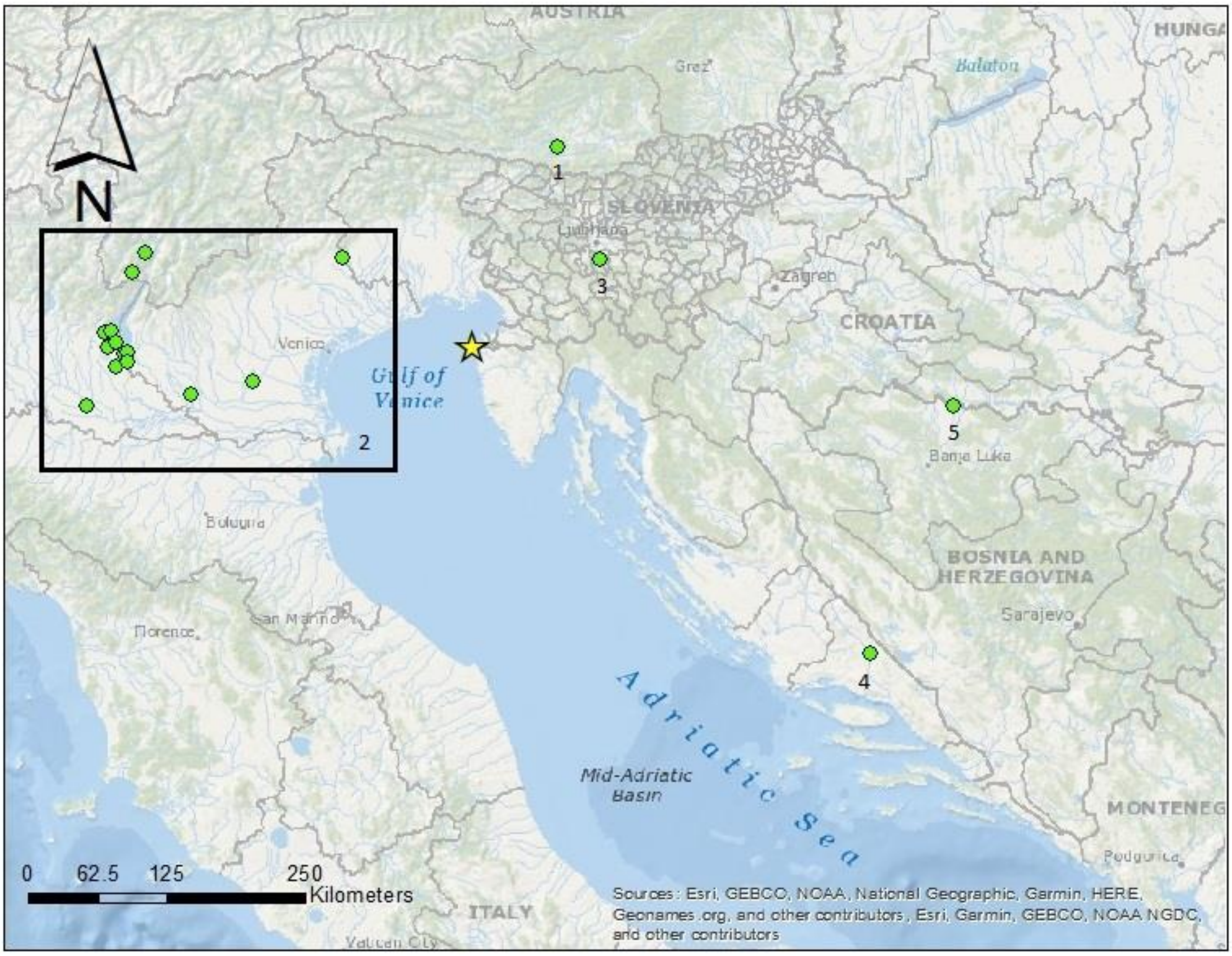

Figure 52 Prehistoric pile-dwellings nearest to Zambratija: Austria (1), Italy (2), Slovenia (3), Cetina (4), Sava (5).

Cultural developments in the Eastern Adriatic from the Late Neolithic to the Bronze Age

Debates regarding the Eastern Adriatic Neolithic chronological and geographical expansion have been ongoing for many decades (Batović 1979; Chapman and Müller 1990). It remained poorly defined chronologically, however, until recently when Forenbaher et al. (2013) synthesized the first thorough overview of old and new radiocarbon dates from 136 reliable stratified contexts across the Eastern Adriatic coast. Soon thereafter, 40 new radiocarbon dates were added to this list by McClure et al. (2014). Traditionally in the region, the chronological stages of the periods between Early Neolithic to the Early Bronze Age are divided by the typological characteristics in the ceramic material culture. For now, five known and distinctive cultural pottery groups, which are sometimes divided into localised sub-variants, can be recognised throughout the duration of the Eastern Adriatic Neolithic and Copper Age period. These are the Impresso (Cardial) ware, Danilo, Hvar, Nakovana-style and Ljubljana/Cetina groups.

The neolithization process and Early Neolithic – Impressed (Cardial) ware

Although the manufacture and use of pottery is just one of the few key Neolithic innovations, it is still the most reliable cultural feature for investigating the chronological and geographical spread of agriculture in the Eastern Adriatic (Forenbaher and Miracle 2005:517; McClure et al. 2014:1021). The beginning of the spread of the agropastoral economy in the region is characterised by the appearance of the Impressed or Cardial ware pottery phenomenon (**Figure 53**), which first entered the Adriatic Basin at around 6200 BC from the northern Ionian Sea (Forenbaher and Miracle 2005:519).

Image removed due to copyright.

Figure 53 The spread of neolithization across the Adriatic Basin, according to Forenbaher and Miracle (2005).

Palaeoenvironmental data revealed that the domesticated cereal grains collected from controlled samples, are genetically similar to Western Asian varieties, supporting existing academic consensus about the cultural migration spread of farming to Europe from the East (Forenbaher 2002:366, 2009:237; Willis and Bennett 1994:327). The Cardial ware cultural phenomenon was named after its specific decorative style characterised by impressed imprints of fingernails and various tools, which were very often the edges of *Cardium* shells, into the ceramic vessel's external wall surface before it was baked (**Figure 54**) (Forenbaher 2002:366; Forenbaher et al. 2013:598; McClure et al. 2014:1022). The pottery shapes were simple bowls with thick walls, and judging by the rim fragments' calculated radiuses, mostly large in size (Komšo 2004:14).

Figure 54 Examples of Impressed (Cardial) ware from Forenbaher et al. (2013).

Although the relationships between the Adriatic variations of Impressed-ware pottery and the rest of the Mediterranean are unclear, it seems that the use of this type of ceramic spread to the Western Mediterranean through an Italian route (Forenbaher and Miracle 2005:520), reaching the Iberian Peninsula by the early 5th millennium BC (Zilhão 2001:14182).

So far, the earliest known Early Neolithic radiocarbon date from the Eastern Adriatic taken from a stratigraphic context with Cardial ware pottery is the Dalmatian open-air site of Pokrovnik (**Figure 52:2**), at 6025–5905 Cal BC (McClure et al. 2014:1028). The pottery style reached the Istrian Peninsula by 5900 BC (Forenbaher and Miracle 2005:520), where it can mostly be found on open air settlement sites (Komšo 2004:13; Zlatunić 2007), and sometimes in caves (Jerbić Percan 2011:13). Further north, in the Slovenian and Italian Karst region, the style developed into a local variety known under the name *Vlaška-horizon* or *vasi a coppa*, with radiocarbon dates showing a timespan between around 5600 and 4500 BC, overlapping chronologically and spatially with the Cardial ware as well as the Dalmatian Middle Neolithic Danilo culture complex (Forenbaher et al. 2013:599; Montagnari Kokelj 2003:76).

Middle Neolithic – Danilo culture complex

The Middle Neolithic of the Eastern Adriatic is characterised by its local pottery production and the first evidence of long-distance obsidian maritime exchange with the Italian Lipari islands (Forenbaher 2009:223; Teoh et al. 2014:351). This socio-economic phenomenon is known under the name of Danilo culture complex (Forenbaher et al. 2013:599). It was first described in 1952 by Josip Korošec, an archaeologist from the University of Ljubljana, Slovenia, who conducted the excavations on the eponym open-air site of Danilo (**Figure 55:3**) near Šibenik, Croatia (Korošec 1952).

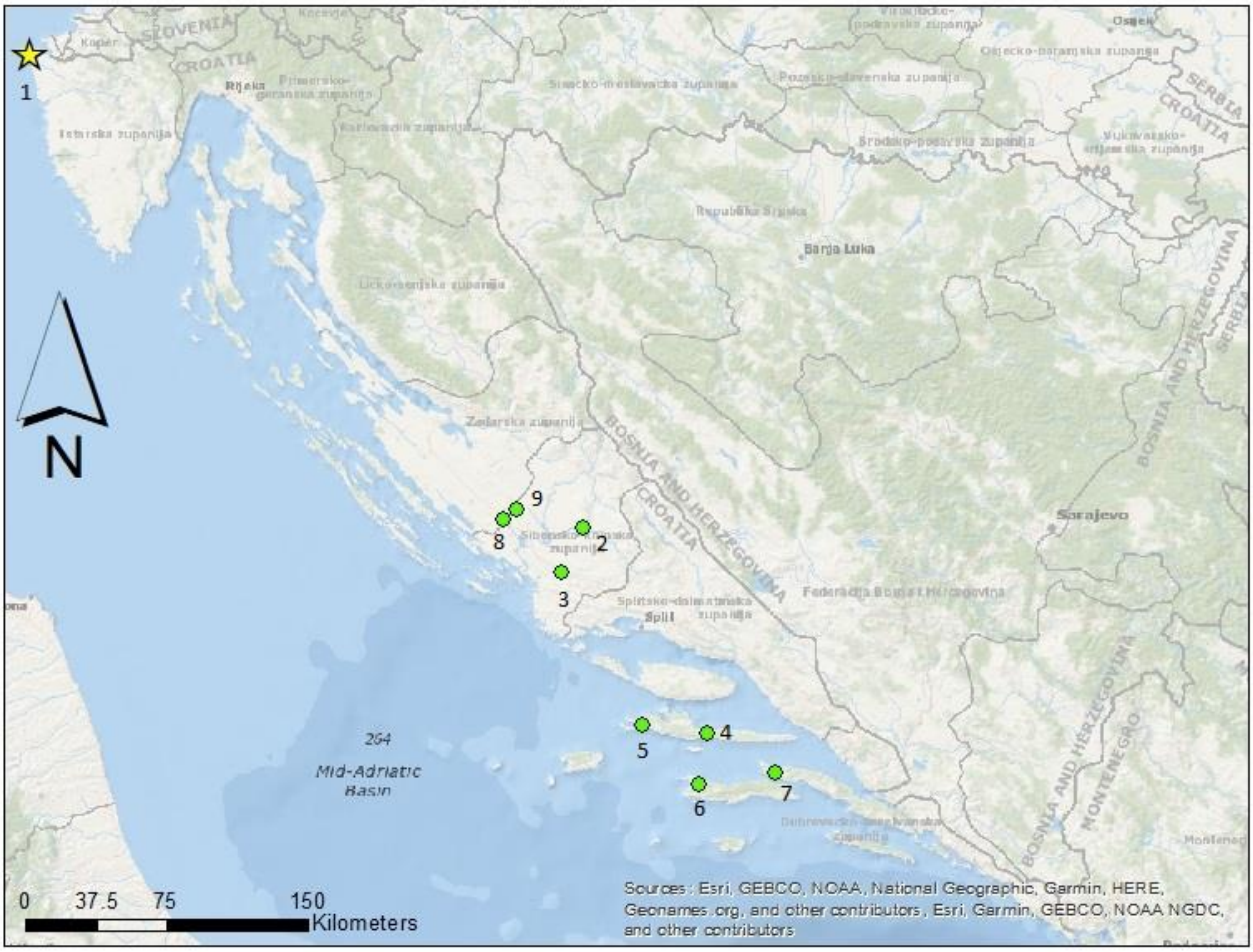

Figure 55 Neolithic sites relevant to Zambratija Bay (1) mentioned in text: Pokrovnik (2), Danilo (3), Grapčeva (4), Markova (5), Vela Spila (6), Nakovana (7), Velištak (8), Bribir (9).

The ceramics (**Figure 56**) are best known through a local Dalmatian variant with decorated smudged and burnished fine kitchen ware, also named *figulina* or Danilo polychrome, with incised, carved and/or painted spiral ornaments (McClure et al. 2014:1022; Moore et al. 2007:19). Recent laboratory analyses of the *figulina* ceramics showed that it was locally produced, but its inevitable stylistic similarities with contemporary Italian Ripoli-style ceramics may also indicate a well-established socio-economic maritime network (Forenbaher 2009:224; Teoh et al. 2014:358). Some of the most intriguing aspects of the material culture are the presence of luxurious items, the famous Danilo 'rythons', as well as anthropomorphic figurines (McClure et al. 2014:1022; Moore et al. 2007:19), which connect the Danilo sites to those of the Bosno-Herzegovinan Middle Neolithic Kakanj culture (Batović 1979; Forenbaher 2002:369). The mentioned factors make the Danilo culture a part of a wide-spread socio-economic Middle Neolithic complex.

Figure 56 Examples of Danilo pottery (Modifed after Forenbaher et al. (2013)).

Radiocarbon determinations from stratigraphic layers containing Danilo ceramics in Central Dalmatia range between 5300 and 4900 Cal BC (McClure et al. 2014:1029). In Istria, the dates are similar, however the Danilo pottery there is considered to be closely connected to the Vlaška pottery, deriving from the Early Neolithic Impressed ware (Forenbaher et al. 2013:591).

Late Neolithic – Hvar culture

The Hvar culture was first described by the Croatian archaeologist Grga Novak in 1955, after he conducted archaeological excavations of the multi-stratified Grapčeva cave (**Figure 55:4**) on the Southern Dalmatian island of Hvar (Novak 1955). Most of the sites with this richly decorated pottery, which was made in a variety of incised and painted techniques, designs, shapes and sizes (discussed below), are located the Dalmatian islands and the Dalmatian hinterland (Forenbaher et al. 2013:602). The sites are mostly multi-stratified caves with stratigraphical sequences ranging from Impressed ware horizons until the Early Copper age. The best known is Grapčeva cave (Forenbaher and Kaiser 2010), but also another Hvar cave – Markova (**Figure 55:5**), with a complete Neolithic stratigraphy (Forenbaher 2002:367), Vela Spila cave on the island of Korčula (**Figure 55:6**), and Nakovana cave on the Pelješac Peninsula (**Figure 55:7**) (Forenbaher et al. 2013:594). An exception to the cave sites is the early Hvar culture open-air site of Velištak (**Figure 55:8**) (Podrug 2010), with the most recently sampled six radiocarbon dates, including human bone samples, from reliable stratigraphic contexts providing dates between 5000 and 4700 BC (McClure et al. 2014:1027).

These typological variations can be chronologically divided into two main phases. The first is the outlined style (**Figure 57**), with advanced geometric motifs produced in a technically advanced way, including incision and burnishing before baking, sometimes followed by a red paint finish. This style has so far been radiocarbon dated to around 4800–4400 BC (Forenbaher et al. 2013:601-602).

Figure 57 Hvar outlined style (Modified after Forenbaher et al. (2013)).

Some of the most intriguing examples of artistic expressions on Early Hvar ceramics are fragments with incised markings that have been interpreted as evidence of nautical knowledge. A fragment was found at the site of Bribir (**Figure 55:9**), with the depiction of a half moon and flag-like object, interpreted as a comet (Petrić 2002:12) (**Figure 58:1**). Another fragment was found in Grapčeva cave (**Figure 55:4**) with a depiction of a boat-like object (Petrić 2002:13) (**Figure 58:2**).

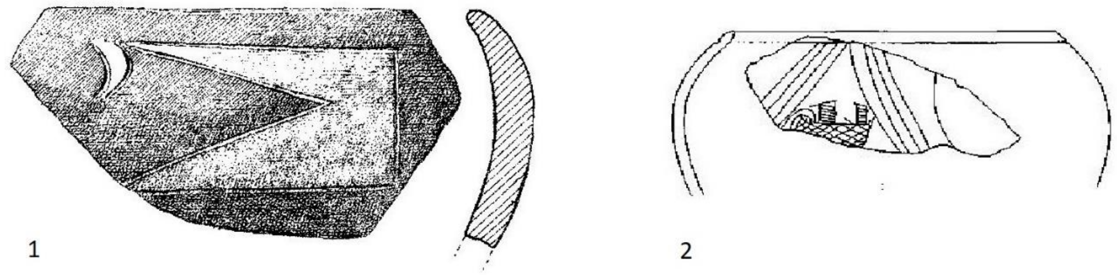

Figure 58 Hvar culture ceramic fragments with depictions interpreted as a comet (1) and a boat (2) (Modified after Petrić (2002)).

These motifs indicate that the Hvar culture community might have had knowledge of astronomy and navigation, which can be supported with the earliest archaeological evidence of prehistoric maritime connectivity found on the offshore islands of the Adriatic Sea (Forenbaher 2009). Dark, burnished pottery, sometimes bearing series of parallel channels (**Figure 59**) have been attributed to the second, later variety of Hvar culture, with most examples found in Grapčeva and Nakovana caves, where they have been radiocarbon dated to around 4300–3950 BC (Forenbaher et al. 2013:602). The typology and stylistic expressions of Hvar culture also indicate cultural connections to the Italian Serra d'Alto and Bosnoherzegovinian Late Neolithic Butmir cultural complexe (Petrić 2002:11). An important cultural connection is represented in the appearance of Nakovana-style pottery within the Late Hvar culture stratigraphic layers. These are believed to be a direct import from the Early Copper Age Central Balkans (Forenbaher 1999–2000:374). According to Forenbaher et al. (1999–2000) synthesis of radiocarbon dates, the entire collection of reliable samples attributed to Hvar culture from Grapčeva, Nakovana and Jačmica cave (the latter being situated in the Istrian Peninsula around 40 kilometres east from Zambratija) showed a radiocarbon date range between around 4800 and 3950 BC. The sample from Jačmica revealed an age of 4230–3985 Cal BC (Forenbaher et al. 2013:592; Jerbić Percan 2011:7), almost identical to the preliminary Zambratija date.

Figure 59 Hvar burnished style (Modified aftr Forenbaher et al. (2013)).

Copper Age – Nakovana-style and the Ljubljana/Cetina groups

Current knowledge about the Copper Age of the Eastern Adriatic remains poorly defined compared with other post-Mesolithic periods. This is because, until recently, archaeological periods were historically determined and defined through the lens of pottery typology. This prevented a precise dating of the transition from the Neolithic to the Copper Age, as the pottery styles of the Early Copper Age are similar with those of the Late Neolithic. One distinctive set of shapes and decorations, however, seemed to have emerged at the time, known under the term Nakovana-style (Forenbaher et al. 2013:602).

Current knowledge about the Copper Age of the Eastern Adriatic remains poorly defined compared with other post-Mesolithic periods. This is because, until recently, archaeological periods were historically determined and defined through the lens of pottery typology. This prevented a precise dating of the transition from the Neolithic to the Copper Age, as the pottery styles of the Early Copper Age are similar with those of the Late Neolithic. One distinctive set of shapes and decorations, however, seemed to have emerged at the time, known under the term Nakovana-style (Forenbaher et al. 2013:602).

The defined term and recognition of Nakovana-style pottery was introduced in the late 1970s by the archaeologist Nikša Petrić, after he examined the pottery finds from the already mentioned Grapčeva, Markova and Nakovana caves (Forenbaher 1999–2000:373; Petrić 1976:305). Even though this channelled fine-ware style was first defined by Petrić, it was described in more detail by Stojan Dimitrijević, who argued that it represents imports from the Central Balkan Early Copper Age Vinča culture, after which it developed into a local stylistic variety. Since the stratigraphical contexts were highly disturbed, he divided the Nakovana-style into proto-Nakovana and Nakovana, based only on stylistic criteria, defined with reference to the Vinča culture (Dimitrijević 1979:371; Forenbaher 1999–2000:374). Nakovana-style is, however, no longer considered to be simply a foreign import but is understood in more nuanced detail as an Eastern Adriatic stylistic trend which started as a direct consequence of imported influences from the contemporary Northern Copper Age societies (Forenbaher 1999–2000:380). The style progressed further north into the Adriatic Basin, to the Istrian Peninsula and the Trieste Karst. It developed there into a locally distinctive variation, sometimes referred to as the Brijuni-group, named after the Javorika-Gromače site on the Brijuni isles where it was first recognised (Čuka 2009:19; Petrić 1979:218).

Nakovana-style (**Figure 60**) has a few defining shapes and ornaments. The colour of the ceramics is either dark, almost black or light brown with black spots. The surface is burnished and decorated with shallow vertical or diagonal channels. The bowls are conically shaped with rounded or angular shoulders, and it is here that the channelling is most often cut. The bowls have cylindrical necks with slightly everted rims and usually do not have handles, but sometimes have vertically performed sub-surfaced lugs and perforations (Dimitrijević 1979:371-372; Forenbaher 1999–2000:373; Koncani Uhač and Čuka 2015:39). As demonstrated in Chapter 2, Nakovana-style pottery has been found in the stratigraphic contexts at Zambratija, with stylistic analogies found across the Istrian Peninsula and Eastern Adriatic Copper Age sites (Koncani Uhač and Čuka 2015:36).

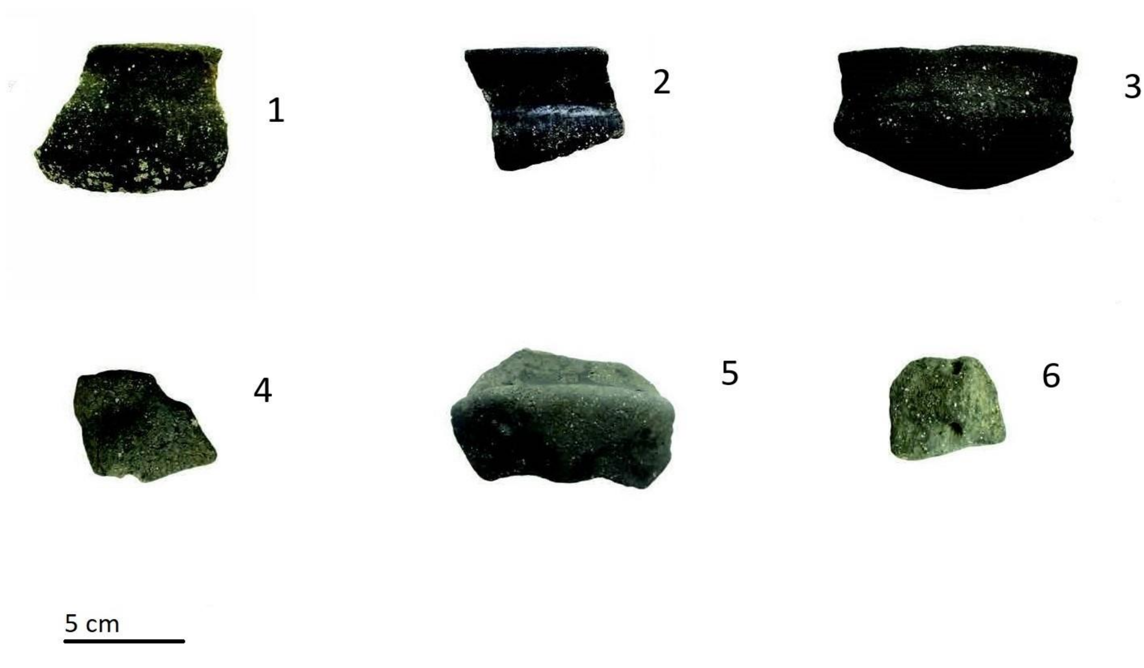

Figure 60 Nakovana pottery from Zambratija Bay (Modified after Koncani Uhač and Čuka (2015)).

Reliable radiocarbon dates from stratified sites across the Eastern Adriatic show that the layers with Nakovana-style pottery appear from around 4000–3500 Cal BC. The closest sites attributed to Nakovana-style in Istria are from Novačka and Pupićina caves and have yielded a radiocarbon range between 3968–3797 Cal BC (Forenbaher et al. 2013:592), partially overlapping with the slightly older Zambratija date (Koncani Uhač and Čuka 2015:28) (see **Figure 25** in Chapter 2).

The Ljubljana culture and its territorial and chronological spread has been a topic of many discussions in Slovenian and Croatian archaeology. At first described as a western output of the Late Copper Age Balkan Vučedol metallurgical civilisation (Dimitrijević 1979:319), it was soon recognised as a separate cultural phenomenon (Velušček 2004:78). The pottery is known for its round-shaped vessels with imprinted or engraved friezes, filled with white incrustations (Dimitrijević 1979:319). There are a few sites with Ljubljana culture pottery in Istrian cave sites of Srbani and Laganiši, which are believed to be direct imports from the contemporary pile-dwellings in today's Slovenia (Čuka 2009:22). Dendrochronological sequences taken from the Ig and Založnica pile-dwellings situated in the Ljubljana marshlands and containing Ljubljana culture pottery, have demonstrated continuous occupation over a 40-year period. The exact dates of the sequences are not known but they fall between the 28th and 24th centuries BC (Velušček 2004:79). The latest known occupation of these sites coincides with the beginning of a transition to the Bronze Age (Velušček 2005) across prehistoric Europe.

The origin and expansion of living on pile-dwellings in prehistoric Europe

In prehistoric Europe, occupation of stilt houses within or adjacent to lakes seems to have originated in the early Western European Neolithic (Menotti 2004b:2). A possible exception to this pattern is the Mesolithic pile-dwelling settlement on the Škofljica site in the Ljubljana marshlands in Slovenia (Frelih 1986; Velušček 2004:75). Palaeobotanical research so far suggests that the origins of the lake dwelling phenomenon in continental Europe is closely connected to the spread of the tetraploid naked wheat (*Triticum durum/turgidurum*) (Jacomet 2004:168), with its earliest traces found in two Western Mediterranean Neolithic stilt house settlements from the 6th millennium BC. These are La Draga on Lake Banyoles near Girona (**Figure 61:2**), Spain and La Marmotta on Lake Bracciano near Rome, Italy (**Figure 61:3**) (Menotti 2004b:2; Schlichterle 2004:30; Tarrús 2008:20, 30). The analyses showed that the grain, sometimes referred to in literature as the 'lake dwelling wheat' (Menotti 2004b:2) is amongst the most common botanical remains found on Neolithic Alpine pile-dwellings (Jacomet 2004:168). So far there are no results implying tetraploid naked wheat within the Zambratija settlement. This could potentially change with the execution and publication of a pollen analyses, which is suggested as one of the further research recommendations in Chapter 9.

The tetraploid naked wheat was cultivated by the people of the Mediterranean Early Neolithic Cardial ware pottery culture (Palomo et al. 2014:68), and is archaeologically supported not only with ceramics but also with grain harvesting tools (Schlichterle 2004:30).

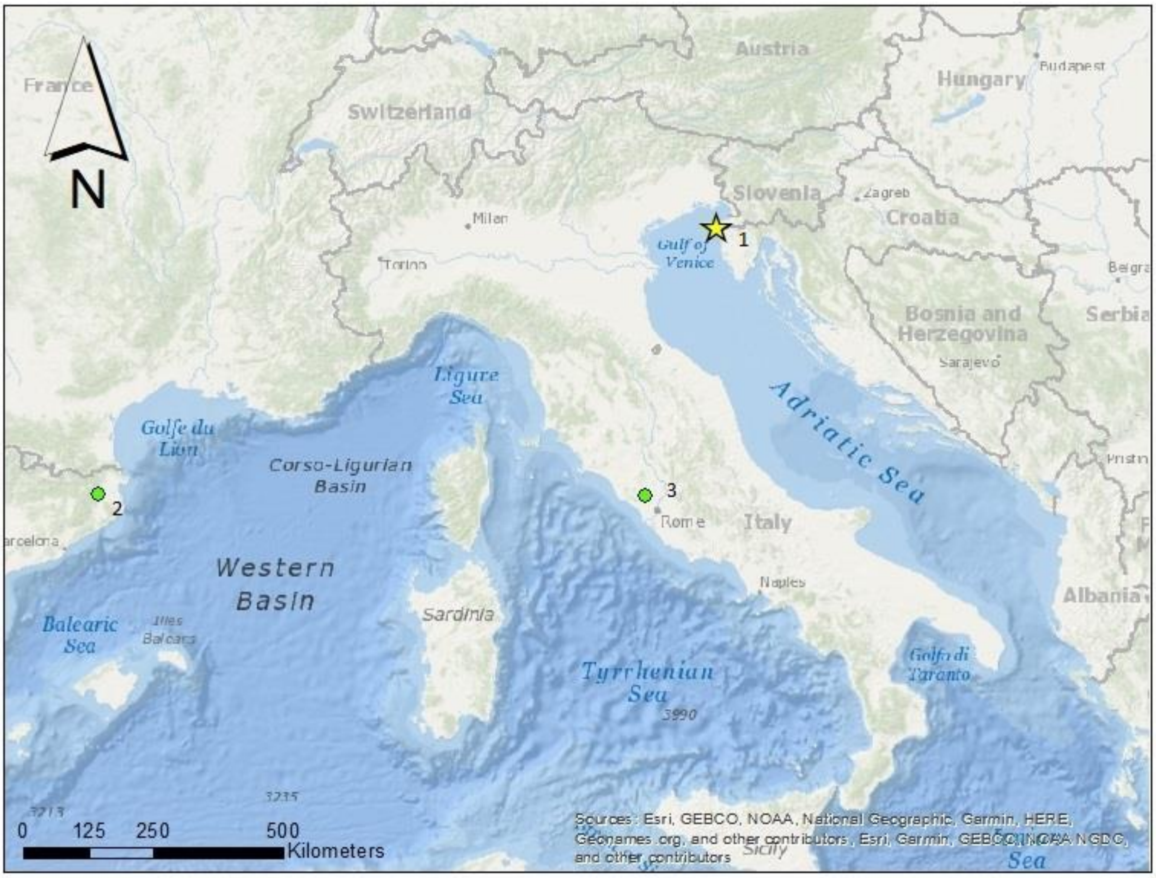

Figure 61 Zambratija Bay (1) and the earliest known Neolithic pile-dwelling settlements in the Mediterranean: La Draga (2) and La Marmotta (3).

La Draga, an Early Neolithic pile-dwelling on lake Banyoles near Girona, Spain represents the earliest known chronological starting point for living on the lake in Europe as well as some of the earliest Western Mediterranean Neolithic (Zilhão 2001:14181). It was discovered in 1990 during a routine rescue archaeology campaign in advance of construction of a park. The archaeologists found prehistoric cultural material on the bottom of the lake, which represented the first case of lacustrine prehistoric archaeological material found in Spain (Tarrús 2008:17). Pottery sherds and other small remains revealed that the village was inhabited by the people who produced the Western Mediterranean Early Neolithic Cardial-ware pottery. This conclusion was also supported with a total of 22 radiocarbon dates (Palomo et al. 2014:66), of which 13 short life-span organic samples fall between 5320 and 4800 Cal BC. Although the analysed tree-rings from the site could not be accurately placed into a dendrochronological curve, they revealed a complete lifespan of the settlement, which was no longer than one hundred years (Tarrús 2008:20) with at least six occurrences of wooden structure rebuilding or replacement (Tarrús 2008:22). Systematic excavations lasted for 18 years, making it one of the most exceptionally well-recorded pile-dwelling settlements in Europe. Although the period of occupation was continuous, it was divided into two distinct phases with a collapse in between (Palomo et al. 2014:62). The village was a near-lakeshore settlement with its waterside edges being frequently flooded by the lake's natural fluctuation processes. The final stratigraphical layers indicated that the abandonment coincided with severe fires (Tarrús 2008:20). La Marmotta in central Italy was excavated in 1989 (Tarrús 2008:31) and also considered as one of the starting points of the lake-dwelling wheat cultivation (Boscato et al. 2008) and expansion (Menotti 2004b:2). It was culturally connected to the Cardial-ware pottery of the late 6th millennium BC, where a local Mesolithic group transformed their lifestyle to an early Neolithic-style lacustrine pile-dwelling (Malone 2003:247). Here, the dendrochronological sequence revealed a total settlement lifespan of 139 years (Tarrús 2008:20).

La Draga and La Marmotta represent a significant change in mode of subsistence that occurred in the 6th century BC Early Neolithic western Mediterranean. These changes involved a shift to long-term occupation of open-space lakeside settlements, near continuously cultivated wheat crops (Antolín et al. 2014:253), as well as in the production of a uniformed pottery style recognisable by its unique decoration of impression patterns made with shells, known as Cardial-ware pottery (Tarrús 2008:31). By the 5th millennium BC, the expansion of the tetraploid naked wheat streamlined into two pathways and ending points – one in Southern Germany and the other on in Austria and Eastern Bavaria (Menotti 2004b:2), when groups with Cardial-ware pottery start to appear in the archaeological record there (Tarrús 2008:31). The Neolithic pile-dwellings in this geographic area represent a new and substantial archaeological complex, known collectively by their UNESCO World Heritage Site designation as the 'Prehistoric pile-dwellings around the Alps' (UNESCO 2017–2018).

Early Neolithic settlements of Western Europe were initially built on dry land, and the origin of building settlements on lakes is considered a combination of two cultural phenomena. The first of such cultural adaptations happened when local Mesolithic hunters-gatherers started settling around the Alpine lakes towards the start of the 5th millennium BC. The second example of is evidenced in the migration of the western Mediterranean Neolithic cultures (Schlichterle 2004:30). The cultural practice of pile-dwelling occupation continued throughout prehistory with several hiatuses, which have been correlated with climate change and lake level fluctuations (Menotti 2004b:3), until around the 7th century BC (Menotti 2015b:25).

After almost 150 years of research (Menotti 2004c), the significance and impact of the Alpine lake dwellings around the lakes and marshlands of today's Austria, France, Germany, Italy, Slovenia and Switzerland to world archaeology was internationally recognised when they were added to the UNESCO World Heritage list of in 2011 (Köninger 2015:32; Menotti 2015b:23; UNESCO 2017–2018; Verdonkschot 2014:40). This boosted interest in the prehistoric freshwater and wetland villages to similar levels as that achieved in the late 19th and early 20th century popularity, when it was popularly referred to as the *Pfahlbaufieber* or 'lake dwelling fever' (Menotti 2001:320, 2015b:16). The fever was then mostly expressed through collection and sale of artefacts (Ruoff 2004:1). Fortunately, the current 'fever' is focused on contextualising the past and present with multidisciplinary research in different parts of Europe, in order to answer important questions about the various connections between human and environmental complex systems. The number of known pile-dwelling sites is already too large to provide a complete list here, but some of the most geographically and chronologically significant ones include: Dispilio on lake Orestias near Kastoria in Northern Greece with an occupational continuity from the Middle Neolithic to Chalcholithic (Karkanas et al. 2011); the lacustrine pile-dwellings of the "Late Atlantic" stratigraphic phase (mid 4th to 3rd centuries BC) in Northwestern Russia, with similar building and lifestyle traditions to the contemporary Alpine pile-dwellings (Kul'kova et al. 2001:92; Mazurkevich and Dolbunova 2011; Mazurkevich et al. 2011); the Late Bronze Age/Early Iron Age pile-dwellings on Lake Luokesas in Lithuania, with possible answers to the abandonment of lakeside living in Central Europe (Menotti et al. 2005); the Bronze Age site Ploča Mičov Grad on Lake Ohrid in the former Yugoslav Republic of Macedonia (Erič et al. 2017:1010; Sherratt 2004:272); and many more. Prehistoric settlement types are being re-evaluated and updated with new, interesting, and most importantly – well preserved archaeological sites, which can bring a multidisciplinary perspective to the topic of the neolithisation as well as the spreading of the lakeside lifestyle pathways across time and space, ending with many local variants throughout Iron Age Europe, such as the crannogs in Scotland and Ireland (Sherratt 2004:273), or riverside pile-dwellings such as that found at the town of Donja Dolina on Sava River in Northern Bosnia and Herzegovina (Potrebica 2003:217).

The discovery and research history of the Alpine pile-dwellings

In 1854 on Lake Zürich near Ober-Meilen in Switzerland, local teacher Johannes Aeppli noticed wooden piles protruding out of the lake bed, which had been exposed when water levels lowered due to extreme winter conditions (Menotti 2001:320). He reported the phenomenon to the local antiquarian society in Zürich. The institution's president Ferdinand Keller immediately recognised a significant archaeological find and by the end that year published a site examination report *Die Keltische Pfahlbauten in den Schweizerseen* (Keller 1854; Menotti 2004b:1, 2015b:15). The same year and on the same lake, on May 22 1854, geologist Alphonse Morlot, together with the Lausanne museum keeper Frédéric Troyon and François-Alphonse Forel performed a prospection of the lake bottom. Their equipment consisted of a bucket-made diving bell and a boat, which not only makes it one of the first pile-dwelling investigations, but also one of the first recorded occasion of using diving equipment for the purposes of archaeology (Hafner 2004:178; Ruoff 2004:11). Keller was the first scholar to present the pile-dwelling phenomenon as something important to the public cultural identity (Keller 1854). He dedicated his life to the investigation and interpretation of the prehistoric pile-dwellings, which resulted in seven more reports, and a further five were published by other authors after his death in 1930 (Menotti 2015b:15-16). Even before his death he became known as 'the father of lake-dwellings' and was supported in his conclusions by prominent contemporary scholars of his time (Menotti 2001:320). Due to the 1869–1888 Swiss flooding control action known as *Juragewässerkorrektion*, the water levels on lakes Bienne, Morat and Neuchâtel were lowered by 2.5 meters (Ruoff 2004:12), revealing even more settlements. The newly discovered sites, in combination with Keller's popular reports, represent the start of two pile-dwelling driven social phenomena – one was the *Pfahlbaufieber*, or the Lake-dwelling Fever, and the other one was an archaeological theoretical dispute known as the *Pfahlbauproblem*, or the Lake-dwelling Problem.

The *Pfahlbaufieber*

Despite the evidence of lacustrine settlements prior to Ferdinand Keller's 1854 investigations of the dwelling near Ober-Meilen on Lake Zürich (discussed below), it was Keller who wrote the first official report, published in *The Bulletin of the Antiquarian Society of Zurich* (Keller 1854) and he presented the prehistoric finds discovered at Ober-Meilen. Keller presumed that the builders and inhabitants of the settlement were most likely Celts, because of the richly decorated bronze objects discovered in the Lake of Bienne (Ruoff 2004:9). The report initiated the Lake dwelling Fever, which was sustained by further discoveries of many other Prehistoric lake settlements in the Alpine region in the following years. Keller named the dwellings *Pfahlbauten*, which translates in English as 'pile-dwellings', and this term was soon adopted by the other two languages spoken around the Alpine lakes, French (*palafittes*) and Italian (*palafitte*) (Menotti 2001:320). It is important to emphasise here that Keller was not the first one to report on the phenomenon. The wooden piles protruding from the bottoms of the Swiss Alpine lakes were mentioned in print on several occasions before, in various reports dating from 1472 to 1806, but were never considered to be of great significance. Reports about ancient lakeside stilt house buildings were also emerging from Lake Constance in Germany, the Salzkammergut region in Austria and Lake Garda in Italy during that time (Menotti 2001:319-320). However, in Switzerland, the *Pfahlbaufieber* inspired a programme of nationalistic ethnic propaganda (Menotti 2015b:19). These ideas were completely abandoned and criticised, and the Swiss lake-dwelling investigations continued and developed into permanent institutions, constituting the leading centre for interdisciplinary European centre for prehistoric pile-dwelling research today.

German archaeologists, inspired by the developments in Switzerland, began archaeological investigations in 1856 on Lake Constance and in 1875 on Lake Feder, where another pioneering idea emerged through the taking of environmental samples for analysis (Schlichterle 2004:22). By 1919, professional archaeologists from the Institute of Prehistoric Research at Tübingen lead by Robert Rudolf Schmidt and his student Hans Reinerth, as well as their archaeological rival Oskar Paret from Stuttgart continued the research. They developed a unique method whereby water was pumped out of watertight chambers (caissons) built in shallow waters, making it possible to excavate the lake bottom. They also made sure to systematically photograph, draw and measure the excavation progress, which resulted in high-quality site maps and illustrations (Schlichterle 2004:23).

In France, the first era of pile-dwelling research started in 1860 on Lake Bourget (Pétrequin and Bailly 2004:36). During that time, the objects found in the lakes were exploited with little regard to their archaeological or stratigraphic context. After that, little attention was paid to pile-dwelling research until 1958 when Oskar Paret's translation of Emile Vogt's series of publications on the "pile-dwelling problem" (see below) was published in French. France consequently joined the 1960s and 1970s revolution of the scientific community, and quickly adopted to the new archaeological advances presented at the time (Pétrequin and Bailly 2004:37).

In 1864, the Austrian Academy of Science initiated the 'Commission for the Search for pile-dwellings in Austrian lakes', which resulted in the discovery of settlements on lakes Keutschacher See (Ruttkay et al. 2004:59) Attersee, Traunsee and Mondsee between 1870 and 1872. As was in the case in surrounding countries, the institutions and individuals in charge were mostly exploiting the sites and accumulating large amounts of finds, without consideration of context. The lake-dwelling sites were mostly investigated through dredging, and little or no information was recorded about the find locations. As was the case with other countries, the situation is much different today and the sites are a part of the UNESCO protected heritage with ongoing interdisciplinary research occurring since the 1960s (Ruttkay et al. 2004:52-53).

In Slovenia, research on pile-dwellings began at Ljubljansko Barje with the accidental find of a wooden dugout boat during a drainage project excavation between 1826 and 1828. Unfortunately, the boat deteriorated quickly after it was excavated as it was allowed to dry out, and therefore its age cannot be determined. Combined with the news of pile dwellings coming from Switzerland, however, it inspired the first archaeological excavations in Slovenia. By 1858, two more dugouts and three stag-horn axes were found in the peat, and in 1875 the first piles were found on the 'Ig road' near Studenec village and reported to the Regional Museum of Carniola in Ljubljana. The importance of these findings was recognised by Dragotin Dežman, who raised the funds for an investigation of the site that same year, making them the first official archaeological excavations in Slovenia (Velušček 2004:72). Throughout the 20th century and until today, the pile-dwellings in the Ljubljana marshlands continue to provide rich evidence that enhance the archaeological record with well-preserved and documented traces of prehistoric life (Velušček 2004:74-75). At the site Škofljica, a few small units excavated in the 1980s, were interpreted to represent a rare case of a Mesolithic pile-dwelling settlement (Frelih 1986).

In Italy, ancient stilt-house villages were known since the eighteenth century, but as was the case with other countries around the Alpine lakes, they became more interesting to the public and the academic community after Keller's first publication in 1854. Several sites were subsequently documented in the Piedmont, Lombardy, Veneto and Trentino regions (Marzatico 2004:83). The next 50 years were marked by pioneering investigations, revealing a range of different settlement types from Neolithic to the Iron Age (Marzatico 2004:85). This also included Fiavé, one of the most significant multilayered pile-dwelling sites in European wetland archaeology. The peat bog at Fiavé was investigated between 1969 and 1976 by not only archaeologists, but also environmental scientists, botanists and dendrochronologists, creating a comprehensive palaeo-ecological and archaeological chronological database (Marzatico 2004:86).

European prehistoric lake-dwelling research went through several transformations throughout its one-hundred-and-fifty-year history (Menotti 2004c). The significance of the pile-dwelling lacustrine way of life, which persisted through 3500 years, and the cultural and environmental impact it had on European prehistoric societies and ecosystems is evidently still greater and more complex than what is known today. The large quantity of publications devoted to the topic is such that this area is almost a sub-discipline of its own. The challenge of modern research to focus on re-evaluating the already known information, and collecting new data with scientific integrity and precision (Sherratt 2004:269). The current number of known prehistoric pile-dwellings around the Alpine lakes is 937, and 111 from all six countries were included in the UNESCO World Heritage List in 2011 (Čufar et al. 2015:91). This recognition is an unquestionable confirmation of resilience, not solely of the inhabitants of the dwellings that were in constant search for better and more efficient ways to adapt, but also of all the past, present and future researchers in constant problem-solving search to answer how they kept succeeding.

The *Pfahlbauproblem*

The discovery and study of the Alpine pile-dwellings throughout the 19th and early 20th centuries provided a few pioneering contributions to archaeology, such as the development of underwater archaeological fieldwork (see Hafner 2004), and the application of interdisciplinary scientific research (eg. Billamboz 2004; Magny 2004). The discoveries were most famous, however, for the multiple attempts to describe the nature and practical reasoning of the physical connection between the wooden architecture and the environment it was built in. Theories about the relationships of these buildings with the lakes themselves have changed radically over the years since the first recognition of pile dwellings. The central question was whether the dwellings were placed next to, partly over, or entirely over the water surface and what caused the builders to choose this specific lifestyle. This discussion, known as the *Pfahlbauproblem*, is significant for being one of the first and longest theoretical disputes in the history of archaeology (Menotti 2015b:16). The term was officially introduced in 1955 by the Swiss prehistorian Emil Voght in a series of papers *Das*

Pfahlbauproblem (Pétrequin and Bailly 2004:37; Ruoff 2004:14), in which he reviewed the contemporary theoretical disputes on the topic of prehistoric pile-dwellings.

Keller was the first to theorise about the architectural and building nature of the settlements and inspired by the then-contemporary water-dwellers in New Guinea and New Zealand (Ruoff 2004:9). He concluded that the settlements must have been built directly over bodies of water all year round – the *Pfahlbauten* (Menotti 2001:320, 322) (**Figure 62**). As more and more sites were discovered, it soon became evident that there were as many differences between them as there were similarities. In addition to sites found in lakes, new types of settlements in peat deposits and marshland environments started to appear in Switzerland, Germany and Italy. These environments allowed the wooden remains and house floors to be preserved exceptionally well but did not reveal whether they were built directly on the ground, over it, or over a body of water. Keller decided to call this newly discovered type of settlement *Packwerckbauten*, or 'houses built on wooden floors' (Menotti 2001:321). The aforementioned German researchers Schmidt and Reinerth started their investigations on the Lake Feder (*Federsee*) peat deposits in the 1920s, where they applied an interdisciplinary approach and included geology, climatology and botany into their research. The results of these investigations made them believe that Keller's *Packwerbau* was an inappropriate term for the settlements, and they changed it to *Moorbau*, or 'marshland houses' (Menotti 2001:321).

Image removed due to copyright.

Figure 62 Keller's theory (Modified after Menott (2001)).

Reinerth developed this theory further and argued that the houses were built on relatively low piles and positioned in the near vicinity of a lake or any area that was subject to seasonal floods caused by natural water level fluctuations (Menotti 2015b:21; Ruoff 2004:13). Reinerth supported his own theory (**Figure 63**) with results from the 1929/1930 excavations on Lake Constance, where he applied his newly developed wooden caisson excavating technique. He investigated around 500 m^2 of the submerged Neolithic settlement as if it was a terrestrial site and managed to demonstrate using archaeological techniques that it had been built on the immediate lake shore, but not in the water (Menotti 2001:322).

The third, and final theory was presented by Schmidt and Reiner's rival, Paret (Schlichterle 2004:23) in the 1940s, drawing on evidence from Neolithic and Early Bronze Age dwellings on Lake Baldegg in Switzerland. There, settlements appeared to have been built on dry land, and the stratigraphic layers containing marsh lay either beneath or above the cultural layers. Paret argued that these lake sediments must have been deposited due to lake fluctuations well before and after the area was inhabited (Menotti 2001:323) (**Figure 64**).

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Figure 63 Reinerth's theory (Modified after Menotti (2001)).

This introduced the concept of past climate change into the discussion which was later proven to be one of the most important factors for occupational hiatuses of Bronze Age lake-dwellings (Menotti 2001:326). This theory was finally accepted in the early 1950s, and the terminology was changed once again. Lake-settlements now became lakeside-settlements, making the centenary jubilee of the first Keller's pile-dwelling theory an ironical discreditation of their original description (Menotti 2001:324).

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Figure 64 Paret's theory (Modified after Menotti (2001)).

With this long dispute settled, the theoretical and research focus over the past four decades has changed direction towards more contemporary archaeological questions (Menotti 2001:324). The reason for that was the rise of the New Archaeology in the 20th century, especially the development of radiocarbon dating and dendrochronology. At the time, the Alpine pile-dwellings became a proving ground for interdisciplinary and scientific research approaches that are today a norm for any kind of archaeological investigation (Menotti 2015b:24). Twentieth century investigations finally revealed that Keller, Reinerth and Paret were all, in fact, correct depending on different settlements and their environments throughout the time of the prehistoric Alpine pile-dwelling tradition (**Figure 65**). The emphasis of modern pile-dwelling research is on determining and reconstructing occupational patterns and chronology – or more precisely, the discontinuity of occupational patterns and chronological hiatuses, as well as the reasons for the disappearance of the pile-dwelling phenomenon in the 1st millennium BC (Menotti 2001:326). These new questions were a direct consequence of the revolutionary discovery of dendrochronology and the creation of large chronological sequences dating back to the Central European Late Neolithic and Bronze Age. With this dating technique it was possible to distinguish different villages built in the same place with sometimes only a few years of occupational time between them (Ruoff 2004:16).

Image removed due to copyright.

Figure 65 The Pfahlbauproblem solved (Modified after Menotti (2001)).

Chronological, environmental and cultural setting of the Alpine pile-dwellings

The development of dendrochronological analysis and the accuracy it allowed revolutionised not only the research of pile-dwellings but also the entire chronology of Central European prehistory (Ruoff 2004:16). Today, the occupation of pile-dwellings of the Northern Alpine range can be followed back to the Neolithic on a calendrical time scale (Billamboz 2004:117). Long tree-ring databases in combination with the analysis of anatomical features of the wooden remains can answer archaeological questions beyond dating. Traces of flooding or frost, or even human activity such as cutting or shredding wood can all be addressed and used as proxies for determining the relationships between the environment and human populations and their lifestyle (Billamboz 2004:129). Considering all the information above, multiple chronologies were built for each region and the initial research into pile-dwellings became the starting point of the archaeological discipline known today as Wetland Archaeology (Menotti 2012). The differences between the chronologies of occupation of pile-dwellings in the Northern and Southern Alps (Menotti 2004a:211, 2015b:24), are due to specific environmental variables in the tree-ring data that allows large sequences, as well as different research histories (Billamboz 2004:127). For this reason, the data from the Northern Alpine region for now represents a more reliable source of chronological information.

The chronology of Northern and Southern Alpine pile-dwellings

The first attempt to place the Alpine pile-dwellings into a relative chronological order was made in 1967 by Vogt (Vogt 1967), and that timeline was then complimented with the first radiocarbon calendrical dates in the 1970s (Menotti 2015b:24). The first complete dendrochronological sequence for the Northern Alpine dwellings was concluded in the 1980s (Becker et al. 1985) which revealed a 3500-year-old lake-dwelling period. This sequence is known as the German-Hohenheim oak chronology, and today it covers an undisturbed timeline between the calendrical years 8480 BC and 2009 AD, making it the world's longest existing tree-ring sequence (Čufar et al. 2015:92). Dendrochronological sequences from Swiss, German and French dwellings (Köninger 2015:36) show that the phenomenon of pile dwelling occupation in the Alpine region started in the Early Neolithic, around 4200 BC and ended in the Iron Age around 630 Cal BC with a ±1 year or sometimes even a ±6 month accuracy (Köninger 2015:37). During that time the occupation of the lake settlements was interrupted several times. This 'discontinuous continuity' (Menotti 2001:326, 2004a, 2004b:2, 2015b:24) is characterised with interchanging periods of intense occupation and total abandonment, with the reasons for the abandonment being different every time. The interchangeable periods are visible in the archaeological remains as traces of sudden and abrupt lifestyle re-adaptations to drastically different new environments (Menotti 2004a:207, 2015b:25), where the cultural continuity is attested in the material culture through indicators such as decorative patterns in the pottery (Menotti 2004a:214).

Three occupational hiatuses can be recognised there and appear to be closely connected to environmental changes. Living near or on a lake naturally means that the lifestyle was highly dependent on lake level fluctuations, which are dependent on the variations in humidity (Menotti 2004a:211). Past lake levels have been calculated based on the visible peaks in the atmospheric ^{14}C record, which implies a high solar activity and therefore a warmer climate. This also indicates periods of lower lake levels suitable for lake-dwellings (Magny 2004:138). Even though understanding the palaeoenvironment is important, environmental deterministic approaches that suggest settlement pattern changes were exclusively in response to changes in climate conditions should be avoided. Scholars agree that this kind of generalisation is outdated and misleading and that many other factors were involved, including cultural factors not easily traceable in the archaeological record (Marzatico 2004:93; Menotti 2009:62). Further ongoing investigations such as paleoenvironmental (eg. Jacomet 2004; Magny 2004) and palaeozoological (eg. Schibler 2004; Stopp 2015) research have the potential to shed light on these questions. Cultural change was also triggered by socio-economic and behavioural factors, such as changes in population density, warfare or economic relations to other cultural groups with different architectural and other traditions (Menotti 2004a:211). Settlement abandonment might have also occurred as a result of poor crop and other natural resource management during times of environmental crises (Menotti 2009:61).

The first of the mentioned hiatuses occurred in the Middle Neolithic, between 3540 and 3410 BC (Menotti 2004a:211, 2015b:24), and seems to have been caused by the rising lake levels, although the climate deterioration at the time was not as severely harsh for total abandonment. In some cases, however, like on Lake Constance in the Northern Alps, abandonment is precisely what happened, which implies other determining factors such as an individual lake's morphological and hydrological characteristics (Menotti 2009:62). The second hiatus is visible in the Early Bronze Age period, between 2400 and 2000 BC, which was again a result of a combination of environmental and cultural occurrences. According to the paleoclimatic data, the lake levels at the time were indeed high, but not for the entire 400 years. Archaeologists argue that the lifestyle pile-dwelling population was not only interrupted by the climate, but also by the contemporary expansion of the Bell Beaker cultural complex happening at the time (Barfield 1994). The settlement type hiatus might mean that the lake-dwelling settlers were either forced to leave, or they might have adopted the Bell Beaker's lifestyle (Magny 2004:138; Menotti 2004a:211). With reference to Zambratija, the Eastern Adriatic variation of the Bell Beaker complex is the already mentioned Cetina culture (Forenbaher 2009:237), and the. The third and final hiatus happened in the Middle Bronze Age, between 1500 and 1200 BC, and it coincided with an intense period of lake level fluctuations that were severely flooding their surroundings (Magny 2004:138; Menotti 2004a:211) (**Figure 66**).

Hiatus time range	Period	Hiatus explanation
3540 and 3410 BC	Middle Neolithic	Lake level fluctuations, other locale-specific factors
2400 and 2000 BC	Early Bronze Age	Higher lake levels, Bell Beaker expansion
1500 and 1200 BC	Middle Bronze Age	Lake level fluctuations

Figure 66 Occupational hiatuses of Northern Alpine pile-dwellings and their explataions.

The chronology of Southern Alpine dwellings in Slovenia, Austria and Northern Italy is still less reliable and accurate than that of the Northern dwellings. The Alpine mountain range is a natural boundary and that boundary is strongly marked in the tree-ring signals, making oak trees growing on the opposite ranges not always compatible for matching (Čufar et al. 2015:91). For this geographical reason, the floating tree-ring sequences are not all connected to one master sequence, and the sites are therefore mostly radiocarbon dated. Floating sequences can be wiggle matched to radiocarbon dates bringing the year-range resolution accuracy in the Southern Alpine dwellings to around ±10–30 years (Barfield et al. 2010; Billamboz and Martinelli 2015; Köninger 2015). It is well-established that the pile dwelling occupation started there in the Late Neolithic, reached a peak in the Early Bronze Age and was then completely abandoned much earlier than in the North, around 1200 BC in the Late Bronze Age (Marzatico 2004:93; Menotti 2015b:24; Velušček 2006a:63) with only one exception at the Italian site of Viverone radiocarbon dated to the late 11th century BC (Köninger 2015:71).

Recent wiggle-matching attempts of floating oak tree-ring sequences from the Ljubljansko barje pile-dwellings slowly started to fill in the missing gaps in the dendrochronological database of the Southern Alpine region (Čufar et al. 2010; Turk and Velušček 2013:184). For now, Slovenian oak chronology can be traced backwards from calendrical years AD 2003–1456 and can be used for cross-dating with sequences within a 700 kilometre radius around Ljubljana (Čufar et al. 2010:2038) with all other tree-ring sequences still floating. The Slovenian pile-dwelling chronology was originally based on 2541 wooden samples from seven dwellings, of which 41% was oak (Čufar et al. 2010:2033). The sequences from these samples were wiggle-matched with calibrated ^{14}C dates, and the calculations showed that the evidence for occupation of pile-dwellings of Ljubljansko barje was strongest from around 3600–3071 Cal BC, with an occupational hiatus between 3332–3160 Cal BC (Čufar et al. 2010:2038). Interestingly, along with the commonly accepted reasons associated with environmental change mentioned above, some authors argue that this hiatus might have been triggered by the sudden decrease of interest in copper, visible in the contemporary Central European archaeological evidence (Velušček 2004:77).

Teleconnection, a referencing method that was later developed, allowed matching of long, multi-centennial sequences from the south with those from the north of the Alps, so that the dendrochronology evidence could be more accurately calibrated (Čufar et al. 2015:92). By referencing a German/Swiss matrix covering a timespan between 3771–3330 Cal BC, Čufar et al. (2015) calibrated the oldest tree-rings from around 3600–3570 Cal BC, and the start of the occupational hiatus from 3332–3330 Cal BC. The attempts to use teleconnection on the period after the hiatus were not as successful (Čufar et al. 2015:96). If, or more optimistically, when the Slovenian oak database becomes an undisturbed calendrical tree-ring sequence, it might be possible to match it with the oak tree-ring sequence from Zambratija, which is situated around 100 kilometres south-west from the Ljubljana marshlands, well within the mentioned 700 kilometre reference radius and on the same, southern side of the Alpine mountain range.

Settlement typology and adaptations

Today, the *Pfahlbauproblem* is considered to be resolved (Menotti 2001:324), and all three theories by Keller, Reinerth and Paret have eventually been accepted as correct (Menotti 2015b:23). Excavations show that there is no specific time when the villages were universally built in one way or another. The decisions about building houses near, partly over or entirely over the water surface were influenced by both environmental and cultural factors, where choices were made according to the most efficient way to adapt to the environment (Menotti 2001:326). This was originally confirmed with the excavation at Fiavé in the bogs of former Lake Carera near Trentino in Northern Italy in the 1960s, where all three types of pile-dwellings were found in one place (Menotti 2001:325; Ruoff 2004:17). The horizontal stratigraphy of the settlement shows that he houses in Fiavé were interchangeably occupied in three zones throughout seven chronological stages from the Late Neolithic, when the houses were built on dry land (Menotti 2001:326) to the Middle Bronze Age, when the settlement was entirely placed over water (Menotti 2001:326; Ruoff 2004:17). Another interesting example of lifestyle re-adaptations can be seen in the Kreutzlingen area settlements scattered around the shoreline and close hinterland belt of today's lake Constance in Switzerland. These settlements were occupied between the 15th and 12th centuries BC, during one of the major lake-dwelling hiatuses. A comparative analysis of house plans and typological features of the found pottery as well as a GIS spatial study proved cultural continuity between the Early Bronze Age lakeside dwellings and the Late Bronze Age dry-land villages (Menotti 2004a:212).

In regards to the abandonment of the pile-dwelling lifestyle and the connection to living in a flood-impacted area, it is important to mention that the lake level fluctuations in Austria seemed to have an influence on settlements being built over wetlands versus over the lake water surface on Mondsee lake (Swierczynski et al. 2013:1610). The oldest radiocarbon dated wooden piles from the Scharfling and See pile-dwellings on Mondsee lake have been radiocarbon dated from 4940 ± 120 to 4800 ± 90 conventional ^{14}C age BP (Swierczynski et al. 2013:1604), which makes them around 200 conventional ^{14}C years younger than the original Zambratija date of 5260 ± 30 BP. However, the lake level oscillations were not the only impact factor to the lifestyle changes, which is evident from the fact that the final decline of the Mondsee group happened during the time of environmentally favourable conditions (Swierczynski et al. 2013:1610).

A positive example of systematic pile-dwelling research can be seen in the extensive research of the submerged Late Bronze Age pile-dwelling of Bevaix-Sud in Bevaux bay on Lake Neuchâtel in Switzerland, published as monograph by Arnold and Langenegger (2012). The underwater excavations lasted there from 2004 to 2007, and the preparation, fieldwork and laboratory research there was executed following the highest methodological standards. The dendrochronological data revealed that the village was originally built in the winter of the calendrical year 1011/1010 BC and had several architectural readjustments and reinforcements throughout its occupation with the youngest architectural oak post being chopped during the calendrical winter of 952/951 BC (Arnold and Langenegger 2012:209).

The evolutionary development of the spatial organisation of stilt houses can be recognised chronologically on individual sites. Topographical reconstructions showed that the oldest houses in Upper Swabia from around 4200–3650 BC were rectangular and organised in irregular patterns facing the lake shoreline. Around 3500–3300 BC on Lake Constance and Lake Feder, the villages that occurred every 2.5–5 kilometres were organised in clusters of houses with streets. The settlements there began building protection fences, palisades and other types of fortifications at around 3850 BC, which lasted until around 3000 BC. The inhabitation lifespan of one village was between 10 and 80 years, and sometimes the same position was re-occupied later on (Schlichterle 2004:29).

Cultural connections between the Late Neolithic/Copper Age Southern Alps and the Eastern Adriatic

The relatively small area of the Alpine glacier lakes was evidently a crossroads where cultural and environmental influences overlapped throughout prehistory. The research database has already created more questions than it has given answers but fortunately, modern archaeology and interdisciplinary research are ongoing and constantly improving (Schlichterle 2004:26). Material culture found in the settlements shows that a variety of cultural groups were using the stilt-house building technique throughout its 3500-year-long tradition. Late Neolithic beginnings of the phenomenon in Central Europe seem to be closely linked to the beginnings of copper processing (Ruttkay et al. 2004:56), which is culturally and economically associated with the metallurgical expansion from the Balkan and Carpathian mountain ranges in the 4th millennium BC (Ruttkay et al. 2004:57). The key examples will be presented here to highlight the evidence linking the Southern Alpine pile-dwellings to Eastern European and Eastern Mediterranean Late Neolithic and Early Copper Age cultural complexes, evidence of which has also been found in the pottery from the underwater research in Zambratija.

The Neolithic pile-dwelling situated on a small hill submerged under the *Keutschacher See* Lake in the Austrian Carinthia district was first discovered in 1864 as a direct consequence of the *Pfahlbaufieber*. The floating oak chronology from the site was successfully synchronised with other northern Alpine sequences revealing an occupational end date of 3887 Cal BC, which together with a radiocarbon date range from 4100–3700 Cal BC makes the Keutschacher settlement the oldest known pile-dwelling in Austria. Copper finds from there represent the oldest evidence of arsenic copper in Central Europe (Ruttkay et al. 2004:59-60). The typological characteristics of the ceramics found on site imply that the settlers were a part of the Kanzianiberg-Lasinja group of the Late Neolithic Epilengyel cultural complex, which was occurring at the same time in Croatia, Hungary and Austria (Samonig 2003:41).

The Kanzianiberg-Lasinja group overlaps chronologically with Resnikov Prekop, which is the oldest pile-dwelling settlement in the Ljubljansko barje marshland dated to around 4400 BC (Velušček 2006b:63), and the material culture suggests that the settlement had cultural contacts with both Eastern Alpine and Western Carpathian groups (Velušček 2004:76). Two interesting connections regarding cultural groups in Croatia and the Eastern Adriatic were found there. The first example are the typologically similar pottery sherds associated with the Sopot IIA–III cultural complex (Velušček 2006a:63), which was prevalent in the south-eastern Europe throughout the 4th millennium BC and characterised by tell-type settlements and simple pottery (Obelić et al. 2004). The second example is a dish attributed to the Late Neolithic Eastern Adriatic Hvar culture (Velušček 2006b:62).

The occupation of Ljubljansko barje marshlands at around 4400 BC is characterised by the appearance of copper finds at the Hočevarica site, which appeared to have been an important metallurgical centre at the time. The minerals traced in the metal finds indicate raw materials mined in the Alps and therefore a trading connection to that area (Velušček 2004:76). Influences from Early Copper Age Eastern Adriatic can be seen in the dark coloured pottery, which can additionally be supported with the finding of a stingray bone fragment (Velušček 2004:77).

After Hočevarica, chronological continuation is seen in the pile-dwellings at Maharski prekop and Stare Gmajne, which lasted until around 3500 BC, leading into the start of the already mentioned occupational hiatus visible in the dendrochronological sequences (Čufar et al. 2010:2038; Čufar et al. 2015:96). The next re-appearance of the pile-dwelling lifestyle happened there around 2800 BC and lasted until the 2300 BC. It was mentioned earlier in this chapter that the material culture from this period was defined as the Ljubljana culture, which was contemporary to the Copper Age 'metallurgical giant' from the Balkans, the Vučedol culture complex (Velušček 2004:78).

Riverside living? A case study demonstrating the importance of interdisciplinary research

Evidence of prehistoric riverside pile-dwellings has been confirmed in the early European Iron Age (Potrebica 2003:217). However, the prehistoric pile-dwellings around the Alps have invariably been found by lakes and lake marsh deposits. Recent Slovenian research suggests that stilt houses were also built beside rivers. Since Dežman's first investigations in the 19th century, more than 40 prehistoric lakeside dwellings were recorded in the Ljubljansko barje marshlands, dating from the Late Neolithic to the Middle Bronze Age (Turk and Velušček 2013:184), some of which were successfully wiggle-matched and referenced to the northern Alpine oak sequence, as explained in previous paragraphs (Čufar et al. 2010; Čufar et al. 2015). The complex relationships between settlement patterns of Slovenian pile-dwellings and environmental changes have been studied through series of interdisciplinary paleoenvironmental investigations (Turk and Velušček 2013:184).

Models and reconstructions of landscape and sea-level evolution generated by remote sensing techniques and advanced software are considered as standard methodology, and large and complicated datasets are starting to reveal new types of information. Recent LiDAR topographical surveys of the Ižica floodplain in the Ljubljana marshlands revealed a series of paleochannels, with sediments that were radiocarbon dated to before 3770 Cal BC, contemporary to the Eneolithic settlements in the floodplain (Budja and Mlekuž 2010:1269). This made some archaeologists rethink the lakeside dwelling hypothesis, and suggest that instead of lake-related settlements, these were, in fact, riverside stilt house villages (Budja and Mlekuž 2010:1269; Turk and Velušček 2013:184). Consequently, sedimentary analyses were conducted in the Ljubljansko Barje marshlands, with the aim to investigate the type of wet environment that the villages were built in and how the settlement patterns adapted through time as the environment was changing. The results showed an evolution of the former lake basin progressively withdrawing towards the floodplain centre, with the oldest settlements situated closer to the basin edge, while the younger sites were situated further away from to the basin. By the end of the pile-dwelling era, in the Middle Bronze Age and after, the settlements were built on dry land, the lake had disappeared, and the marshland was traversed by a few meandering river streams (Turk and Velušček 2013:188). By then however, the new settlers built their houses on completely dry land on the marshland outer edges (Velušček 2005). Combining the archaeological data with the sedimentary results therefore contradicts the prehistoric riverside living in Slovenia hypothesis originally suggested by Budja and Mlekuž (2010).

This Slovenian example demonstrates the importance of multidisciplinary research, not only in wetland archaeology but across archaeological sub-disciplines. Whether driven by nature, culture or a combination of factors, human occupation and its relation to the environment can be seen as a historical sequence of chain reactions and decisions. Cultural groups suffered the consequences of these relationships depending on their chosen adaptive pathways, which were not always successful (Menotti 2009:64). These pathways can be seen in archaeological research, by focusing attention to not only past human complex systems but also the natural systems, the results of which can be used in modern day debates related to planning a successful adaptation to present and future climate change (Van de Noort 2011:1046). For that reason, the results obtained for this PhD research will be studied through the lens of Climate Change Archaeology.

CHAPTER 5: THEORETICAL FRAMEWORK

The archaeologically and environmentally circumstances of Zambratija Bay led to an unexpected discovery, therefore the initial underwater research did not include theoretical and methodological skillsets or developed interdisciplinary connections to engage in a comprehensive and systematic exploration of the site. (Benjamin et al. 2011a; Boetto et al. 2015; Koncani Uhač 2008, 2009; Koncani Uhač et al. 2017a; Koncani Uhač and Čuka 2015; Koncani Uhač and Uhač 2012). The duration of each those initial investigations did not exceed more than two weeks. This is due to several factors – the remains of the settlement lay three metres below MSL and therefore archaeological excavations and the following of stratigraphic and cultural contexts can only be conducted by diving. This provides some technical, organisational and financial barriers to overcome as compared with a land-based archaeological operation (Bailey 2011; Faught and Flemming 2008; Nutley 2014:267). Some of the larger questions, such as the spatial extents of the settlement, occupational timeline(s) and socio-economic developments in the settlement, as well as the environmental history and climatic occurrences which triggered all the site formation processes leading to the conditions we see on the site in present time, therefore remained unknown. A few of these questions will be addressed in this thesis, based on the small-scale research due to the budget- and timeline-sensitive nature of an independent PhD project. The design and motivation for this thesis was therefore developed as a proposal for a sustainable investigation model designed around the specific characteristics of the site. Supported by a combination of empirical evidence and archaeological research and interpretation, the thesis could create a realistic opportunity for a larger project in the future. The research was done by fieldwork, followed by a series of selected interdisciplinary laboratory analyses. The results were then overlapped with those from the 2008–2015 investigations, creating a larger dataset with enough environmental and archaeological evidence for a comprehensive analysis of past relationships between the natural and human complex systems in Zambratija Bay. The fieldwork and laboratory methods were chosen based on a combination of collected theoretical and empirical site-specific preliminary knowledge presented in Chapters 2–4, which can, according to the way it was obtained, be divided into 1) introductory, 2) empirical and 3) desk-based knowledge:

1) A 3-metre-deep seabed in Zambratija Bay in the Northern Adriatic basin showed evidence of a submerged landscape and an archaeological site. The collected evidence opened a set of archaeologically and environmentally important questions about the relationships between past climate change and cultural influences. The mentioned evidence included wooden piles protruding from the seabed, remains of peat on the seabed close to the piles and ceramics with a typology showing similarities to known local prehistoric cultures, found on the seabed around the piles and peat. The found wooden piles show a regularity, possibly

a building pattern, which was further supported by findings of daub, while the horizontal extents of the site shows a circular pattern following a natural feature.

2) The bathymetry of the bay showed that the site is located on the edges of a submerged karstic sinkhole filled with sediments and protected by natural limestone ridges. One hundred wooden piles were georeferenced so far, with a total number still unknown. The collected daub in combination with the piles around a sinkhole with the presence of peat, indicated submerged stilt houses built over a freshwater environment. Five excavated units revealed stratified layers of marine, brackish and freshwater sediments. The brackish sediments contained remains of pottery and lithics. The found pottery is typologically determined to the Adriatic cultural complexes ranging from the Late Neolithic/Early Copper Age to the Bronze Age. The Early Copper Age Nakovana-style pottery was found in the stratigraphic contexts of Units 1 and 5. A fully excavated wooden oak pile from Unit 1 with a sharpened end showed a radiocarbon age of 4230–3980 Cal BC, a date corresponding with the Nakovana-style contextualised fragments from other sites in the area.

3) The formation of karstic depressions or sinkholes is a natural process which occurs in aerobic conditions. The most recent time when the Northern Adriatic Basin was terrestrial landscape was 20,000 years ago, when local sea-level was around 110 metres lower than today, and it was rapidly rising until around 2,000 years ago when it reached present-day levels. Submerged karstic depressions contain preserved stratified evidence of previous marine transgressions and paleo-landscapes. By analysing geochemical and biological proxies found in the sediments, it is possible to chronologically reconstruct the deposition of stratigraphic sequences, and therefore the local sea-level rise and its impact to the submerged landscape. The peat, wood and cultural remains indicate that this was a pile-dwelling built over a brackish or freshwater environment. Submerged prehistoric sites with similar pottery and evidence of buildings on stilts on the Eastern Adriatic coast show a maritime nature of the settlements, not freshwater. The nearest known stilt house buildings in freshwater environments are a part of the Alpine prehistoric pile-dwelling phenomenon which discontinuously lasted for almost 3000 years from the Late Neolithic (around 4300 Cal BC) to the Early Iron Age (around 500 Cal BC). Both the Adriatic and Alpine cultural influences on the site have similar radiocarbon date ranges to the one from Zambratija. According to sea-level change calculations, the Adriatic Sea was up to 4.0–9.0 m lower around 4000 Cal BC.

In conclusion, the Zambratija Bay site in the only known submerged prehistoric pile-dwelling in the Adriatic Sea. It was built over a freshwater paleo-landscape, preserved today because of a combination of anaerobic environmental circumstances, which were a consequence of a global sea-level change. The archaeological evidence supported by one radiocarbon date shows a combination of Adriatic and Alpine prehistoric cultural connections. The radiocarbon date is also aligned with the Holocene marine transgression, which reached the Northern Adriatic at around 6000 years ago, possibly influencing the abandonment of the site. The formation and abandonment of the site is chronologically unclear, and its disclosure would be of great significance for submerged prehistoric archaeology worldwide.

International examples, comparable with Zambratija do exist, however they are relatively rare. Similar chronologically contemporary sites are known from Northern Europe, including the Late Mesolithic settlement of Tybrind Vig (Andersen 1985, 2011, 2013). However, the Danish sites were not pile-dwellings, though the archaeologists working at Tybrind Vig recorded cultural continuity from 5400–4000 Cal BC, submerged 2–3 metres under the western Baltic Sea with exceptionally well- preserved organic remains. Submerged Middle and Late Holocene pile-dwellings to date were globally known only from the lagoonal sediments on the Sozopol and Urdoviza sites in the Black Sea (Draganov 1995), showing a similar continuous discontinuity to the Alpine pile-dwellings with an occupational hiatus of a few hundred years, possibly connected to the increased rate of sea-level rise in the mid 4th century BC (Flaux et al. 2016:65). Most recently, an Early Bronze Age pile-dwelling architecturally similar to the one in Zambratija Bay was found in the Alepu paleo-lagoon, submerged from -5.8–6.8 m MSL on the western coast of the Black Sea (Flaux et al. 2016).

Whether submerged under the sea or a lake, or preserved under layers of peat, all the mentioned sites above have three common components. First, they were all built and used as settlements between the Late Neolithic and the Bronze Age. Second, they were constructed in environmentally different circumstances than of those found in the present. Third, both of those components are overlapping on the Zambratija site, making it an archaeologically interdisciplinary combination of Prehistoric Archaeology of the Continental Shelf (PACS) (Bailey et al. 2017b; Benjamin et al. 2011b; Harff et al. 2016a; Lewis Johnson and Stright 1992; Masters and Flemming 1983b) and Wetland Archaeology (Menotti 2004b, 2012). As a consequence, these archaeological sites, including Zambratija, today represent a suitable ground for studying the impact of previous climate change and how it affected the relationships between past environmental and cultural systems. Therefore, the investigation methods for this PhD research were chosen based on those previously successfully performed on prehistoric continental shelf and wetland archaeological sites, both of which use a set of interdisciplinary methods known as Environmental Archaeology (Dincauze 2000; Reitz and Shackley 2012). The results of these methods were then interpreted through the theoretical lens of Climate Change Archaeology, originally described by Van de Noort (2011) (**Figure 67**). Therefore, in order to choose the most effective research methods for investigating the submerged pile-dwelling in Zambatija Bay, it was necessary to understand the archaeological disciplines which represent the theoretical viewpoints through which the site can be assessed from.

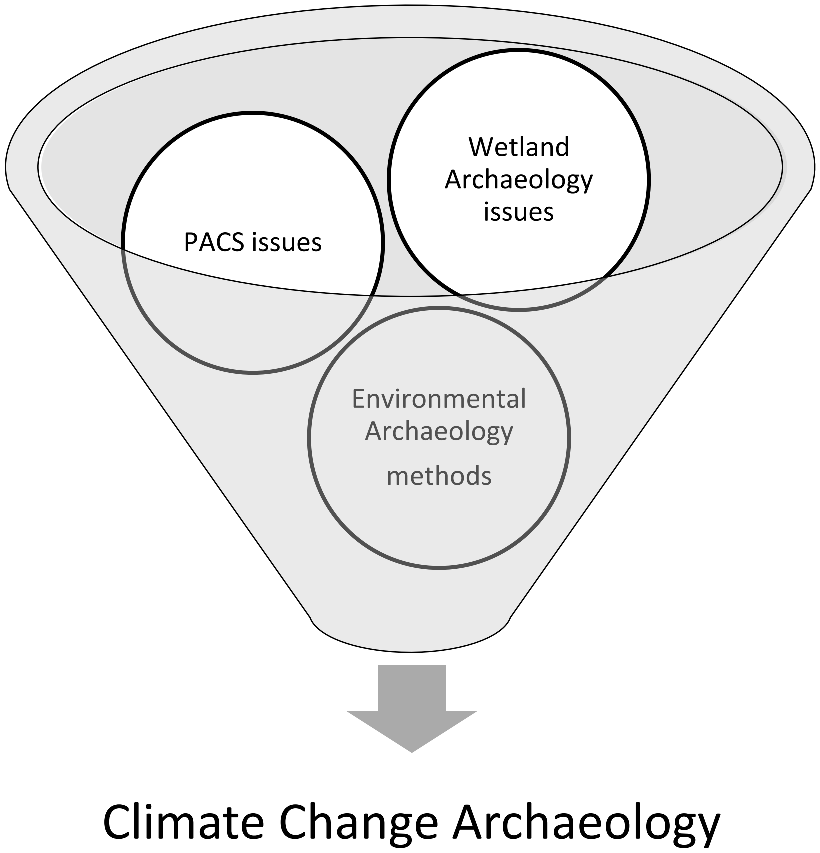

Figure 67 A graphical illustration of the combination of archaeological disciplines used for choosing the research methods. The specific environmental and cultural issues of the submerged Zambratija Bay pile-dwelling are a combination of Submerged Prehistory and Wetland Archaeology. Both of these disciplines use Environmental Archaeology research methods for addressing their hypotheses. In Zambratija, the hypothesis will be addressed through the theoretical lens of Climate Change Archaeology.

Prehistoric Archaeology of the Continental Shelves

According to *Article 1* of the Convention on the Continental Shelf held in Geneva in 1958, the term 'continental shelf' refers to *"(a) the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas; (b) to the seabed and subsoil of similar submarine areas adjacent to the coasts of islands*" (UN 1958:2). In archaeology, a continental shelf is the part of the seabed exploited by society in the form of navigation, fishing or mineral exploration (Chiocci and Chivas 2014:2). As presented in previous chapters, the exposure of past coastal landscapes and shorelines on the continental shelves to subaerial conditions during periods of lower sea levels has been known for over a century (Andrijašević 1910; Reid 1913). The focus on the post-glacial marine transgression and Holocene landscape evolution and their impact on prehistoric coastal societies has seen a renewed interest in the archaeological community over the last decade (Bailey and Flemming 2008; Bailey et al. 2017b; Benjamin et al. 2011b; Evans et al. 2014; Harff et al. 2016a), however the origin of this development can be traced back to the 1981 Symposium held in La Jolla, California at the Scripps Institute of Oceanography (Masters and Flemming 1983a). Although attempts have been made in addressing the archaeological potential of the submerged landscapes on the continental shelves (Emery and Edwards 1966; Shepard 1964), the significance of this symposium is known today as the first global recognition and identification of the world's continental shelves as a mutual field of interdisciplinary study which included oceanographers, geologists, climatologists, anthropologists and archaeologists (Bailey 2011:312, 2014:291; Masters and Flemming 1983a). The proceedings of the symposium, *Quaternary coastlines and Prehistoric archaeology: Towards the prehistory of land bridges and continental shelves* by Masters and Flemming (1983b), therefore represents a benchmark in archaeological literature as the first academic attempt to include archaeological research as an equal participant in sea-level change and paleo-climate studies of the continental shelves worldwide.

When addressing the issues regarding the impact of sea-level change to prehistoric coastal communities and the missing prehistoric archaeological record which is now submerged under shallow coastal waters around the world, authors with a mutual interest in the topic have used a combination of several different terms. These terms, such as Submerged Prehistory (Benjamin et al. 2011b; Faught and Gusick 2011), the Underwater Archaeology of Submerged Landscapes (Benjamin 2010; Benjamin et al. 2018; Ward et al. 2016) and the Archaeology of the Continental Shelf (Bailey 2011; Bailey and Flemming 2008) or their combinations (Harff et al. 2016a; Lacroix et al. 2014), all have a mutual interest in identifying archaeological deposits in natural environments submerged by the rising sea-levels throughout history. Due to the fact that archaeological remains and past landscapes can be submerged not only under the oceans but also lakes, rivers and other aquatic environments, the term used in this thesis will be Prehistoric Archaeology of the Continental Shelves (PACS), which indicates that the case study for this thesis is a prehistoric site that was transgressed by a marine environment and is currently located submerged under coastal waters.

Since its beginnings, the discipline of investigating PACS has evidently been a collaborative science which included a number of different, but equally important and cross-referential methods and approaches, most often as a combination of archaeology, geology, oceanography and environmental sciences (Harff et al. 2016a; Lewis Johnson and Stright 1992; Masters and Flemming 1983b). The re-emergence of PACS revoked some issues regarding the organisation of the methodological steps to take in order to investigate a submerged site to its fullest potential. Although several edited books and scientific papers (Draganov 1995; Lambeck et al. 2002; Lewis Johnson and Stright 1992; Quinn et al. 2002; Šegota and Filipčić 1991; Stein 1986) emerged in the years following the Masters and Flemming (1983b) edition, it wasn't until the last decade when archaeologists worldwide started to express a deeper interest in the landscapes and the archaeology which were submerged due to the polar ice deglaciation after the LGM. Published research such as Antonioli et al. (2016), Bailey et al. (2017c), Dixon and Monteleone (2014), Gearey et al. (2017), Ward et al. (2015) and others have a common interest in the environmental mechanisms behind these post-LGM processes worldwide, but also in the multidisciplinary research methods and practices for investigating the natural and cultural responses to those processes. The results of these methods and practices have a potential to improve and change our knowledge of past human behaviour and migration patterns, which shaped the world we live in today (Dixon and Monteleone 2014:95). Today, the academic interest in PACS seems to have reached a global level of understanding regarding the archaeological significance of the landscapes lost due to sea-level rise, however the interest in the topic was not equally represented in the academic literature in the past. Systematic underwater archaeological investigations of PACS started in the areas with geographic, tectonic and climate conditions favourable for long term preservation of sediments and organic remains (Fischer et al. 2011:332; Flemming 1983b), and where archaeological research was already highly developed during the emergence of SCUBA gear in the mid 20th century (Masters and Flemming 1983a:xi). In Europe, these pioneering systematic investigations were performed in the Western and Eastern Mediterranean and the Baltic Sea. In the Western Mediterranean, The French Department for Underwater Archaeological Research (*Département de Recherches Archéologiques Sous-Marines* – DRASM) carried out their first studies of underwater caves between Marseilles and Cassis during 1968–1980, which resulted in the first findings of Palaeolithic occupation in the submerged cave of Grotte des Trémies near Cassis, which lies 20m below sea level (Clottes et al. 1992:583). The Eastern Mediterranean investigations started on the Israeli Mediterranean coast, where a submerged Neolithic village at Neve Yam was exposed due to a storm in 1968 and immediately excavated (Wreschner 1983:325). In the Baltic Sea, the first excavations of the Late Mesolithic Ertebølle culture submerged settlements at Tybrind Vig in Denmark started in 1972 (Andersen 1985, 2011, 2013).

As mentioned, PACS is now a recognised archaeological discipline dedicated to the investigation of land areas of the continental shelf worldwide, which were submerged due to the past global sea-level, tectonic and climate change events (Sturt et al. 2018:655). The focus of interest of many archaeologists studying PACS is to identify the preserved submerged archaeological sites that have not yet been discovered, which are spread across vast areas of seabed. This is evident in the most recent edited books (Bailey et al. 2017b; Benjamin et al. 2011b; Evans et al. 2014; Harff et al. 2016a) with chapters discussing the importance of collaborative research on submerged prehistoric sites led by archaeologists. Expert-led research has so far mostly been limited to survey such as remote sensing, landscape surveys, seabed mapping and sub-bottom profiling (Cassen et al. 2011; Dixon and Monteleone 2014; Faught 2014; Flemming 1983a; Missiaen et al. 2017b; Quinn et al. 2002), and unfortunately still relying on chance and amateur finds (Clottes et al. 1992:584; Masters and Flemming 1983a:xi) which, as a consequence, were either partially or completely contextually ruined (Geddes et al. 1983:179; Lacroix et al. 2014:24; Pearson et al. 2014:54).

Unlike most archaeological disciplines, current PACS research does not rely on excavated, stratified sites and material culture but rather on predictive models and survey results. This lack of physical evidence significantly limits the research, which often does not happen due to unsuccessful grants and a loss of interest from the general public and potential investors. That is why it is important to develop an additional methodological step to fill out this 'methodological gap' between survey and excavation, which can even be seen in the earliest publications which raised issues such as *"Does significance merit the effort?"* (Masters and Flemming 1983c:605) and *"…controversy is healthy as long as it is accompanied by dialogue."* (Lewis Johnson 1992:v). The technical advances in the precision of marine seabed research methods such as remote sensing and radiocarbon dated seabed cores and a worldwide recognition of underwater archaeological evidence (Bailey and Flemming 2008:2154), as well as the development of high-resolution past sea-level geophysical models such as that of the Mediterranean by Lambeck and Purcell (2005), stimulated further archaeological questions in the twenty-first century. Not only that these new datasets demonstrated a significant gap in knowledge about the extents of past landscapes and their occupation and exploitation, but PACS also provided evidence of settlement and migration patterns in past human behaviour regarding the use of marine resources, which were unavailable or have not yet been supported by the finds provided with terrestrial archaeology (Bailey and Flemming 2008:2162). However, with more evidence of PACS which is constantly updated with new data, it becomes evident that submerged sites are often endangered by the same natural forces that reveal them.

Factors such as seabed erosion, biological destruction and extreme climate events (Fischer 2011), represent a current threat to submerged archaeological evidence. As a consequence of this threat, combined with the mentioned methodological gap in the discipline, archaeologists recently revoked the old questions (*"…where next?"* (Bailey 2011)), and started suggesting possible solutions for a systematic research infrastructure (Flemming 2011) with clear research questions (Bailey 2014:294) and exploration strategies (Bailey 2014:297). With authors reaching as far as suggesting mathematical equations to assess the significance of a submerged site (Flatman and Evans 2014:6) (**Figure 68**), current academic discussions emphasise the importance of an interdisciplinary approach, which would include not only scientific research but also other areas of the society such as governments, industry and the general public (Bailey 2011:327; Bailey et al. 2017a:15; Flatman and Evans 2014:8; Harff et al. 2016b:7; Holmlund et al. 2017; Salter et al. 2014; Satchell 2017; Sturt et al. 2017).

$$W \text{ (area)} + X \text{ (potential)} + Y \text{ (likelihood)} = Z \text{ (significance)}$$

Figure 68 PACS Significance Equation by Flatman and Evans (2014).

One part of the solution to these new/old issues lie in the publication of not only new research and data, but also sharing experiences and providing advice and possible solutions. Recently, maritime archaeology studies and projects such as Gately and Benjamin (2017) or Sturt et al. (2017) have already started discussing about experiences within some of these mentioned areas (general public and industry in the mentioned cases) and started identifying and addressing the misunderstandings with which maritime archaeology is faced with today and the lessons that were learned for the future. Another part of the solution is to develop a research methodology for the efficient recognition of submerged archaeological sites (Lacroix et al. 2014:18) of great significance to the understanding of past, present and future human behaviour and relationship to the environment.

Although not originally developed for the purposes of archaeological research, seabed mapping methods such as sidescan and multibeam sonar surveys and shallow water sub-bottom profiling, as well as aerial photography and SCUBA diving surveys, are now considered the standard in maritime investigations whose aim is to recognise submerged archaeological sites (Benjamin and Bonsall 2009:166; Carabias et al. 2014:143; Dunbar et al. 1992; Faught 2014; Garrison 1992:104; Keegan 1992:11; Lacroix et al. 2014:21; Moseley et al. 1992). However, for many reasons such as legislation or budget restrictions (Salter et al. 2014:155), and unfortunately for PACS, this is often the moment when most fieldwork research stops. In the rare cases when the research is continued further, it involves diving, excavation, coring or dredging (Carabias et al. 2014:134; Faught 2014:44) which are actions that represent a stressful risk for both the archaeologists and the investors, not only because it involves diving and underwater excavations, but also because of the high likelihood of a negative archaeological result (Faught 2014:46), regardless of the promising preliminary surveys. This is why PACS often relies upon chance finds, mostly due to industrial and commercial seabed drilling, dredging or trawling (Bynoe et al. 2016:858; Emery and Edwards 1966:733; Faught 2014:37; Geddes et al. 1983:179; Kraft et al. 1983:88; Lacroix et al. 2014:14; Pearson et al. 2014:54; Stanford et al. 2014:73). Some improvements have been made, thanks to the large, government-financed and archaeology-based projects worldwide, with a focus to improve, investigate and promote PACS as a significant contributor to the knowledge of the global cultural and environmental past. Some of these recent and current projects are *Gateway to the Americas* (Dixon and Monteleone 2014:104), with the aim to search for Late Pleistocene PACS sites in the North Pacific; *SINCOS (Sinking Coasts—Geosphere, Ecosphere and Antroposphere of the Holocene Southern Baltic Sea)*, focused on the research of changes in coastal landscapes od the German Baltic coast (Jöns and Harff 2014:173); SPLASHCOS – investigating European submerged landscapes[5] (Bailey 2014:295; Bailey et al. 2017a:1; Galili et al. 2017a; Uldum et al. 2017:65); The Lost Frontiers project – investigating Doggerland[6] (Gaffney et al. 2017); and Deep History of Sea Country – investigating submerged landscapes in Australia[7] (Benjamin et al. 2018). Seabed coring provides an insight into the submerged environment, and of the cultural layers of a mapped site. Therefore, the risk of 'empty' units is minimised, and the sediment contents represent a connection between archaeological survey and fieldwork. As one possible step towards filling and/or overlapping the mentioned methodological gap, this thesis proposes a research-based and

[5] https://www.splashcos.org
[6] https://lostfrontiers.teamapp.com
[7] https://deephistoryofseacountry.com

tested interdisciplinary method: a combination of geological, environmental and archaeological fieldwork and laboratory techniques, under the term 'Archaeology of the Core', described in more detail in Chapter 6.

Wetland Archaeology

The oldest fossil records of a wetland ecosystem comes from the Silurian era 440 million years ago (Greb et al. 2006:4). The ecological appearance seen in the fossil footprint of wetlands was evidently changing throughout the millions of years reaching the Quaternary, which is when environmental records show the start of peat moss or *Sphagnum*-mire complex domination (Greb et al. 2006:29). The growth and development of *Sphagnum* moss is closely connected to low oxygen levels, which allows for organic material to accumulate over time and develop into peat deposits, which are known to be a natural reservoir of fuel, building material and agricultural soil (Reitz and Shackley 2012:194) highly valuable within human societies throughout history (Greb et al. 2006:30).

The term 'wetland' was first internationally recognised and accepted at the 1971 Convention on Wetlands of International Importance in Ramsar, Iran[8]. According to the convention, wetlands are *"…areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.*" (Matthews 2013:38). In other words, a wetland is an ecosystem which was at some point in its existence, whether seasonally or daily, partially or entirely covered by water (Nicholas 1998:721). Being extremely biologically diverse and susceptible to environmental change, wetlands represent ideal case studies for the investigation of past and present climate and seasonal variations (Coles and Coles 1995:1; Greb et al. 2006). Due to attractive biodiverse characteristics which are economically favourable for human occupation, such as being a natural resource of food, water, fuel, raw material and fertile ground, wetlands have had an important role within the Early Holocene societies worldwide (Greb et al. 2006:30; Nicholas 1998:722; Van de Noort 2013). The development of the earliest civilisations as well as the beginning of neolithisation were geographically positioned in wetland locations, such as the Nile River delta in Egypt and the river systems of Euphrates and Tigris in the Arabian Peninsula (Greb et al. 2006:30). Wetlands therefore represent an important resource of not only environmental but also archaeological information, and due to their aquatic nature a methodologically transitional area between terrestrial and maritime archaeology (Coles 2004:98; Menotti 2004b:3).

Wetland Archaeology investigates waterlogged ancient remains found in the past and present wetland environments (Menotti 2012:1). Due to the mentioned oxygen deficiency, wetlands represent a

[8] www.ramsar.org

natural repository of organic remains not only in the form of plant and animal fossils (Greb et al. 2006:26), but also human remains, such as the well-known bog bodies (Coles 2004:111), and remains of material culture such as wooden architectural components (Flaux et al. 2016) or artefacts made from organic material like wood (Gaspari et al. 2011) or textile and leather items (von Carnap-Bornheim et al. 2007). One of the world's oldest archaeological evidence of hunting, the 400,000-year-old spears found inside the remains of a horse in the Schöningen cole mine in Germany, were preserved because of the anaerobic conditions of the superimposed peat (Dennel 1997). The biological and cultural diversity is reflected in wetland studies with the use of interdisciplinary scientific methods (Menotti 2004b:3). The discovery of prehistoric Alpine pile-dwellings in the nineteenth century (Chapter 4) is considered as the start of wetland archaeology (Menotti 2004b, 2012) and the beginning of using scientific methods adopted from geology and environmental sciences to answer archaeological research questions. In the twenty-first century, archaeological laboratories investigating the relationships of natural and cultural histories of wetlands coexist with laboratories for dendrochronology and other paleo-environmental scientific disciplines such as sedimentology and palynology (Billamboz 2004; Jacomet 2004; Schlichterle 2004:25; Stopp 2015; Wiemann and Rentzel 2015).

One of the most important contributions to wetland studies is the reveal of accurate prehistoric cultural and environmental timelines which was made possible with the discovery and application of dendrochronology. Dendrochronology is a science which gathers information on the annual growth rate of trees by looking at the content and structure of tree-rings, and applying that information to answer questions regarding past historical events and environmental variations (Kaennel and Schweingruber 1995:91; Menotti 2012:365). In comparison with other absolute dating methods, dendrochronology is considered highly precise and calendrically accurate (Menotti 2012:20), and has a co-dependant connection with radiocarbon dating (Kromer 2009). The precision of long dendrochronological sequences is often used to calibrate radiocarbon dates (Kromer 2009:16; Reimer et al. 2004:1031), and vice-versa, where 'floating' tree-ring sequences without an available master sequence are wiggle-matched to a certain chronological timeframe (Barfield et al. 2010; Billamboz 2008:117; Kromer 2009:450; Menotti 2012:232) The use of dendrochronological sequences to date historical objects and events by determining the timeline period of the chain of events from felling, transporting, processing to using the wood for manufacturing and construction is often referred to as dendroarchaeology (Kaennel and Schweingruber 1995:90; Reitz and Shackley 2012:253).

Dendrochronological databases with undisturbed timelines can therefore be used for determining the age of not only prehistorical, but also any other wooden historical find. Examples of using a tree-ring database for historical objects can be seen in the study of the assumed Antonio Stradivari-built "Messiah" violin, where a dendrochronological assessment confirmed that it was indeed made during his lifetime (Grissino-Mayer et al. 2004), as well as in the calendrical dating of New Zealand Māori *waka* canoes where the findings showed a potential to use dendroarchaeology as a research method for dating waka canoes from museum collections across New Zealand (Boswijk and Johns 2018:448). There are limitations for dendrochronological determinations, such as the necessity of long and localised tree-ring sequences, the availability of a single species (eg. Oak) to be present in a certain area through time, as well as the fact that the time of the tree cutting may have not been the time when the dendrochronologically determined objects were manufactured and used (Reitz and Shackley 2012:254). These limitations, however, are frequently re-examined with examples such as Jarman et al. (2017) who studied Sweet Chestnut tree-ring sequences which were successfully compared to contemporary Oak sequences. This revealed a new potential assessment method for paleo-environmental, historic and archaeological events in Britain. The growth of tree-rings is primarily associated with establishing calendrical chronologies of specific tree species for the purposes of dating historical, geological, ecological and climatic events (Reitz and Shackley 2012:253; Schweingruber 1993:vi). This is because tree-ring growth is closely connected to local environmental conditions, and the physical characteristics of tree-rings such as their width or colour represent the natural records of these conditions in past climates. The utilisation of tree-ring climatological data to reconstruct past and present climates is known as dendroclimatology and is also often applied in addressing archaeological issues (Kaennel and Schweingruber 1995:67; Reitz and Shackley 2012:253; Van de Noort 2013:54).

Due to its high-resolution calendrical dating potential and a variety of assessment categories (such as dendroarchaeology and dendroclimatology mentioned above), dendrochronology is considered to be a key method for the investigation of waterlogged wood from prehistoric lake dwellings and wetlands (Kaennel and Schweingruber 1995:381; Menotti 2012:260). Dendroarchaeology has therefore also been widely applied in Alpine pile-dwelling research, where the preservation of large quantities of waterlogged piles offered the opportunity to analyse more than 50,000 pile-dwelling individual timbers to date (UNESCO 2017–2018:28). As described in Chapter 4, the building of the German-Hohenheim oak chronology, which is the world's longest existing tree-ring sequence covering an undisturbed calendrical timescale of 10489 years (Billamboz 2004:117; Čufar et al. 2015:92), was initiated in the 1980s during archaeological research of the Swiss Alpine pile-dwellings (Becker et al. 1985). Tree-ring data has also been useful for paleo-environmental reconstructions concerning past forest management, providing valuable information on the relationships between climate variations, environmental changes and pile-dwelling settlement patterns (Billamboz 2004:126; Menotti 2012:261). As mentioned, dendroecology provides a paleo-ecological insight into the investigated site. This can be done by closely studying the anatomical features which can be recognised as a product of environmental changes, such as frost or insect activity, or as a product of human interventions such as cutting and shredding (Billamboz 2004:120).

Other than preserving waterlogged wood, wetlands also represent reservoirs of past micro and macro botanical remains which contain crucial information for the interpretation and reconstruction of paleo-environments and climate (Magny 2004, 2015; Magny et al. 2009). Using paleo-environmental databases, such as geochemical, biological and physical data and comparing it to archaeological records from the same areas is often referred to as Environmental Archaeology (Reitz and Shackley 2012:18). The sampling techniques of non-archaeological remains combined with the archaeological ones, represent the crucial component for accurate interpretations in Environmental Archaeology. If the correct standard of sampling methods procedures have been followed during the collection of botanical and archaeological samples, these remains have the potential to reveal the nature of archaeological contexts in the investigated samples in the form of primary (intentional or unintentional deposits as a result of a specific activity in an archaeological stratigraphic context) or secondary (unintentional deposits in an archaeological context) refuse (Menotti 2012:245) (**Figure 69**).

Wetland archaeology also represents a combination of cultural studies, science and technology with the aim to address archaeological issues within wetland studies (Menotti 2004b:3). This combination is also present in lake-dwelling research, where interdisciplinary approaches helped build a database network composed of chronologies (Billamboz 2004; Billamboz and Martinelli 2015; Čufar et al. 2015), paleo-climate (Magny 2004, 2015; Magny et al. 2009; Menotti 2009), archaeozoological (Schibler 2004) and archaeobotanical (Jacomet 2004) reconstructions of the environment and economy (Antolín et al. 2014) as well as cultural and socio-economical (Menotti 2004a) aspects of prehistoric communities around the Alpine lakes. Some of the occupational hiatuses in the prehistoric Alpine lakeside settlements were proven to be closely connected to lake level fluctuations caused by rapid climate changes (Magny 2004:139), which was confirmed with the studies of paleo-climate by using multi-proxy data. As an example, three different types of assessment of a lakebed sediment core sampled in will be presented below.

Refuse type	Sampling factor	Influence on final results			
		Grid/unit (Archaeology)		Core (Paleo-environment)	
		Advantages	Limitations	Advantages	Limitations
Primary	Sample density	Large scale	Limited to specific area	Possibility of network grid	Small scale
	Sample volume	Large quantities	Risk of negative results	High resolution	Risk of small quantities
	Sample type	Low risk of excluding taxa	Poor analysis of taxa quality	Effective quantity analysis	High risk of excluding taxa
Secondary	Sediment type	High chance of diversity	Disturbed surface layers	Multy-disciplinary	Disturbed layers
	Sediment stratigraphy	High chance to identify events (eg. burning)	Risk of profile collapse disturbance	Secure stratigraphic control	Risk of identification errors

Figure 69 A combination of archaeological and paleo-environmental sampling procedure factors and their potential influence on final results. Table designed by the author after (Menotti 2012:246).

The first assessment includes extracting plant macrofossils from the core sediments. The species of the found macrofossils are known to only grow, develop and therefore be deposited in specific zones within a lake ecosystem. By following the uniformitarianism principle, the changes in the macrofossil assemblage throughout the vertical stratigraphy of the core is assumed to reflect the past lake level variations of the geographical position where the core was taken. The second assessment includes the investigation of sediment texture, lithology and concretion variations throughout the core where the changes in the relative frequency of each of these sedimentological categories indicated past lake-level fluctuations (Magny 2004:135). The third assessment is often used in past precipitation and seasonal reconstructions by looking at fossil pollen assemblage deposits throughout the core, by determining the vegetation structure or biome from which they originated from and finding modern day analogues (Magny et al. 2009:140).

Avoiding the pitfalls of Environmental Archaeology in Zambratija Bay

When investigating the human past in the context of its environment, it is important to include not only archaeological, but also all other types of evidence, and be aware that cultural systems and the environment are interlinked. These presumptions allow the application of a broad range of scientific methods, which can then give cross-referenced support for the interpretations of changes and connections in human behaviour in a given environment. Holocene studies are known for including both cultural and environmental sciences. Archaeologists try to interpret the past by examining contextualised archaeological remains, but those remains represent a statistically unknown portion of evidence. More answers lie in the sediments and soils which, although also prone to changes during long periods, contain many organic and inorganic evidence to confirm the changes in human behaviour and past interactions with the environment. In order to have a more accurate idea of the past, the relationships between all the mentioned types of evidence should be examined. Environmental archaeology uses theories and practices which originated from biology, chemistry, physics, and social sciences, which makes it an eclectic, but very reliable scientific method with multiple ways of self-assessment (Reitz and Shackley 2012:1).

Paleo-environmental reconstructions often apply uniformitarianism as a tool of understanding the past (Magny 2004:134). This approach represents a potential risk for the archaeological interpretation of in the form of environmental determinism and opportunism, where cultural change is explained as an exclusive result of the environmental pressures; as well as environmental relativism, where the influence of the environment is included as a post-processualist concept used in the past in landscape archaeology (Budja

2015:173; Van de Noort 2013:22-24). There are, however, mechanisms to avoid these traps, explained in further text on the example of the archaeological potential in Zambratija Bay.

In an environmentally deterministic model, a visible decline in the immediate environmental resources is interpreted as food excess, which consequently shapes new ways of supply-providing organisation. Another version of this model is its opposite, opportunist variety, in which a community seizes the newly available resources visible in the archaeological record, which are then interpreted as a result of environmental change favourable to local communities (Roberts 1998:146). If these were the only models applied in the archaeological interpretation of Zambratija Bay, it would be a case of environmental determinism, where the only considered trigger for the changes in human behaviour would be the environment. Furthermore, if the hypothetical evidence would suggest that the settlement in Zambratija was indeed a maritime outpost of a, otherwise traditionally lacustrine Alpine pile-dwelling, the environmentally relativistic approach might consider that the different Adriatic landscape had little or no effect for a population to give up on their Alpine building traditions. In other words, it would suggest that the people who have, and those who still do live in a specific landscape have their own perspective of the environment they inhabit. These biased assumptions would make the interpretation and role of Zambratija dramatically different to what they are in this thesis. A different approach to the same landscape can also be seen in the experience of an insider versus an outsider (Menotti 2012:22). A number of other questions can be generated from the archaeological landscape viewpoint, and if they would be used exclusively it would be a case of environmental relativism, because the people and their perception of landscape would be more important than the landscape itself.

The traps of environmental determinism, opportunism and relativism can be avoided by applying theories and practices from ecological sciences, in the forms of cultural ecology, human ecology and historical ecology (Reitz and Shackley 2012:7). The latter is an approach used in Climate Change Archaeology (Van de Noort 2011, 2013), which will be discussed in the following paragraphs.

Climate Change Archaeology

Established and described by Robert Van de Noort (2013) as "*a repository of ideas and concepts that can help build the resilience of communities in a time of rapid climate change*", Climate Change Archaeology is a combination of theories and methods with an aim to explore and test the ability of past communities to cope with their contemporary environmental impact of climate and sea-level changes (Van de Noort 2013:vii). By investigating past human behaviour during rapid environmental changes, archaeology becomes an essential part of contemporary climate change debates and scientific research. The Intergovernmental

Panel on Climate Change (IPCC) was established in 1998 as a provider of meta-analyses of published academic climate change studies, presenting them in the form of Assessment Reports, with their Fourth Assessment Report (AR4) (IPCC 2007) being rewarded with the Nobel Peace Prize (Van de Noort 2011:1039-1040). The IPCC is currently in their Sixth Assessment cycle[9], and released their most recent, Fifth Assessment Report (AR5) in 2014 (IPCC 2014). The AR5 report predicts that future global sea-levels between 2081–2100 will very likely be rising at a rate from 8–16 mm/year in more than 95% of the world's ocean areas, with approximately 70% of coastlines experiencing sea-level change within ±20% of the global mean values (IPCC 2014:62) (**Figure 70**).

Although the report's future sea-level change predictions are presented as averages, which has been critiqued as not being useful in practice due to uneven local sea level variations across the world's oceans and seas (Gehrels and Long 2008:11), the IPCC report should be considered as an authoritative statement and the starting point for further in-depth research and observations (Van de Noort 2013:7). Together with the twentieth century data, where the average global sea-level rise rate was 1.7 mm/year with short periods of intensified rates of up to 5.1 mm/year (as was the case between 1975–1985) (Gehrels and Long 2008:12), the IPCC report supports the fact that current climate and sea-level changes are affecting global coastal landscapes and populations at a rate that hasn't been recorded since the end of the LGM and the beginning of the Holocene (Van de Noort 2013:11-14). Climate Change Archaeology therefore investigates the combination of archaeological and environmental evidence from the post-LGM and Early Holocene coastal wetland sites and recognises elements of human adaptive pathways from the past that have a potential to build resilience of modern coastal communities are faced with rapid climate change (Van de Noort 2013).

Image removed due to copyright.

Figure 70 The AR5 predictions of global average surface temperature change and global MSL, represented in two scenarios, or Representative Concentration Pathways (RCP). RCP2.6 (blue) represents a conservative scenario, calculated based on constricted greenhouse gas emission results, whose measurements were available in scientific literature. RCP8.5 (red) is a scenario based on a presumption where greenhouse gas emissions have not been constricted (IPCC 2014:2) (Simplified after IPCC (2014)).

Climate Change Archaeology is an improved and modified systems theory (Van de Noort 2013:23) (**Figure 71**). Systems theory, as a theoretical framework, is adopted from the natural sciences (Salmon 1978:174). It was first applied to archaeological research by early processual archaeologists (Hodder and Hutson 2003:21; Plog 1975) With its distinct and quantitively measurable categories of self-regulation, positive and negative feedback, oscillation and dynamic equilibrium, the systems theory became attractive to young scholars in the 1960s and 1970s which had also started experimenting with the first applications of

[9] https://www.ipcc.ch

software simulations to archaeological interpretations (Doran 1970:290). Used in studies such as Flannery (1968) for identifying the exploitation of agricultural resources in ,000–200 BC Mesoamerica, the adaptations of an environmental approach to archaeological discourse faced difficulties early on, making the conclusions unclear and attributing cultural evolution to the cognitive capacities of the human mind, such as inventions and genius, without further explanation (Flannery 1968:85). It is important to emphasise that even at the time, archaeological scholars using the systems theory were criticised and warned of its limitations, the main one being that the environmental systems are simplistic compared to the multidimensional and complex human socio-economic systems, making it a non-applicable and redundant framework (Doran 1970:291; Salmon 1978:182). Later on, post-processualists argued that the systems theory and its categorisations are based on a Western worldview pointing out that concepts such as subsistence, trade, society and symbolism might not be fitting for the interpretation of past societies (Hodder and Hutson 2003:29). Although the systems theory represented a benchmark in archaeological theory by interpreting remains not only as objects but also as ideas, and including cultural production and human agency to the discussion, the archaeology of human 'systems' was dismissed because of the timelessness of human activity which is driven by relationships rather than historical progressions (Hodder and Hutson 2003:43).

Image removed due to copyright.

Figure 71 Relationships between Earth and Human systems according to Van de Noort (2011, 2013).

In building his framework, Van de Noort (2013) argues that the focus of his attention is not to conceptualise human behavioural patterns into a systematic categorisation, but rather connect the natural and human aspects of the environment and search for the evidence of feedback mechanisms and interactions between the two. That way the natural systems can be linked to human behaviour, and the framework investigation has a focus on their mutual dynamics (Budja 2015:171; Van de Noort 2013:3). This conceptualisation of systems theory which views systems as being composed of interconnected components is known as Complex Systems Theory, which is also used as the framework for the structuring of the IPCC reports (IPCC 2014:vii). Complex systems can be studied through various spatial scale and timeframe factors, which means their analysis can be constrained by specific localised landscapes or global environments in certain short or long-term historical periods (Crumley 2006:17). They are considered to be dynamic in their nature, which means that the social and environmental histories of a specific landscape is examined through the lens of historical influences and memories visible in specific timeframes (Crumley 2006:18; Van de Noort 2013:32).

In Zambratija, these influences and memories will be examined through comparative research of two datasets composed of new data from radiocarbon dated seabed core vertical stratigraphy and the data from excavation units recorded in the investigations between 2008 and 2014. Such investigation, which uses archaeological and archival research combined with environmental proxies provided by Earth science research is used Historical Ecology (Crumley 2006:18), which is together with resilience and sustainability one of Climate Change Archaeology's three building blocks. According to Van de Noort (2013), they have been named as 'building blocks' due to their mutual interest in the various links between the human and natural parts of the world (Van de Noort 2013:28).

Historical ecology

Cultural ecology, as a discipline, defines cultures and environments as having a relationship where environments play an active role in human affairs, as opposed to being passive. Furthermore, human ecology attempts to expand that idea by applying ecological concepts in order to predict the relationships between people and the environment they inhabit. This kind of approach includes system models to understand cultural behaviour. The next stage in the progression of the concepts of combining cultural and ecological theories is historical ecology, a methodological tool which includes time into the interpretations of changing landscapes (Reitz and Shackley 2012:7). Historical ecology is composed of scientific research methods from the biological and physical sciences that are applied to theoretical frameworks of the humanities and social sciences (Crumley 2017:565; Van de Noort 2013:31). In other words, it allows experts with a mutual interest to the element of research, which is usually the landscape, including the submerged landscape, to collaborate in its scientific exploitation (Bailey 2011:325-327; Crumley 2006:17). That way, different disciplines can create an all-including framework, with the use of complex systems theory. Complex systems theory states that systems are built of interconnected historical, biophysical and human elements. All those elements are integrated into joined human-environment systems, while following every discipline's specific conventions (Van de Noort 2013:33). Therefore, historical ecology will serve as a chronological background for the original results obtained with the research methods adopted from environmental sciences.

The first research question (*How did the physical environment evolve at Zambratija Bay during the Early and Middle Holocene, with special reference to sea-level changes?*) focuses on past sea-level and climate change, because those were the global events which chronologically overshadowed the cultural and social interactions in the bay since prehistory, and they are still ongoing today. As presented in Chapter 3, the post-LGM sea-level rise was progressing at an uplift mean rate of 10 mm/year between 17,000–5000 BC (Benjamin et al. 2017:14), after which GIA models show a significant decrease in the rate of sea-level rise. The latter indicates that the process of the glacio-isostatic water melt into the oceans has stopped, and the global sea levels were starting to stabilise (Vacchi et al. 2016:173). The global occurrences can also be seen in the Mediterranean, where predictive post-LGM marine transgression calculations show similar sea-level uprise trends (Lambeck and Purcell 2005; Stocchi and Spada 2007). By 4000 BC, the values for the Northern Adriatic Sea show and inconsistency in the sea-level uplift, where the local RSL levels were between 4 and 9 metres lower than those for the rest of the Mediterranean. This was at first hypothetically connected (Lambeck and Purcell 2005:1976) and later on discussed (Stocchi et al. 2005) with the accumulation and episodical deglaciation of the Alpine glacier, resulting in the stabilisation of the Northern Adriatic sea level uplift, aligning with present-day levels at around 2000 BC (Monegato et al. 2017; Stocchi et al. 2005:140), after which the changes were mostly influenced by tectonic factors made visible in submerged and coastal archaeological sea-level markers (Antonioli et al. 2007; Antonioli et al. 2009; Faivre et al. 2011; Florido et al. 2011; Lambeck et al. 2004b).

Resilience

As defined by ecologists, resilience is a measure of a system's ability to absorb change and disturbance and maintain a state of stability after those occurrences. It offers a model that can be successfully used for understanding ecosystems but has not been persuasive when used on human systems. Applying a social component gives it a new perspective called socioecological resilience. It is described as the capability of a community to manage with the impact of the varieties of forms of environmental changes (Budja 2015:176; Van de Noort 2013:28-29). It is evident that the Adriatic Basin was highly impacted by the post-LGM sea-level and climate changes (Vacchi et al. 2016) and addressing that issue in Zambratija Bay will build enough evidence to answer the question how strong were the connections between environmental change and site abandonment (Benjamin et al. 2011a:195). The answer will not only help build a high-quality dataset for interpreting submerged prehistoric sites worldwide, but also provide new answers to the existing problems visible in the interpretation of occupational hiatuses in the Alpine pile-dwellings and their connection to climate and social changes (Magny 2004, 2015). The second research question (*What affect did the environmental changes have on the people living at the prehistoric pile-dwelling in Zambratija Bay and on the taphonomy and preservation of the archaeological site left behind?*) will therefore address the resilience capacity of the prehistoric community in Zambratija Bay.

The results of the systematic dendrochronological research of the Alpine pile-dwellings revealed an incredibly accurate chronology of Central European Prehistory on a calendrical timescale with a six month resolution (Köninger 2015:37), and stemmed the longest undisturbed tree-ring sequence in the world of the Northern Alpine oak, today dated between 8480 BC and 2009 AD (Čufar et al. 2015:92). The Alpine mountain massive represents a physical barrier, naturally dividing the lakes and their surrounding environment and consequently the prehistoric pile-dwellings to the Northern and Southern variations. Dendrochronology showed that life on the Northern lakes lasted from the Late Neolithic, at around 4,200 Cal BC to the Iron Age around 630 Cal BC (Köninger 2015:37), with three occupational hiatuses between 3,540–3,410 Cal BC, 2,400–2,000 Cal BC and 1,500–1,200 Cal BC (Menotti 2004a:211, 2015b:24). Due to different biological markers to those in the Northern Alpine oak tree-rings, the dendrochronology of the Southern pile-dwellings is still under reconstruction. However, wiggle-matching dating methods (Billamboz 2004:125; Billamboz and Martinelli 2015:95) and teleconnection (Čufar et al. 2015:92), which use radiocarbon dated floating southern oak tree-ring sequences and align them with the northern master sequence, showed a shorter pile-dwelling tradition in the south, lasting from around the Late Neolithic to the Early Bronze Age (Marzatico 2004:93; Menotti 2015b:24; Velušček 2006a:63), with a hiatus found in Slovenian dendrochronology between around 3,300 and 3,160 Cal BC (Čufar et al. 2010). The date from Zambratija indicates that this is one of the earliest examples of a prehistoric pile-dwelling south of the Alps, with an open possibility of it being a maritime outpost of a traditionally lacustrine settlement building practice. The nearest contemporary pile-dwellings are in Austria (Ruttkay et al. 2004; Swierczynski et al. 2013), Italy (Marzatico 2004; Pini 2004; Visentini 2001) and Slovenia (Velušček 2006a, 2006b), showing evidence of flood risk and other climate variations which have had an impact on occupational discontinuity (Menotti 2009).

Indirect cultural connections between Zambratija and the southern Alpine settlements are visible in the pile-dwelling building tradition unusual for the Northern Adriatic. However, the pottery remains show a cultural continuity with connections to the Eastern Adriatic prehistoric complexes. Together with undeniable sea-level uplift which was still transgressing and shaping the Northern Adriatic shoreline, the colliding Alpine and Adriatic social networks visible on site indicate that Zambratija represents an ideal case study for the investigation of the impact of rapid climate change to a socio-economically complex coastal community. The possibility of revealing the adaptive pathways which this community used to adapt to the fast-changing environment would not only answer this research question but also reveal to which extent does cultural change follow climate change and vice versa, and how it can be confirmed and empirically proven through interdisciplinary investigation of archaeological sites throughout history and worldwide. In Zambratija, both resilience and sustainability can be explored by investigating the adaptive paths that made the settlement keep functioning in its lifetime, and possibly find a reason for final abandonment.

Sustainability

Sustainable development is a state of successful maintenance of political and social structures, when economic resources are permanently accessible (Budja 2015:175; Van de Noort 2013:34). The connections between environmental and economic sustainability are evident, but in the case of social sustainability those links are not equivalent (Van de Noort 2013:34). The relationship between the environment and human sustainability is facilitated in problem-solving capacities. As presented in previous chapters, the prehistoric Alpine pile-dwellings have had multiple exchanging periods of intense settlement and abandonment in their overall occupation. The reasons for that could have been either cultural or environmental, but it is definite that in the times of rebuilding there were periods of lifestyle readaptation to the new environment (Menotti 2004b:3). This is why the focus on answering the third research question (*With consideration for the site's chronology, spanning the Late Neolithic to the Bronze Age, what socio-economic developments are* *observable at the Zambratija Bay site relative to the braoder Alpine Adriatic archaeological record(s)?*) will be to find evidence of cultural connections between the prehistoric Alpine pile-dwellings and their lacustrine lifestyle and the establishment of the Zambratija near-shore settlement. The paleo-environmental evidence from the site will serve as a comparative reference to argue whether there were environmental similarities between the Alpine and Northern Adriatic localities during their occupations, and how did the population of the Zambratija settlement sustain a lifestyle which was adapted to a different ecosystem. Focusing on sustainability will explore the cultural migrations of Late Neolithic/Early Copper Age pottery styles on the Eastern Adriatic coast, through a framework with potential to give valuable new insight into one of the most enigmatic periods in the prehistory of that area (Forenbaher et al. 2013:603). That way the three conditions of sustainable development – environmental, economic and social sustainability, will be addressed through the analysis of environmental and archaeological evidence found on site. Sustainability requires constant effort and it can be assessed with evidence of resilience. Sustainability and resilience often clash, because the first one is striving to continue a certain condition or process despite the outside political or social changes, while the second one is trying to adjust to those changes (Budja 2015:176).

The typology of the pottery found around the seabed as well as in the stratigraphic contexts of the five excavated units in Zambratija, sets the occupational timeframe of the submerged settlement between the Late Neolithic to the Early Bronze Age of the Eastern Adriatic cultural complexes (Koncani Uhač and Čuka 2015). More precisely, the Nakovana style pottery, described as the first appearance and originally a direct stylistic import of the Central Balkans Early Copper Age Vinča culture in the Adriatic (Dimitrijević 1979:371; Forenbaher 1999–2000:380), was found in the stratified seabed layers of Unit 1 and 5, together with lithics, and remains of land animal bones and botanical remains (Koncani Uhač and Čuka 2015). It is common for Late Neolithic/Early Copper Age sites on the Eastern Adriatic coast to show stratified evidence of Nakovana style pottery. Although scarce, but reliable, radiocarbon dates from Nakovana contexts on the Eastern Adriatic all show a consistency of setting these pottery sherds into the timeframe between 4000–3500 BC (Forenbaher et al. 2013:592). Other than Nakovana style, the other found pottery shows a diverse collection of shapes and decorations attributed to wider timeframes, such as brushed surface pottery found in layers ranging from the Late Neolithic to the Early Bronze Age in the Eastern Adriatic (Čuka 2009; Jerbić Percan 2011; Vitasović 1999).

The most recent fragment found on the seabed in Zambratija is a triangular handle, which is a shape that appears in the Early Bronze Age in Istria (Koncani Uhač and Čuka 2015:37). This find indicates a cultural continuity on the site connecting two significant socio-economic stages of Central European and Mediterranean Prehistory – the Neolithic/Copper Age and the Bronze Age, where Copper Age represents a transitional period. One of the most evident cultural features that divides the two socio-economic stages are settlement patterns (Buršić-Matijašić 2012). The Neolithic and Copper Age sites are represented by caves and open-air sites (Čuka 2009; Jerbić Percan 2011; Komšo 2004, 2007, 2008), and the Bronze Age is represented with fortified megalithic structures on high positions overlooking the surrounding landscapes, known as hillforts (Buršić-Matijašić 1998, 2007; Hänsel et al. 2005). Pile-dwellings were not found in the Adriatic coast. In the Alps however, they represented an architectural solution, in some cases confirmed to have been closely related to climate change (Magny 2004, 2015; Magny et al. 2009; Menotti 2004a:211) which showed a 3000-year-old continuity around the Alpine glacier lakes and marshlands (Menotti 2004a, 2015a), seemingly not being influenced by the carriers of the Bronze Age and later on Iron Age cultural traditions. Archaeologists have argued that one of the occupational hiatuses in the Alpine lake-dwelling tradition might have been connected to the Early Bronze Age Bell Beaker Culture expansion around 2400–2000 BC (Magny 2004; Menotti 2004a:211). The one radiocarbon date in Zambratija was obtained from a wooden pile rammed into the peaty sediments in Unit 1 (Koncani Uhač and Čuka 2015), dating the submerged site between 4230–3980 Cal BC, which chronologically connects the site to both the contemporary Eastern Adriatic and Alpine settlements.

CHAPTER 6: RESEARCH ORGANISATION AND METHODS

It is evident that several archaeologically and environmentally significant events occurred in Zambratija Bay during the mid and late Holocene. Starting with the most recent of these events, and progressing further back in time, the order of their appearance is: 1) Sea transgression to present-day level and the deposition of marine sediments, 2) The construction and use of the Roman Antiquity embankment, 3) Late Bronze Age/Early Iron Age boat abandonment, 4) The building and settlement of the pile-dwelling, 5) The formation of peat deposits in a brackish environment, 6) The formation and marine disturbance of freshwater environments. This thesis will attempt to chronologically reconstruct the timeline of these events through the lens of archaeology. The research questions were built around the knowledge progression used for creating the research hypothesis. They also represent archaeological disciplines through which the site was investigated, starting with a globally significant topic of the Holocene marine transgression and the significance of submerged prehistoric sites, followed by a discussion on the neolithization and transition to the Bronze Age in the Alpine Mediterranean. By focusing the discussion to the occupational discontinuity connected to the undeniable relationships between culture and climate, which is an underlying topic of almost all research of PACS and Alpine pile-dwellings, this thesis should set Zambratija on the list of archaeological sights worldwide, which represent historically significant cultural progressions that shaped modern civilisation. In Zambratija, that progression was investigated by combining methods from environmental sciences and archaeology, which will be described in the following chapter.

Fieldwork was conducted in Zambratija Bay in May and June 2017 with the aim to test the presented hypothesis. It was an interdisciplinary project which included an international team of environmental scientists, volunteers and maritime archaeologists. The fieldwork project had two separate components – the first one was seabed coring, which resulted in 7 sediments cores. The second part was an underwater survey of a selected area in the bay with a dense concentration of wooden piles protruding from the seabed, which resulted with a georeferenced site plan, a photomosaic of the area as well as 20 samples from wooden piles. Taking cored samples of seabed soil for paleo-environmental research and wood for dendrochronology are methods of environmental research used in both the investigation of PACS (Berger 1983; Flaux et al. 2016; Gifford 1983; Stein 1986) and Wetland Archaeology (Billamboz 2004; Billamboz and Martinelli 2015; Čufar et al. 2010; Čufar et al. 2015; Flaux et al. 2016). The mentioned archaeological disciplines also frequently use digital reconstructions based on geophysical investigations as well as 3D photogrammetry models as a tool to better understand site formation processes and finding large-scale patterns (Faught 2014;

Harff et al. 2016a; Jöns and Harff 2014; Locke 2004). The methods were deliberately chosen to be interdisciplinary and performed by an international team of environmental scientists and underwater archaeologists in order to include Zambratija and future research on the Eastern Adratic into the global PACS network of the 21st century.

All mentioned interdisciplinary elements were collected by following the sampling methods used in underwater (Hafner 2004) and wetland archaeology (Menotti 2004b) in combination with modern technology (Locke 2004). Some of these methods and practices have been used in this thesis, by examining a combination of archaeological and environmental evidence found on site in order to answer the research questions. The answers to the questions have the potential to change and expand the existing knowledge on the prehistoric societies, their cultural interactions as well as their pathways to adapt to the Middle Holocene climate and sea-level changes in the Alpine and Adriatic region, which are historically significant for the broader Central European area.

The unique environmental and cultural background of Zambratija Bay, which includes a submerged paleo-landscape with evidence showing human occupation during the time prior to inundation, allows for an interdisciplinary study which involves a SCA of the submerged paleo-landscape and settlement. The interdisciplinary approach and therefore the chosen methods were designed to address three issues. Firstly, the determination of the physical characteristics of the paleo-landscape (Research Question 1); secondly, the archaeological interpretation of how the defined paleo-environmental characteristics mirror human behaviour in the landscape (Research Question 2); and thirdly, a comparative analysis of that human behaviour in Zambratija on a local scale of the Istrian Peninsula as well as on a broader scale of Alpine pile-dwellings and Central European Neolithic/Copper Age transition (Research Question 3).

Regulatory context and background

In order to address the research aim and collect all the necessary data, a sustainable strategic plan had to be carefully developed and successfully implemented. Therefore, a plan of fieldwork, composed of interdisciplinary surveys and investigations, and which included multiple governmental, academic, cultural and environmental institutions from Australia, Croatia, France and the United Kingdom, was conducted periodically in Zambratija bay, Croatia between March and June 2017. The responsible institution for this site and the holder of the archaeological investigation permit (**Appendix II**) was the Archaeological Museum of Istria (AMI) In Pula, Croatia. The lead underwater archaeologist, and the head of the AMI Underwater archaeological collection was senior curator Ida Koncani Uhač. All the necessary permits for performing the campaign were obtained by AMI, and the fieldwork was undertaken on the basis of an agreement between the museum and the author (**Appendix III**).

AMI is financed by the Croatian Government, and therefore must follow governmental legislation policies and rules regarding underwater archaeological investigations, all of which are stated in the aforementioned permit issued by the Croatian Ministry of Culture. On a list of some twenty specific laws and regulations that are completely or predominately related to culture, there are two that are specific for conducting underwater archaeological investigations: The Law on the Protection and Preservation of Cultural Assets and the Maritime code (Primorac et al. 2014). A brief explanation of the Croatian cultural laws and legislations in the English language can be found in the Country profile: Croatia by Primorac et al. (2014)[10].

All Croatian laws regarding underwater archaeology legislations and codes can be found on the Croatian Government website[11], the Croatian Ministry of Culture website[12], and the Ministry of the Sea, Transport and Infrastructure website[13]. The English translations of the laws and legislations are available on the Ministry of Foreign Affairs website[14]. Every Croatian participant of an archaeological investigation in Croatia must undertake training and pass the tests for: "Working in a safe manner", and the testing of knowledge according to the "Program for implementation of preventive measures for fire protection and rescuing people and property threatened by the fire". The author has passed both tests in 2011.

Croatia ratified the UNESCO Convention on the Protection of the Underwater Cultural Heritage on December 1 2004 (Rodrigues 2005:22), which represented a natural follow-up to its rich and long tradition of ethical underwater archaeological exploration (Radić Rossi 2012a). An overview of applying underwater archaeological standards in Croatia can be seen in the "Exploring Underwater Heritage" Handbook (Bekić and Miholjek 2009).

The PhD research fieldwork was performed for the purposes of a PhD project at the Maritime archaeology program at the College of Humanities, Arts and Social Sciences at Flinders University, which has a well-established and frequently updated Diving Procedures Manual (2016), which explains the safe procedures that must be understood and followed for all diving and snorkelling conducted through the University. All diving approvals and forms were obtained, assessed and approved before the start of the fieldwork by Flinders University (**Appendix IV**).

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[10] www.culturalpolicies.net.
[11] https://vlada.gov.hr
[12] www.min-kulture.hr
[13] www.mppi.hr
[14] http://www.mvep.hr

Research design

Zambratija represents a suitable research ground for performing site catchment analysis, where the resource potential accessible from a single site can be its own assessment (Roberts 1998:147). Since the site catchment was performed by using methods borrowed from environmental sciences, the chosen methods tools can be defined as Environmental Archaeology. The diversity of different sciences used in Environmental Archaeology allows environmental archaeologists to develop their ideas and methods without the case of overlapping them, thus creating a scientific environment where different types of information is oriented around the same site (Reitz and Shackley 2012:18). The traditional methods of studying regional climate change is through proxies such as pollen, foraminifera, ostracods, fossil insects, and testate amoeba, as well as from tree-ring studies, research into tree- and snowlines, and paleosols (Roberts 1998:147). This evidence can be used as indicators of past climate change, and some of them were used in Zambratija (see listed methods below). The concept of using environmental proxies dates back to the late 18th and 19th century assumption made by geologists that the environmental processes and changes that occur in the past, will be the same in the present. This assumption is also known as the uniformitarianism principle (Reitz and Shackley 2012:3; Van de Noort 2013:54), and it allows for all the visible changes to be used as indicators of past climate changes (Van de Noort 2013:54).

It is important to emphasise here that Zambratija is, and continues to be, an elaborate project with many moving parts, involving multiple institutions and people (**Figure 72**). Time management and budget have been a significant consideration, with all the necessary finances expected to be secured and provided by the author. Fortunately, a few successful scholarships, grants and awards, all acknowledged in this thesis, provided enough financial support to undertake the research, as well as to perform further laboratory analyses crucial to the understanding of the archaeological and environmental submerged prehistory in Zambratija. It is the author’s intent that this thesis, which includes a series of tested methods and techniques designed on the basis of other sites with similar paleo-environmental and archaeological characteristics, will potentially serve as a starting point of a large-scale project, thus establishing Zambratija as a globally significant archaeological case study.

Institution	People	Designation	Zambratija project role
Archaeological Museum of Istria in Pula, Croatia (AMI)	Darko Komšo	Director	Agreement signee
	Ida Koncani Uhač	Senior curator, Head of the Underwater Archaeology Department	Fieldwork permit holder, AMI dive coordinator
	Maja Čuka	Senior curator, Head of the Prehistory Department	AMI diver
Aix-Marseille University, France	Alba Ferreira Gomez	PhD student	Volunteer, diver, xylologist
	Dr Lisa Shindo	Researcher	Dendrochronologist
Croatian Geological Survey, Zagreb, Croatia (CGS)	Dr Slobodan Miko	Director, researcher	CGS laboratory supervisor, geochemist
	Dr Ozren Hasan	Researcher	Coxswain, corer, geochemist
	Dr Nikolina Ilijanić	Researcher, Head of Mineralogy and petrology department	CGS laboratory supervisor, geochemist
	Dea Brunović	PhD student	Volunteer, CGS laboratory trainer
	Hrvoje Burić	Technician	Corer
	Dr Ivan Razum	Associate	Corer, geochemist
Flinders University, Adelaide, Australia College of Humanities, Arts and Social Sciences	Dr Jonathan Benjamin	Senior lecturer in maritime archaeology	Primary PhD supervisor
	Dr Wendy van Duivenvoorde	Associate professor in maritime archaeology	Associate PhD supervisor
	Enrique Aragon Nuñez	PhD student	Volunteer, diver
	Katarina Jerbić	PhD student	Agreement signee, fieldwork leader, corer, diver, surveyer, CGS and UYO laboratory trainee
	Kurt Bennett	PhD student	Volunteer, Flinders dive coordinator
N/A	Christian Petretich	Zambratija local, boat owner	Coxswain
University of York, UK (UYO) Department of Geography and Environment	Dr Roland Gehrels	Professor	Adjunct PhD supervisor, UYO laboratory supervisor
	Luke Andrews	PhD student	Plant macrofossil analyst

Figure 72 A list of institutions and people involved in the organisation and execution of the Zambratija PhD project.

List of research methods

The combination of environmental and archaeological features presented in the thesis make Zambratija Bay fitting for the study of the local sea-level, climate and cultural histories. Combined with the one initial radiocarbon date, they represented the research background for the design of the thesis research methods in the form of SCA. The catchment will be interpreted through Historical Archaeology in order to address the issues concerning Climate Change Archaeology. The presented methods below have been chosen based on the literature review of the relevant past and current interdisciplinary studies of sites which share perspective similarities with Zambratija Bay, and where archaeological research contributed significant new knowledge to the disciplines of PACS and Wetland Archaeology.

The environmental and cultural aims and objectives will be addressed with the methods presented below, which can be divided into three categories: fieldwork, laboratory and desk-based methods. They have been performed throughout the three-year period of the PhD candidature. Where applicable, relevant literature is provided as an indicative reference to show where the method was successfully used in the past on archaeological sites, which is then further explained in the following chapters and paragraphs explaining each individual method.

1. Fieldwork methods
    a. Sub-bottom profiling (Bailey et al. 2017c; Cliquet et al. 2011; Faught 2014; Gearey et al. 2017; Hepp et al. 2017; Missiaen et al. 2017a; Missiaen et al. 2017b; Quinn et al. 2002; Ryabchuk et al. 2016; Werz et al. 2014; Westley et al. 2011)
    b. Seabed coring (Bailey et al. 2017c; Carabias et al. 2014; Faught 2014; Hansson et al. 2017; Hepp et al. 2017; Missiaen et al. 2017b; Pearson et al. 2014; Stein 1986)
    c. Underwater archaeological investigations and survey (Abelli et al. 2016; Antonioli et al. 2016; Bailey et al. 2017c; Carabias et al. 2014; Feulner 2017; Galili et al. 2017a; Goldhammer and Hartz 2017; Hafner 2004; Hansson et al. 2017; Leineweber et al. 2011; Missiaen et al. 2017b; Momber 2014; Ruoff 2004; Uldum et al. 2017; Uldum 2011)
2. Laboratory methods
    a. Initial core description and preparation for further analyses (Gearey et al. 2017; Glørstad et al. 2017)
        i. Digital photography
        ii. Magnetic susceptibility (Dalan and Banjeree 1998; Jordanova et al. 2001)
        iii. Colour spectrometry (Manzanilla 1996)
        iv. Discrete sampling

b. Depositional microfauna analysis (Galili et al. 2016; Gearey et al. 2017; Scudder 2001)
c. Grain size analysis (Scudder 2001, 2003)
d. Total Organic Carbon (TOC) and Total Nitrogen (TN) content
e. XRD mineralogy
f. XRF scanning (Holliday and Gartner 2007; Lubos et al. 2016; Manzanilla 1996; Middleton 2004; Shackley 2011; Stanford et al. 2014)
g. Scanning electron microscope
h. Archaeology of the core
i. Microflotation by heavy liquid mineral separation (Lentfer and Boyd 1998)
j. Plant remains identification (Alve and Murray 1999; Antolín et al. 2014; Galili et al. 2017b; Gearey et al. 2017; Hansson et al. 2017; Jacomet 2004)
k. Dendrochronology (Becker et al. 1985; Berger 1983; Billamboz 2004, 2008; Billamboz and Martinelli 2015; Čufar et al. 2010; Čufar et al. 2015; Haneca et al. 2009)
l. Radiocarbon dating (Berger 1983; Dunbar et al. 2016; Gillespie 1984; Kromer 2009)

3. Desk-based methods
    a. Sea-level markers archival data collection (Abelli et al. 2016; Antonioli et al. 2007; Antonioli et al. 2009; Antonioli et al. 2016; Benjamin et al. 2017; Chiocci et al. 2017; Faivre et al. 2011; Florido et al. 2011; Furlani et al. 2014; Glørstad et al. 2017; Karle and Goldhammer 2017; Lambeck et al. 2004a; Lambeck et al. 2004b; Sakellariou and Galanidou 2016; Scicchitano et al. 2017; Vacchi et al. 2016; Van Andel and Tzedakis 1996; Ward et al. 2016; Wurster and Bird 2016)
    b. Digital data processing (Bicket et al. 2017; Chiocci et al. 2017; Feulner 2017; Locke 2004; Missiaen et al. 2017b; Uldum et al. 2017)
    c. Site mapping and data overlay (Dixon and Monteleone 2014; Foglini et al. 2016; Glørstad 2016; Glørstad et al. 2017; Harff et al. 2017; Jöns and Harff 2014; Ryabchuk et al. 2016; Scicchitano et al. 2017; Van Andel and Tzedakis 1996; Ward and Veth 2017)

Fieldwork methods

All fieldwork research for the purposes of this thesis was conducted in Zambratija Bay and organised by the author in collaboration with AMI and CGS. The original idea for performing the fieldwork and the workflow were designed by the author.

Sub-bottom profiling

The sub-bottom profiling survey fieldwork was organised by the author and AMI. It was performed on March 15 2017 by Harpha sea d.o.o., a Slovenian company which provides services of hydrographical sea measurements (**Appendix V**). Harpha sea d.o.o. was also the company that was hired by AMI to perform the bathymetric survey of the bay in October 2012.

Sub-bottom profilers produce a low-frequency beam that penetrates the seabed. The finishing product is a cross-section of the beam's pathway. In archaeology, it represents a non-invasive way of determining partial or complete burials of structures, features and artefacts (Quinn et al. 2002:441-442). Nevertheless, they are more commonly used as a tool for understanding the geological and sedimentary formations under the sea bed (Green 2004:82). The purpose of the survey was to provide an insight into the stratigraphy of the sediment layers in the submerged sinkhole and settlement area, and to add complimentary data to the previously done bathymetric and total station surveys.

The survey was carried out from an inflatable boat equipped with a parametric Innomar SES-2000 compact sub-bottom profiler, with a 1–400 m range, and an acoustic penetration of up to 40 m into the seabed, with a vertical resolution of up to 5 cm (**Figure 73**).

Figure 73 The Innomar SES-2000 compact sub-bottom profiler.[15]

[15] https://www.innomar.com/ses2000compact.php

Real-time Global Navigation Satellite System (GNSS) correction was assured with the Croatian Positioning System (CROPOS), a reference station network that transmits correction for the Global Positioning (GPS) and Global Navigation Satellite (GLONASS) Systems. Two mobile GNSS receivers were used – a JAVAD Triumph-1 and JAVAD TRG3T. Both are carrier phase GNSS receivers that work with GPS, GLONASS and Galileo systems with a horizontal accuracy of ± 2cm in RTK mode. Teledyne Reson PDS2000 software was used for the navigation. The software enables sensor integration, and it monitors the survey and the plotting of the vessel in real-time. The operator can view the data and control navigation according to the survey lines and the cartographic background. The parametric SBP operation and logging was done in the Innomar SesWin software.

Seabed coring

Paleoenvironmental specialists have been extracting vertical sections of sediments for the purpose of assessing their depositional processes through coring methods, the practice has also been used in archaeology since the 1930s (Stein 1986:506). In PACS, seabed cores can mirror information on cultural interventions on the submerged environment which can be seen in the paleo-environmental samples extracted from seabed core layers, such as shells, microfossils, charcoal or pollen (Flatman and Evans 2014:4), and are considered to be the most cost-effective technique for ground truthing of surveyed areas (Nutley 2014:270). Coring is also an effective method for interdisciplinary reconstruction and interpretation of sediment deposits in wetland environments (Menotti 2012:205), especially in archaeological contexts where a combination of multi-proxy data gathered from excavation units and sediment cores from the same investigation areas have been useful in reconstructing the relationships between human and natural systems in the past (Magny 2004:135; Menotti 2012:256). The archaeological investigations in Zambratija between 2008 and 2015 revealed the presence or submerged archaeological remains as well as peat deposits. This unique combination of cultural and environmental elements made Zambratija Bay not just a 6000-year-old submerged landscape but a submerged wetland site with archaeological potential. The field methods selected for this PhD were therefore informed by existing practice in PACS and Wetland Archaeology.

Core sampling was organised and performed by the author and the Croatian Geological Survey (CGS), in collaboration with AMI, the site investigation permit holder, between May 2–5 2017 (**Appendix VI**). Coring involves drilling, pressing or hammering a hollow cylinder into a land surface to take samples of soil. It can require less physical effort than underwater archaeological excavation but provides valuable stratigraphic data with minimal site destruction. The aim is to extract a core, which is defined as "a continuous section of sediment or rock" (Stein 1986:505). Coring is a common method used by researchers to investigate submerged paleo-landscapes in the past (eg. Faught 2004:278; Gifford 1983), and cores containing biological markers have proven to be successful in sea-level studies (eg. Lambeck et al. 2004a:1569). The purpose of the coring in Zambratija was to provide seabed sediments samples for archaeological, paleo-environmental and sea-level change analyses.

CGS operates a 3 m long and 60 mm diameter UWITEC percussion-system Niederreiter 60 system Piston Corer[16] manufactured in Mondsee, Austria. The system consists of a steel tube corer (**Figure 74**) lined with a 2 or 3 m long and 60 mm diameter PVC tube for each individual core (**Figure 75**), a hydraulic core catcher (**Figure 76**) and a stabilizing tripod (**Figure 77**), which keeps the corer in a vertical position. The coring is executed from an inflatable raft secured to the seabed with four anchors. The rope-operated piston corer (**Figure 78**) is hand-driven by a steel hammering 60kg weight (**Figure 79**), which pushes the coring cylinder to the sediment surface, leaving the core catcher in place while the tube penetrates the ground (**Figure 80**).

Figure 74 Steel tube corer filled with sediment (Photo: K. Jerbić).

[16] www.uwitec.at

Figure 75 2 and 3 metre PVC tube liners (Photo: K. Jerbić).

Figure 76 Adding water to the hydraulic core catcher (Photo: K. Jerbić).

Figure 77 The stabilising tripod on an inflatable raft (Photo: K. Jerbić).

Figure 78 The rope operated piston corer inside a PVC tube liner (Photo: K. Jerbić).

Figure 79 The corers pulling the 60kg weight (Photo: I. Koncani Uhač).

Figure 80 The corer tube is visible under the inflatable raft as it is pushed into the seabed surface (Photo: K. Jerbić).

Based on the bathymetric and sub-bottom data, eight positions (**Figure 83**) were picked to collect seabed sediment cores in Zambratija Bay, and seven were performed successfully. After they were collected on site, the PVC tubes with the seven successful cores were then transported to the CGS laboratories in Zagreb and stored in a cooling chamber at +4°C, until they were to be further analysed in due course.

Core code	**Date of coring**	**Total core length measured on site**	**GPS coordinates**	
			X	**Y**
ZAM-1	May 3 2017	(2 segments) 577 cm	45°28'27.65"	13°30'13.55"
ZAM-2	May 3 2017	136 cm	45°28'29.40"	13°30'11.35"
ZAM-3	May 3 2017	190 cm	45°28'26.13"	13°30'14.85"
ZAM-4	May 4 2017	10 cm	45°28'18.04"	13°29'48.28"
ZAM-5	May 4 2017	219 cm	45°28'08.55"	13°30'12.76"
ZAM-6	May 4 2017	283 cm	45°28'15.85"	13°30'23.21"
ZAM-7	May 4 2017	(2 segments) 426 cm	45°28'28.47"	13°30'15.70"
ZAM-8	May 5 2017	201 cm	45°28'26.50"	13°30'22.80"

Figure 81 A list of all cores taken in Zambratija Bay.

It is important to note that, if the sediments show a thickness longer than 3 m, coring is performed on the same position to extract deeper sediments until reaching bedrock, by using a new PVC tube. It is then important to measure the thickness of the sediment sections trapped in the core catcher and then calculate those measurements in the total core length (**Figure 82**).

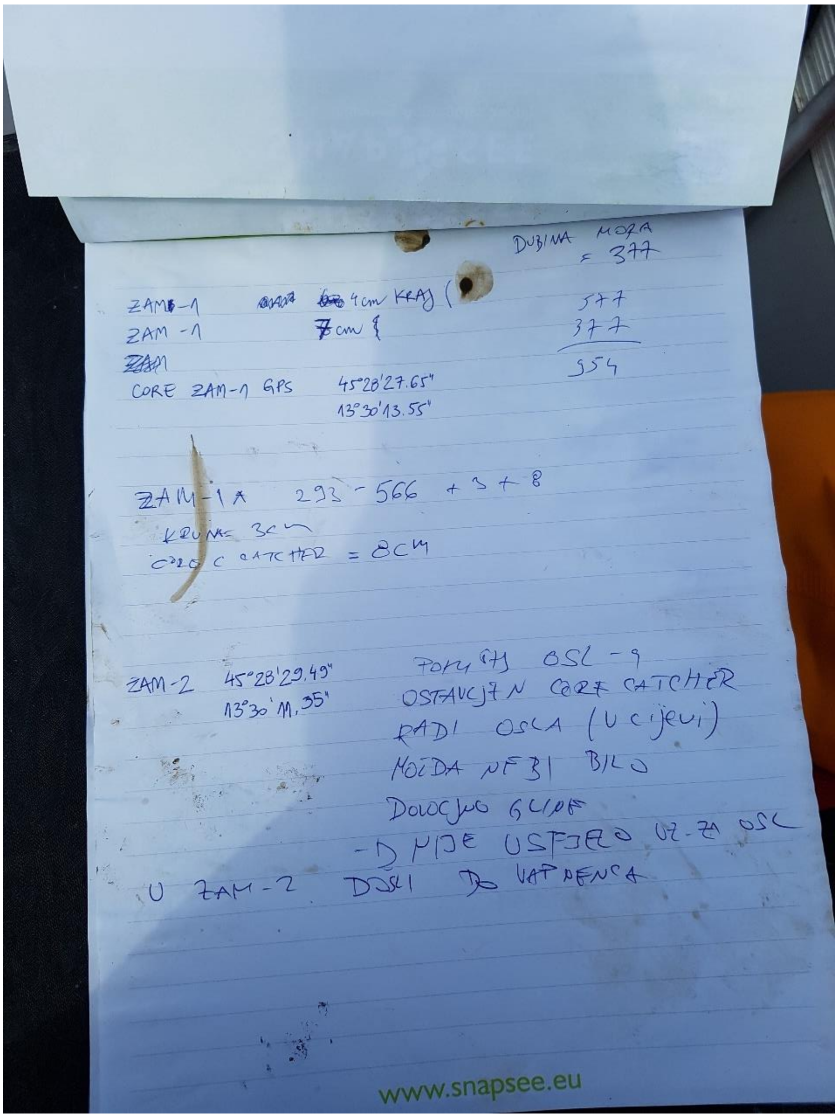


Figure 82 Fieldwork notes with measurements of the sediment trapped in the core catcher and calculating them into the total core length (Photo: K. Jerbić).

Underwater archaeological investigation and survey

The diving-based archaeological fieldwork was organised and led by the author in collaboration with AMI. It was performed between May 29–June 6 2017 by the author and AMI employees, Flinders University and Aix-Marseille University PhD student volunteers and one Zambratija local (**Appendix VII, VIII**).

The diving campaign was designed to produce a 3D photogrammetry model and a site plan of a selected area with visible piles, to document and collect wooden samples for dendrochronology, and to geo-reference the newly investigated area with a total station. Therefore, an assessment plan of the objectives and an outline of research methods was designed to successfully gather the necessary data. This plan was developed by the author based on the knowledge about the site and the available data provided by AMI, coring positions, and research questions, all methodologically framed by following the second edition of

Maritime Archaeology Technical Handbook by Green (2004). The underwater archaeological investigation and survey were designed based on two sets of results. The first one was the preliminary data obtained from the research done on the site by AMI between 2008 and 2015, presented in Chapter 2. The second set of data were the initial results from the sub-bottom survey and the coring sampling presented above. These two sets of data provided valuable information about the geophysical characteristics and sub-bottom stratification, as well as the connection of that evidence to the preserved and recorded archaeological features and material culture found on the site. The location chosen for the recording and collection of wooden architectural components was therefore selected on these criteria:

1. The location had to be placed in the area between the peat platform and Units 1 and 5. The peat represented both an important archaeological landmark as well as an environmental feature crucial for the recognition of potential architectural patterns. Units 1 and 5 were important sources of stratigraphy and contextualised pottery, as well as of the location from where the one preliminary radiocarbon date has been sampled from. Since the peat is composed of very delicate and soft organic matter, it was important not to place the new research area directly on its surface so that the feature stays preserved and intact in situ. The intention for the placement of the new archaeological research area was to connect these two already researched areas.

2. The location had to be in an area with a dense concentration of wooden piles protruding out of the seabed. This was because the research was limited to 6 days, which did not allow for an investigation of a large surface area. The dense concentration of wooden piles inside a smaller area would allow for a short-term research but with a large dataset for further laboratory and desk-based research.

3. For the purposes of obtaining original data, the new research area was to be placed in an area where no archaeological research or surveying has been performed prior to 2017.

After meeting all the requirements described above, a 6-day fieldwork, which included snorkelling and SCUBA diving (**Figure 83–85**) commenced. A 5x7 metre research trench was marked on the south-western ridge of the submerged karstic sinkhole at depths between -3.17 and -3.53 MSL. After the selection of the trench, all visible piles were marked with previously numbered tags. There were two sets of tags prepared, one set was for piles in situ, and the other one was for marking the collected samples which were taken for further analyses (**Figure 86**).

Figure 83 Preparations for a dive (Photo: K. Jerbić).

Figure 84 Pre-dive check on the site (Photo: C. Petretich).

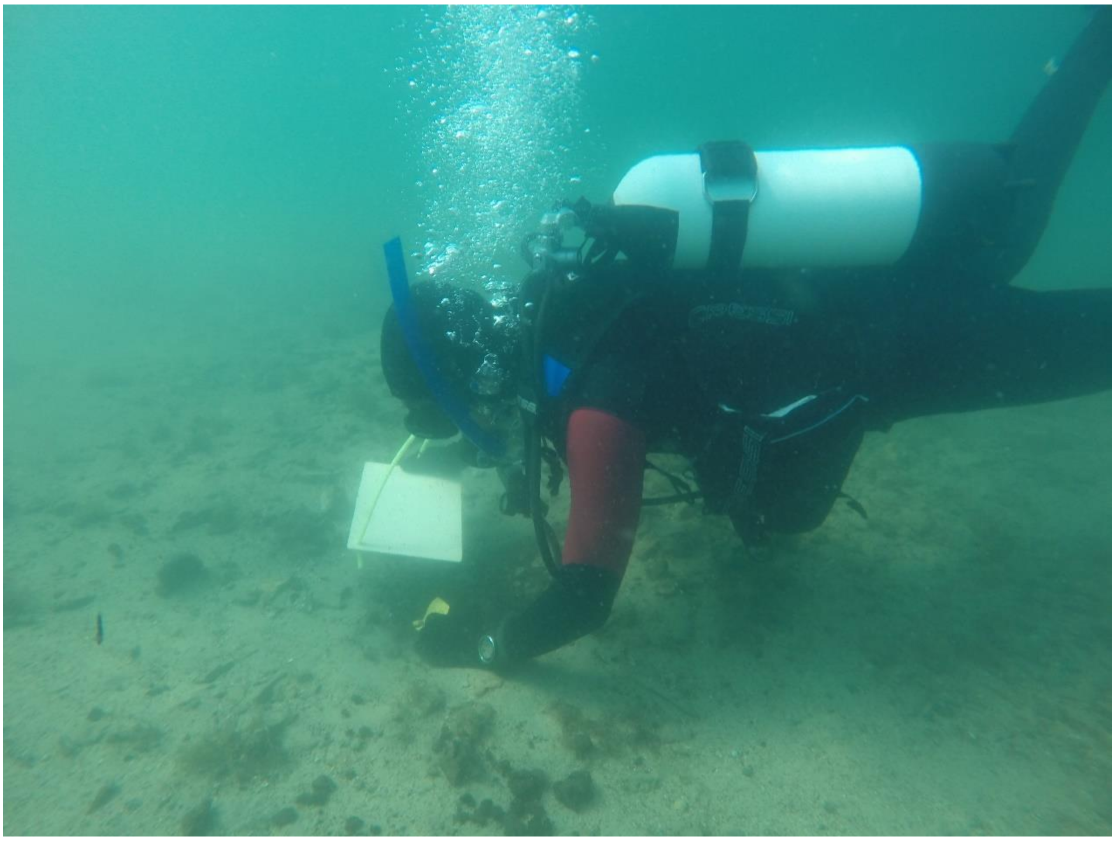


Figure 85 Marking the piles in the selected area and drawing a sketch (Photo: K. Bennett).

Figure 86 Pre-marking two sets of yellow tags (Photo: K. Jerbić).

The marked trench and piles were then photographed with a GoPro Hero3 camera for producing a 3D model of the site. Even though this was a simple and low-cost approach, it has been proven to achieve high-quality results, and is especially suited to smaller investigation areas (McCarthy and Benjamin 2014:96). An initial low-resolution photogrammetric test-model (**Figure 87**) was produced during the first days of the campaign in order to verify the quality of the taken photographs and evaluate whether they were suitable for creating a high-resolution 3D model.

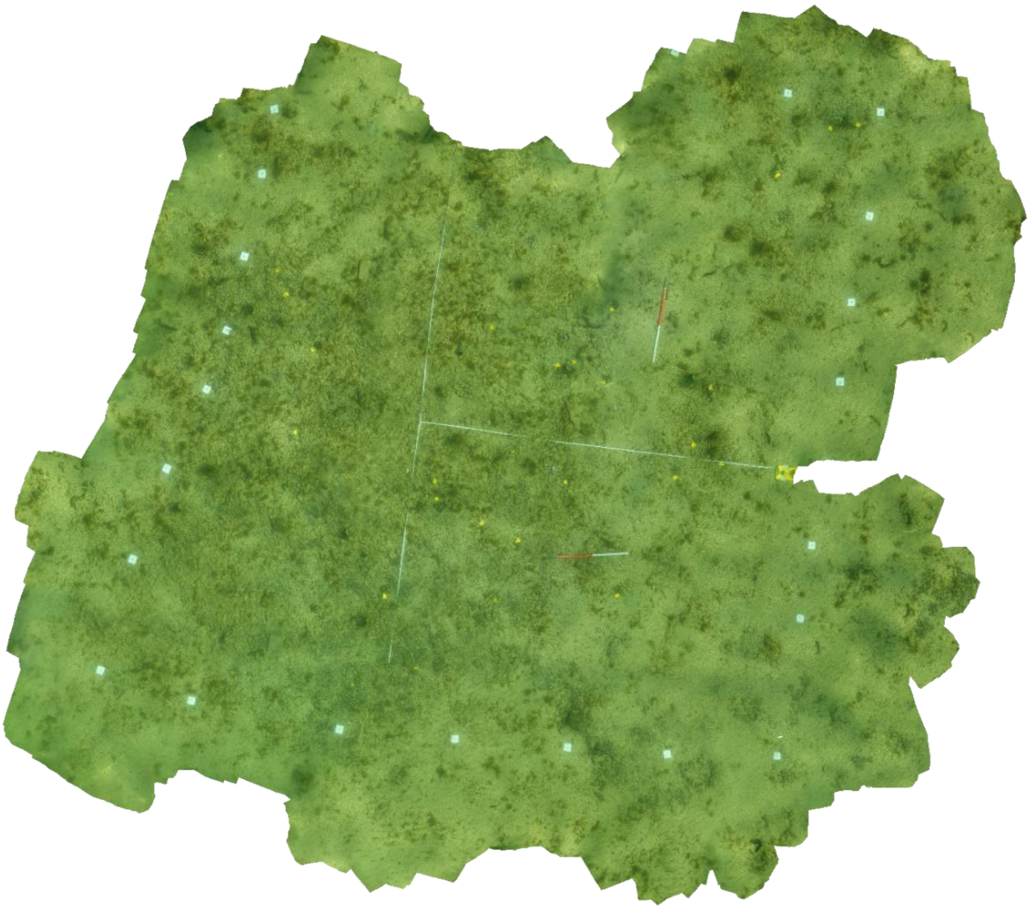


Figure 87 The initial low-resolution 3D photogrammetry model made during the investigation campaign (Author: E. Aragon Nuñez).

The quality of the taken pictures were assessed as suitable for processing a high-resolution model further on in the PhD candidature. The assessment was based on the clarity of visible features placed on the seabed for the purpose of methodological accuracy. These features are seen on Figure 78 as white photogrammetry targets around the research area; yellow and grey tags marking the piles (although the low resolution blurred the numbers, they are visible in the high-resolution model presented in Chapter 8); white tape measures in yellow casings, prepared for the baseline-offset drawing later on in the research; and red and white measuring poles indicating the orientation of the trench. The natural features, such as trepangs, *Pinna nobilis* molluscs, seagrass, and the sea surface wave shadows scattered around the seabed are also detectable. After the verification of the low-resolution photogrammetry, the next step was to produce a hand-drawn site plan, for the purpose of having a reference when processing the digital data as well as an additional dataset for the potential recognition of architectural building patterns. The original site plan was hand drawn underwater (**Appendix IX**), after which it was re-drawn on a clean and dry paper sheet (**Figure 88**) and digitalised after the total station survey, dendrochronological analysis and radiocarbon dating results, presented further in this chapter, were obtained. A total of 35 wooden piles situated inside and slightly around the trench area were identified. Piles that were marked outside the investigation trench were marked for a desk-based spatial analysis.

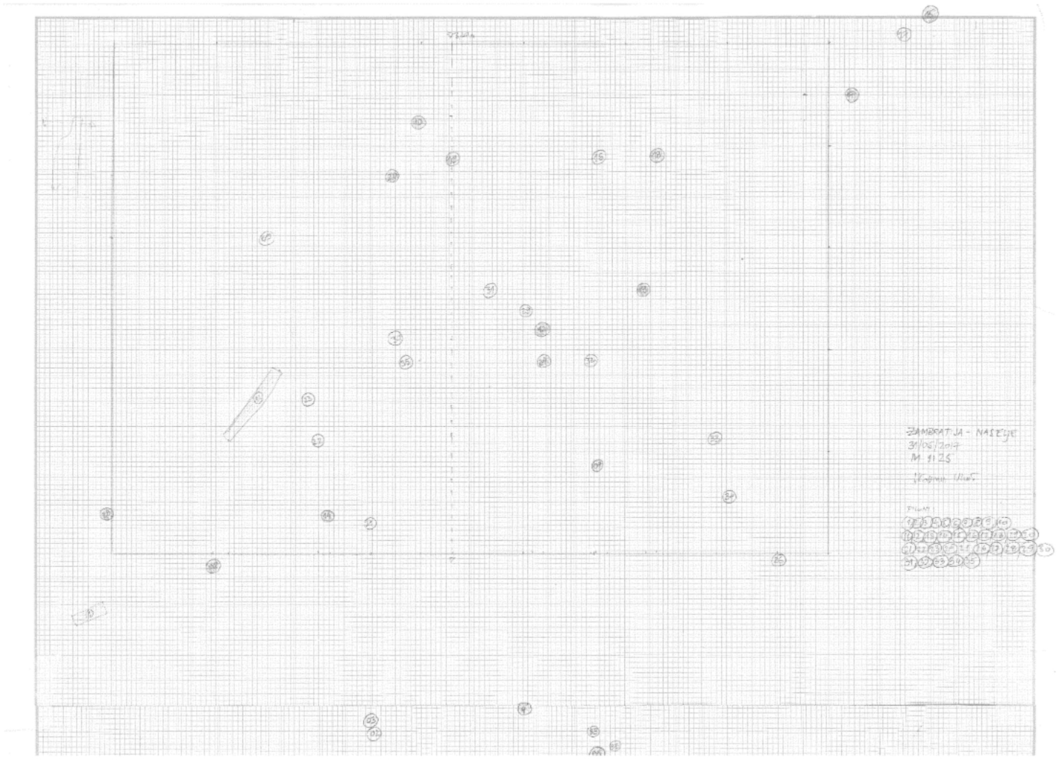


Figure 88 A scanned image of the re-drawn site plan (Author: I. Koncani Uhač).

Out of the 35 marked piles, 20 were sampled for dendrochronology and radiocarbon dating. The final number of samples was pre-defined due to the semi-destructive nature of method performance, as well as due to budget and timeline sensitivity of the PhD project. The underwater archaeologists performing the sampling selected the 20 piles based on the in situ evaluation of the quality of preservation and on their position in the seabed regarding availability for a safe sampling performance. Sampling was performed by hand sawing the visible protruding part of a pile (**Figures 89–90**), leaving the remaining part in the seabed (**Figure 91**). The sample was temporarily stored in the near vicinity of the trench and marked with a previously prepared second tag with a matching number (**Figure 92**), and later transported with the rest of the samples (**Figure 93**) to the fieldwork land base for preliminary analyses and preparations for transport. The samples were cleaned in fresh water (**Figure 94**), after which they were measured (**Figure 95**) and appropriately packed for transport (**Figure 96**).

Figure 89 Pile 23 before sampling (Photo: K. Jerbić).

Figure 90 Pile 23 sampled (Photo: K. Jerbić).

Figure 91 The remaining part of Pile 23 in situ after sampling (Photo: K. Jerbić).

Figure 92 Pile 23 in temporary storage (Photo: K. Jerbić).

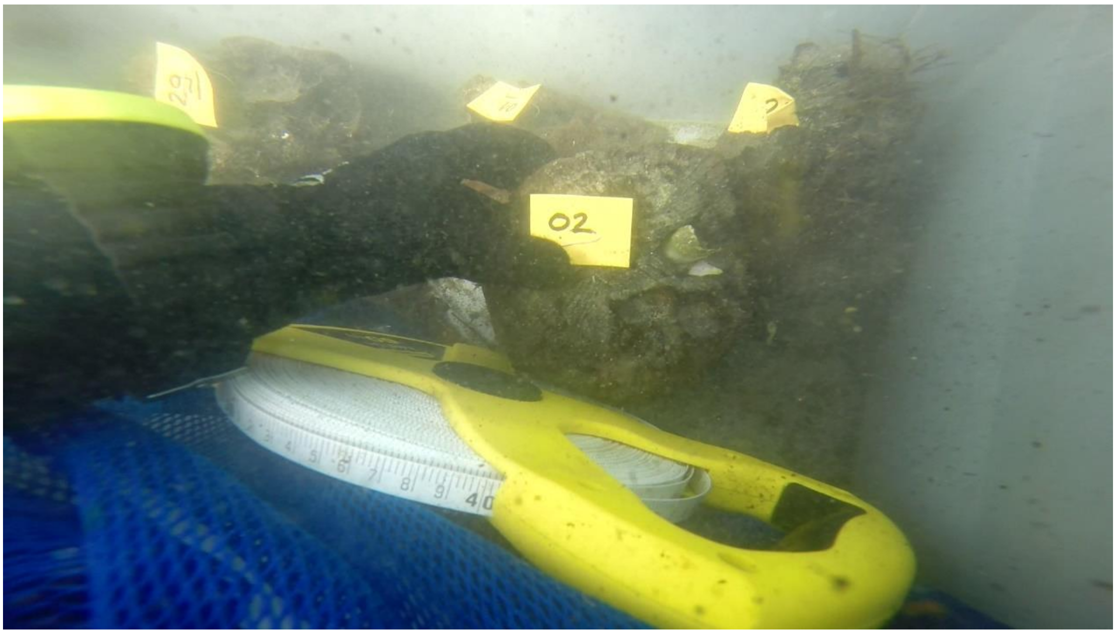


Figure 93 Sampled and marked piles before transporting to land (Photo: K. Jerbić).

Figure 94 Washing the samples in fresh water (Photo: M. Čuka).

Figure 95 Preliminary measurements (Photo: K. Jerbić).

Figure 96 Packed wooden samples (Photo: K. Jerbić).

Since Aix-Marseille University and AMI had a well-established contract allowing collaboration on all the maritime archaeology sites that the Museum holds the permits for[17], the wooden samples were sent to the Centre Camille Jullian for Mediterranean and African archaeology's dendrochronological laboratory at Aix-Marseille University in France for further analyses.

The finished sampling allowed for final site measurements and documentation of fifteen georeferenced points (**Figure 97**) on the underwater site and on land. The measuring was performed by using a Leica FlexLine TS06 manual total station, using the MGI 1901/Balkan zone 5 GIS coordinate system.

Total station point	Description	X	Y	Z
FT 1	Zambratija beach point 1	5383600.9079	5037868.5287	0.9937
FT 2	Zambratija beach point 2	5383599.4035	5037871.7502	1.8261
FT 3	Zambratija beach point 3	5383579.8687	5037876.1621	2.2364
FT 4	Zambratija beach point 4	5383586.8269	5037882.2683	2.4468
FT 5	Zambratija beach point 5	5383572.5995	5037867.5467	1.0317
FT 6	Zambratija beach point 6	5383550.7901	5037881.2412	1.0052
ST 1	Total station position	5383587.5464	5037875.5352	2.3142
SONDA.1	Trench point 1	5383360.5018	5037710.9609	-3.2347
SONDA.2	Trench point 2	5383365.6166	5037710.9396	-3.1709
SONDA.3	Trench point 3	5383364.5671	5037717.1079	-3.3237
SONDA.4	Trench point 4	5383359.5956	5037717.6158	-3.3918
PILON23	Wooden pile no. 23	5383361.1111	5037715.6759	-3.5297
PILON35	Wooden pile no. 35	5383361.2048	5037714.7516	-3.3342
PILON29	Wooden pile no. 29	5383361.3222	5037713.2239	-3.2942
PILON33	Wooden pile no. 33	5383360.3261	5037712.0012	-3.2299

Figure 97 A list of all total station points taken for the 2017 Zambratija diving campaign.

Laboratory methods

The laboratory analyses for the purposes of this thesis were organised by the author in collaboration with Aix-Marseille University, CGS and the University of York. The initial idea for performing the laboratory analyses and the workflow were organised by the author. Methods were performed by the author and other PhD project collaborators from CGS, The University of York, UK and Aix-Marseille University in France. XRF scanning at the Institute of Marine Science (ISMAR) in Bologna, Italy.

[17] www.ccj.cnrs.fr/spip.php?article2104

Initial core description and discrete sample preparation

Due to the budget and timeline sensitivity of this PhD research, three out of the seven cores were chosen for further preparations and analyses. Those were cores ZAM-1, ZAM-2 and ZAM-7. The preparation process was organised and performed by the author at the CGS laboratories in Zagreb, Croatia, under the supervision and training from the scientific and technical staff at CGS (Dr Slobodan Miko, Dr Ozren Hasan, Dr Nikolina Ilijanić and PhD students Dea Brunović[18], Dragana Šolaja and Ivona Ivkić) during periods between June 13–26 2017, January 3–4 2018 and June 3–6 2018; as well as by the CGS scientific staff in 2017 and 2018.

The three cores were taken under a standardised procedure for PVC-held sediment core initial analysis, developed and described by CGS (Hasan 2017). The initial protocol consists of five steps (described below), which allowed for choosing the desired discrete 1 cm samples of sediment for further analyses.

1. Splitting the core horizontally into two identical splits (**Figure 98**). The PVC tubes were cut with a hand-held saw Bosch POF 1200 AE 1200-Watt router (**Figure 99**), and the sediments were carefully cut through with a fishing line (**Figure 100**).

Figure 98 Core ZAM-2 after splitting in half (Photo: K. Jerbić).

[18] Now Dr Dea Brunović.

Figure 99 Cutting the PVC lining of the core (Photo: D. Brunović).

Figure 100 Cutting through the sediments with a fishing line (Photo: D. Brunović).

2. Archiving and sediment descriptions. The surface of both halves were cleaned and smoothed for better understanding of the relations between sediment layers (**Figure 101)**. One half was covered with plastic wrapping and archived in the CGS cold storage for reference and/or additional analyses (**Figure 102**). The other, working half, is where all the data presented in the PhD originates from. A Munsell Soil Colour Chart (Munsell Color Co. 1992) was used for colour descriptions and the sediments were then processed according to the Troels-Smith standard system for describing unconsolidated sediments (Troels-Smith 1955)[19].

3. Digital photography. The working half was photographed with a Canon EOS 500D digital camera, inside a dark box, with controlled lighting (**Figure 103**). The photographs were taken in 5 cm intervals for the entire length of each core.

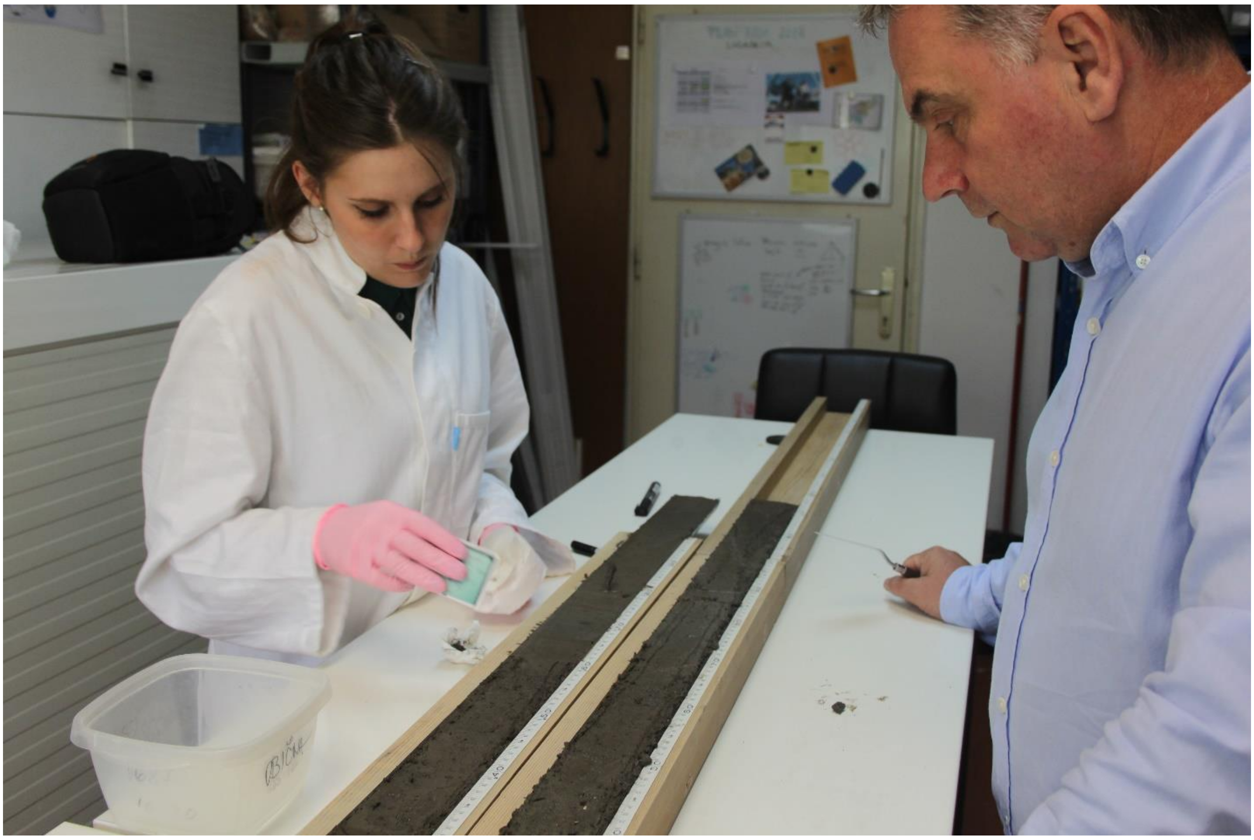


Figure 101 Smoothing out the core's halves surfaces for choosing the archival and working half (Photo: K. Jerbić).

[19] The Troels-Smith standard system for describing unconsolidated sediments (**Appendix X**) was performed retrospectively on the archival halves on cores ZAM-1 and ZAM-2, and on the working half on core ZAM-7 in June 2018 by the author, after consultation with her associate supervisor, Prof. Roland Gehrels in November/December 2017. In order to obtain the necessary training and experience, the author took part as a volunteer on three coring fieldworks led by the University of York's Department of Environment and Geography PhD students Graham Rush (Ythan estuary, Scotland, UK, November/December 2017) and Sophie Williams (Tara valley marsh near Yarram, Victoria, Australia, April 2018; and Simpsons Bay marsh on Bruny Island, Tasmania, Australia, April 2019).

Figure 102 The author wrapping one half of core ZAM-1 for archiving (Photo: D. Šolaja).

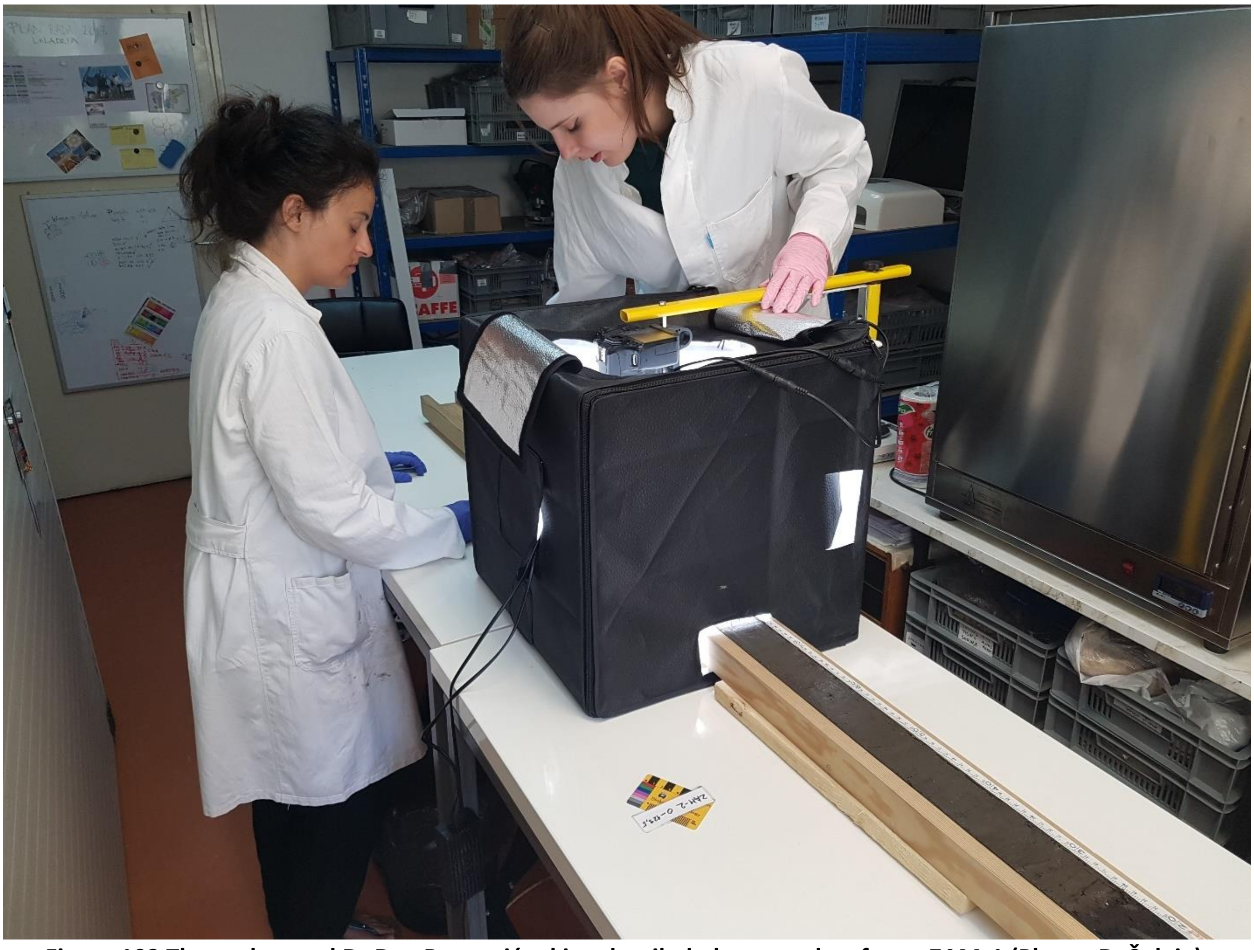


Figure 103 The author and Dr Dea Brunović taking detailed photographs of core ZAM-1 (Photo: D. Šolaja).

4. Spectral colour analysis. After taking photographs, the working half was sent to a 1 cm accuracy spectral colour analysis, with an X-Rite Inc. DTP22 Digital Swatchbook Spectophotometer (**Figure 104**). Used with a laptop (**Figure 105**), this device gave accurate colour measurements in numerical CIE L*a*b (Lightness, red/green and yellow/blue) values (X-Rite and Pantone® 2016:11), according to the International Commission of Illumination (Commission Internationale de l'Eclairge – CIE) (X-Rite and Pantone® 2016:7), which were then digitally transformed into a graph.

5. Magnetic susceptibility. The same working half was then measured in 1 cm distances with a Barrington Magnetic Susceptibility Meter (**Figure 106**) with a MS2E High resolution Surface Scanning Sensor connected to a laptop (**Figure 107**). Magnetic susceptibility measurements were transformed into a graph form, which gave a visible representation of the magnetic changes occurring throughout the core in a 1 cm resolution.

Magnetic susceptibility measurements marked the final step of the initial core analysis, and a working core half was ready for the collection of discrete samples taken from 1-cm-wide positions[20] (**Figure 108**). These discrete samples were placed in labelled bags and sent to further microscopic, chemical and other types of laboratory analyses (**Figure 109**).

Figure 104 X-Rite Inc. DTP22 Digital Swatchbook Spectophotometer (Photo: K. Jerbić).

[20] The positions and analyses were handpicked and chosen by the author under the scientific supervision and consultation with Dr Slobodan Miko, based on the changes and properties seen in the graphs and photographs from the initial core description. It was also important to extract any visible organic remains from each centimetre and set it aside as a potential radiocarbon dating sample.

Figure 105 Inserting measurements taken with the spectrophotometer into a database (Photo: D. Šolaja).

Figure 106 Barrington Magnetic Susceptibility Meter (Photo: K. Jerbić).

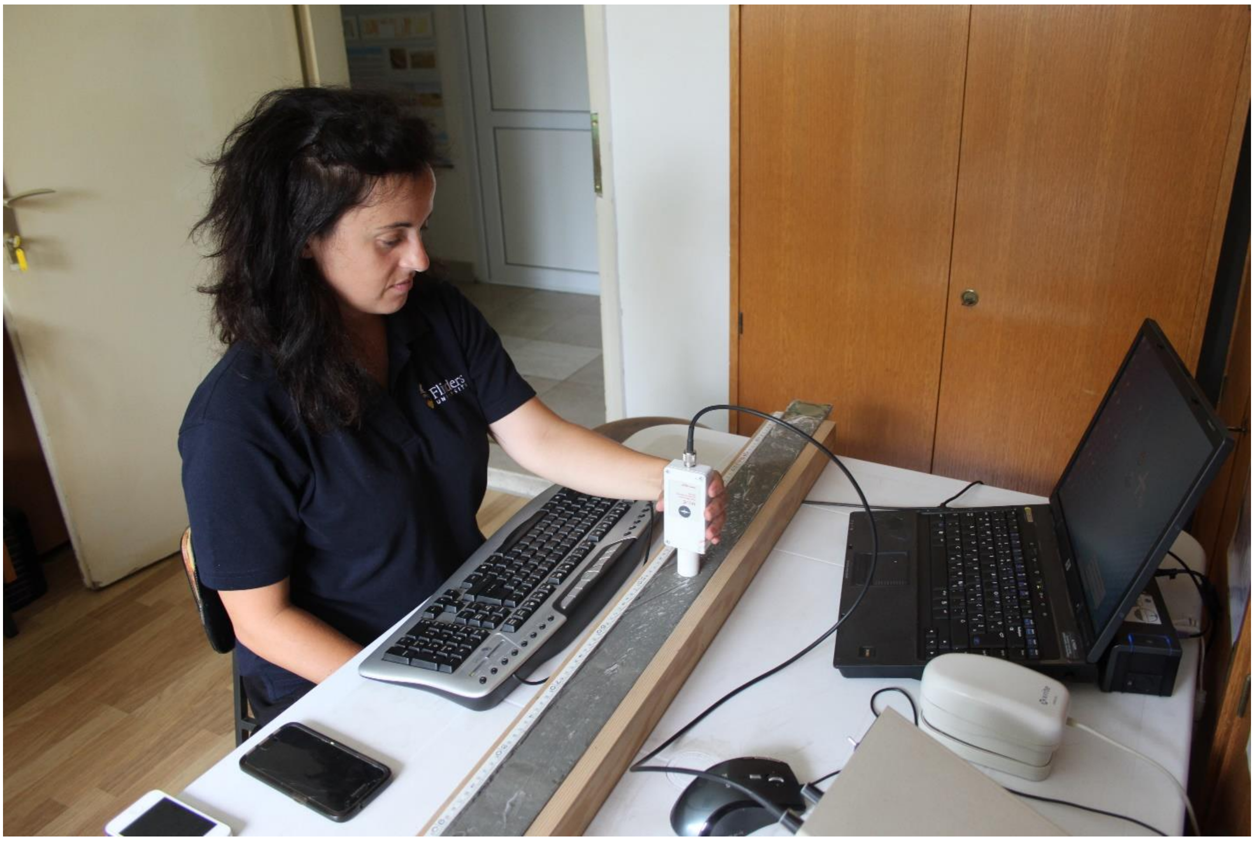


Figure 107 Taking magnetic susceptibility measurements (Photo: D. Šolaja).

Figure 108 Collecting discrete samples from 1-cm-wide positions (Photo: D. Šolaja).

Figure 109 Discrete samples from core ZAM-2 (Photo: K. Jerbić).

Depositional microfauna

The extraction and counting of benthic foraminifera was organised and performed by the author under the supervision of Prof. Roland Gehrels at the Department of Environment and Geography's research laboratories at the University of York, UK between June 28–July 3 2017, November 11–December 11 2017 and July 11–August 13 2018. 18 samples in total were processed, 2 from ZAM-1, 11 from ZAM-2 and 5 from ZAM-7.

Foraminifera are multi-chambered marine microorganisms. Foraminifera shells vary in morphology between different species, making them visually identifiable. Each species has a distinguished habitat preference (brackish/marine, warm/cold water etc.) and is sensitive to variables such as salinity, water depth and temperature. These properties make them useful proxies for tracing environmental histories in vertical sediments, including the history of sea-level change (Gehrels 2000; Jorissen 1987). Therefore, by looking at the statistical average of different species of fossil foraminifera distribution in undisturbed vertical depositions of sediments (cores), it is possible to reconstruct the types of habitats they were formed in (Reitz and Shackley 2012:161-181). An accurate paleo-environmental reconstruction relies on modern-day data, making our knowledge of the past as good as it is of the present. The assumption that the relationships we see in ecosystems today were the same in the past is called uniformitarianism which has its limitations, but has so far proven to be a valuable and accurate principle in paleo-reconstructions (Roberts 1998:28-29). A few studies of modern-day foraminifera have been conducted in the Adriatic so far (Ćosović et al. 2006; Ćosović et al. 2011; Jorissen 1987; Shaw et al. 2016).

Foraminifera was extracted from 1 cm sediment sequences, selected on the specific properties seen in the graphs and photographs from the initial core description. A known volume of each sample was wet sieved between a 500 µm and a 63 µm sieve. The material left in the ≥ 63 µm sieve was collected and washed with deionised water into a beaker to settle and transferred in a counting tray (**Figure 110**). The tray was placed under the 80x magnifying Zeiss Stemi 305 binocular microscope. Foraminifera was hand-picked from the tray and placed on a pre-glued microfaunal slide using a fine paintbrush (**Figure 111**).

Figure 110 Foraminifera counting tray (Photo: K. Jerbić).

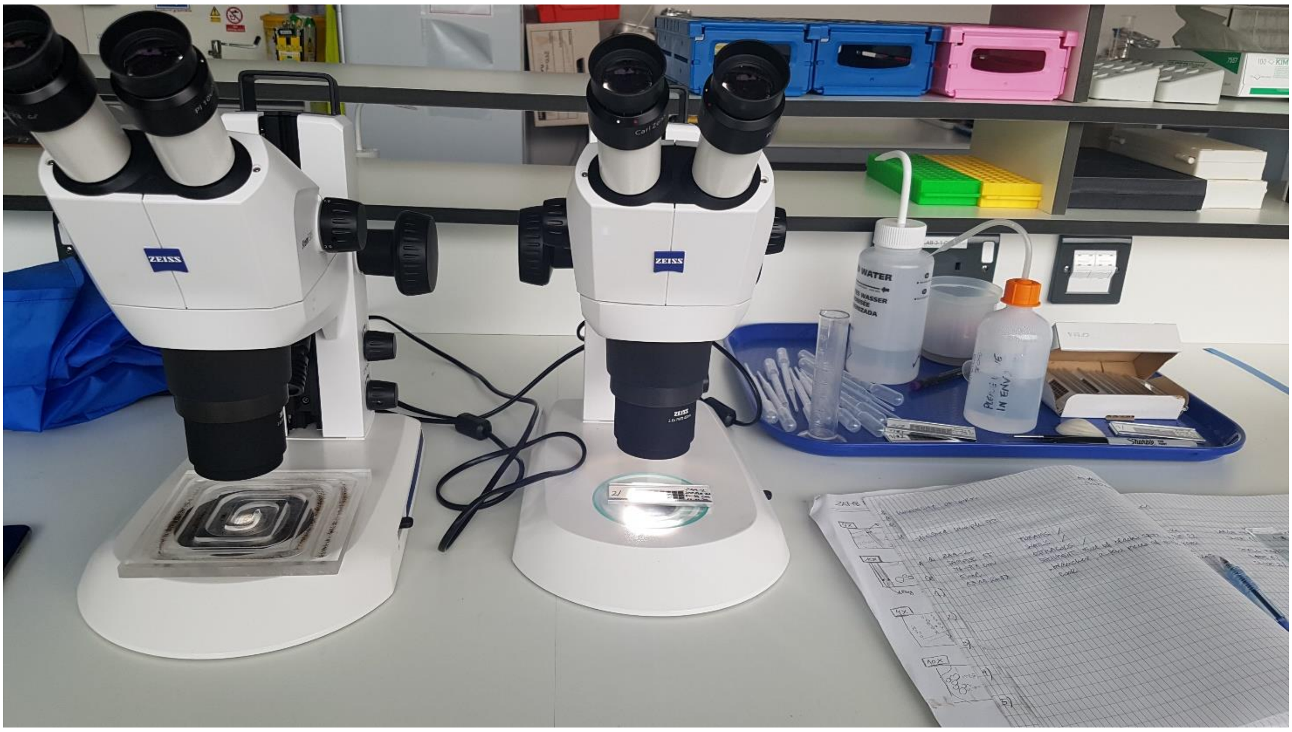


Figure 111 Foraminifera counting tray (left microscope) and the pre-glued microfaunal slide (right microscope) (Photo: K. Jerbić).

Grain size analysis

Grain-size analysis was organised by the author under the supervision of Dr Slobodan Miko at the CGS laboratory in Zagreb. The analysis was performed on samples from core ZAM-1 and ZAM-2 by Dr Dea Brunović in January 2019. The results were plotted in the C2 software (Juggins 2011).

Grain-size analysis is one of the basic methods for sedimentological characterization used to describe the type of sediment accumulation and the water energy dynamics at the time of the deposition (Håkanson and Jansson 2002). In combination with other geochemical and depositional proxies, the down-core distribution of sediment grain sizes is therefore a good indicator of the intensity of changes in depositional environments in archaeological layers (Scudder 2001, 2003).

A total of 73 samples were analysed, 60 from core ZAM-1 and 13 from core ZAM-2. The analysis was performed by using the Shimadzu Laser Diffraction Particle Size Analyzer SALD-2300 combined with the WingSALD II-2300 program, which measures range from 17 nm to 2500 µm. Each 0.1 g sample was added to 2 ml of 30% hydrogen peroxide (H2O2) to remove organic matter. Prior to taking measurements, the samples were dispersed by adding 2 ml of sodium hexametaphosphate. Grain-size results were interpreted using GRADISTAT software (Blott and Pye 2001), which uses following grain-size scale: very coarse sand (2–1 mm), coarse sand (1000–500 µm), medium sand (500–250 µm), fine sand (250–125 µm), very fine sand (125–63 μm), very coarse silt (63–31 μm), coarse silt (31–16 μm), medium silt (16–8 μm), fine silt (8–4 μm), very fine silt (4–2 μm) and clay (<2 μm). Sediments were classified according to Folk and Ward (1957).

Total Organic Carbon (TOC) and Total Nitrogen (TN) content

TOC and TIN analyses were organised and performed by Dr Slobodan Miko at the CGS laboratory in Zagreb. The total number of samples was 73; 60 from ZAM-1 and 13 from ZAM-2. TOC and TIN were analised by using the CN analyser.

Organic carbon and total nitrogen analysis indicate the changes in primary productivity and organic matter source in marine and lake sediments. They give evidence of the input of land plants to sediments. Higher values are a measure of higher nutrient load into the system and lake productivity, and thus associated with warmer climatic conditions (Lamb et al. 2006). The concentration of total organic carbon (TOC) is a fundamental proxy for describing the abundance of organic matter in sediments. Nitrogen concentrations strongly depend on the source of the organic matter; terrestrial plants gave low values, while phytoplankton has higher values. This variation can be tracked using the total organic carbon (TOC) and total nitrogen (TN) ratio. TOC and TN provide information about the proportion of algal and land plant contribution to organic matter (Meyers and Teranes 2001). When the origin of organic matter is from lake algae, atomic TOC and TN values typically lie between 4 and 10, whereas terrestrial plants usually have values of 20 and greater. Atomic TOC and TN values of 12–17 suggest a mixture of algal and terrestrial plant input (Meyers and Teranes 2001).

The TOC and TN analyses were performed with the CN elemental Thermo Fischer Scientific, Flash 2000 NC Analyser. Samples were freeze-dried, finely ground in agate and mortar and packed in tin (Sn) capsules, which are placed in the CN analyser. The analysis is composed of combustion of samples at 900°C, which allows the determination of Total Organic Carbon and Total Nitrogen. TOC is measured after a treatment with hydrochloric acid (10% HCl). The calculation of Total Inorganic Carbon (TIC) is based on the difference between Total Carbon (untreated sample) and Total Organic Carbon (sample treated with HCl). The results of TOC and TN analysis were graphically displayed in the C2 software (Juggins 2011).

X-ray Diffraction (XRD)

XRD analysis of the mineralogical composition of sediments was organised under the supervision of Dr Slobodan Miko and Dr Nikolina Ilijanić at the CGS laboratory in Zagreb. The analysis was performed on selected powdered samples from cores ZAM-1 (32 samples) and ZAM-2 (7 samples) by Dr Nikolina Ilijanić in January 2019.

The determination of mineral phases present in sediments gives valuable information on sediment source, as well as depositional conditions. Since minerals and clays are formed on the soil formation of the Earth's surface, the mineral composition of the analysed soil therefore depends on the general physical characteristics of the geological features of its origin (Chamley 1989:623). For example, kaolinites are found in soils originating in warm and humid climate, and silicates are found in soils originating in cold and dry climates (Sheldon and Tabor 2009:7).

XRD was performed by using the PANalytical X'Pert Powder X-ray diffractometer, equipped with Ni-filtered Cu X-ray tube (CuKα1, λ=1.5405 Å), vertical goniometer with a θ-θ geometry and a PIXcel detector. The dry samples were ground in agate and mortar and packed on aluminium holders for analysis. Measurement conditions were: 45 kV voltage and 40 mA current, step-size 0.02°2θ, time per step 4 s, with a range of 4-66 °2 θ. The interpretation of diffraction patterns was made using HighScore program using ICDD database (PDF4/Minerals), according to Moore and Reynolds (1997).

X-ray Fluorescence (XRF)

XRF scanning was organised by the HGI under the supervision of Dr Slobodan Miko and Dr Ozren Hasan from the CGS laboratory in Zagreb. The analysis was performed on the archival half of core ZAM-1 at the Institute of Marine Science (ISMAR) in Bologna, Italy.

The elemental composition of sediments depends on the origin of the deposited sediments, the environment in which they accumulated, and potential early sediment modifications which occurred immediately after rock formation. Sediments have initially been eroded from a certain source rock/soil and have subsequently been transported by streams/rivers or wind before they finally settle. The geochemical composition of the sediments accumulated at any site, therefore, contains original source rock/soil information (Sheldon and Tabor 2009:8). Increased primary productivity (PP) and anoxic conditions enhance the potential preservation of organic matter, which can result in distinctive black layers. As organic matter is usually darker than the more carbonate-rich, organic-poor sediments, changes in colour can also be applied as proxies for changes in PP or anoxia. Past changes in source material and provenance, sediment runoff and erosion, primary productivity and anoxia, are all impacted by changes in climate. Therefore, if the elemental composition of sediments and the different pathways leading to their deposition are known, the data can be used to reconstruct past climate (Weltje and Tjallingii 2008:424).

Sediment elemental composition of discrete samples is most often determined by applying one of two methods: Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES), which is the most reliable and traditional method and X-Ray Fluorescence scanning (XRF), a non-destructive and less time-consuming method. For XRF, the flat surface of core sediments is excited with X-rays, after which the characteristic fluorescent X-rays emissions are used to determine the elemental composition. This rapid method is considered to be semi-quantitative (Richter et al. 2006; Weltje and Tjallingii 2008).

The archive half of sediment core ZAM-1 (0-559 cm) was scanned at 1 cm resolution with the AVAATECH µXRF core-scanner at Institute of Marine Science (CNR-ISMAR) in Bologna, Italy, during April and May 2018. The sediment was protected with Ultralene during X-ray transmisson foil in order to avoid contamination. Richter et al. (2006) give technical details on the XRF scanning technique. Elements Al, Ba, Ca, Cl, Cr, Fe, K, Mn, P, Rh, S, Si, Ti and V were measured at an X-ray voltage of 10 kV, elements Br, Bi, Cu, Ga, Nb, Ni, Mo, Pb, Rb, Sr, Zn, Zr and Y were measured with an X-ray voltage of 30 kV; and elements: Ag, Cd, Sn, Te and Ba with voltage 50 kV. The count time of each measurement was 30 seconds. The XRF results are expressed as element intensities in counts per second and were graphically displayed in the C2 software (Juggins 2011).

Scanning electron microscope

Some of the extracted minerals and microfossils were documented with a scanning electron microscope (SEM) for a more accurate interpretation and high-resolution imagery and X-ray spectroscopy. The scanning was performed by Dr Ozren Hasan at the the CGS laboratory in Zagreb in January 2018.

Archaeology of the core

As described in Chapter 5, PACS has been faced with a unique problem since its very beginnings regarding research strategies of identifying submerged landscapes and archaeological sites. Although site locations, inundation timeframes and even paleo-landscapes were known facts, they were also well preserved and protected under large masses of water, and, in many cases, marine sediments. The opportunity to obtain archaeological evidence about the human populations that had access to these landscapes, and whether there was ever a time that they exploited or inhabited them (eg. Ward et al. 2015; Ward and Veth 2017) is therefore limited. Once sea-level reconstructions and models started to appear (Berger 1983), scientists and archaeologists became aware that these submerged areas contain not only 'lost' landscapes, but also knowledge of our own past (Masters and Flemming 1983b), making PACS one of the most fast-growing archaeological disciplines in the 21st century. None the less, problems regarding issues such as finding more sites (Flatman and Evans 2014:1) and those regarding logistics and funding (Bailey 2014:298) are still representing significant limitations when trying to investigate submerged landscapes.

When addressing these limitations, authors often conclude that since PACS is a topic concerning all human past as well as our future (Van de Noort 2013:vii), the discipline should have a universal checklist which can be applied to every submerged site around the world, and provide results that can predict a submerged prehistoric archaeological site with as much certainty possible. The checklist starts with models of inundated local geomorphology, preferably with recognisable cultural features and basic environmental factors necessary for humans to inhabit a certain area. Factors can be traced by surveying techniques such as remote sensing and target identification, for creating predictive models. These factors are: traces of fresh water access, natural protection from environmental hazards, and the availability of food (Evans et al. 2014:5). The predictive models, however, have a limitation that often represents the end of a maritime archaeology project, which is the inability to recognise with certainty the presence of a submerged archaeological site remotely (Faught 2014:40). In PACS, when fieldwork research is continued after the initial surveys, it involves diving and underwater excavations. These actions represent a stressful risk for both the archaeologists and the investors, not only because they involve diving and underwater excavations, but also because of the high likelihood of a negative archaeological result, regardless of the promising preliminary indications. In the instances where seabed coring is performed on potential submerged archaeological sites, the sediments are assessed for the purpose of reconstructing the environmental history of the submerged sediments, rather than cultural history those sediments contain.

The proposed method, colloquially named archaeology of the core, represents a consequential product of this research project. It was inspired by the works of Momber (2011), who used a SCUBA diving method of extracting samples of submerged archaeological sediments to land, where they could be more carefully examined (Momber 2011:90) and the concept of Microarchaeology described by Weiner (2010). If applied on sites with archaeological potential, archaeology of the core could become a standard when investigating coastal and submerged archaeology, placing it next to methods such as seabed mapping and 3D modelling. It is important to nothe that, while archaeology of core has a potential to become standard practice, there are some contextual limitations to be considered. These include, but are not exclusive to, situations where the submerged prehistoric sites are only present on the sea bed, or are very shallowly buried (O'Shea et al. 2014), or in sandy contexts where sediments are not consolidated (Galili et al. 2017a). Tested on core ZAM-7, where the core stratification indicated undisturbed environmental and cultural layers, the method is composed of steps known to every trained field archaeologist and therefore easily applicable.

As presented in fieldwork methods, seabed coring is performed from a raft or a boat, and no diving is needed, minimising the mentioned limitations regarding logistics and funding. Since the environmental assessments use only a small percentage of the overall vertical composition of the sediments in a core, the remaining sediments are often put aside and eventually discarded. The discarded sediments, however, represent intact vertical stratigraphical contexts with potential to support the process of site determination and its significance. The sediments might contain valuable archaeological evidence, and the core can be transformed into an archaeological test unit on a micro scale. This is where archaeology of the core can represent the connection between remote sensing and excavation. The risk of empty units and trenches is minimised, and the sediment contents represent a connection between archaeological survey and fieldwork, and potentially add to the archaeological and cultural significance of a submerged site in need of excavation, rescue or protection. A small-scale sediment sample such as a core, and minimal time spent on fieldwork makes it possible to perform an excavation in a laboratory environment, on almost 100% of the sample. This makes the analysis to have a high likelihood of scientifically performed, measurable results necessary for the assessment of a site's future perspective and deciding on what further steps to plan and present to potential collaborators and/or investors. Archaeologists agree that PACS methods should be improved and refined (Flatman and Evans 2014:10). As for the question asked seven years ago by Bailey (2011): Continental Shelf Archaeology: where next?, this method may represent one of many directions.

Archaeology of the core was performed on sediments from the core ZAM-7 by the author, with the assistance of PhD student Luke Andrews, at the Department of Environment and Geography at the University of York, UK in June and July 2018. Sediments were documented as stratigraphic units, divided to 1 cm discrete samples and wet sieved through a 500 µm sieve (**Figure 112**).

Figure 112 Fractions after wet sieving ready for an archaeological assessment (Photo: K. Jerbić).

Smaller fractions were collected into a 63 µm sieve and stored in labelled viles for potential environmental analyses. Fractions left in the sieve were placed on paper towels to dry (**Figure 113**). Once dry, the sample was carefully examined with a picking tool, where recognisable finds were extracted, documented and separately stored for further processing.

Figure 113 Fractions drying on paper towels ready to be picked (Photo: K. Jerbić).

Microflotation by heavy liquid mineral separation

Microflotation by heavy liquid separation was organised by the author under the supervision of Dr Slobodan Miko at the CGS laboratory in Zagreb. The analysis was performed on six 2 cm^3 volume samples from core ZAM-7 by Dr Ivan Razum in December 2018.

The heavy liquid flotation method is commonly used to extract silicified plant material, or phytoliths (Lentfer and Boyd 1998), which are used in archaeological contexts for determining decayed or burned plant remains (Reitz and Shackley 2012:286). A part of the analysis requires for phytoliths to be separated from sediment, clay and other microscopic fractions in order to perform a quantitative analysis (Lentfer and Boyd 1998:1159). In the ZAM-7 core, the focus of the analysis was to identify those separated fractions, with the aim to find potential particles of anthropogenic origin such as microscopic pottery particles or lithic microdebitage, in order to potentially identify the cultural site formation processes (Hull 1987).

All samples were wet sieved where the fractions between 32–125 μm in size were taken retained for a microscopic analysis. To remove carbonates, samples were treated with 10% acetic acid to prevent apatite dissolution (Mange and Maurer 1992:11). The insoluble fraction was analysed on glass slides, with Canada balsam used as mounting medium (Mange and Maurer 1992:16). The optical analysis, which consisted of estimating the observed quantities of microscopic pottery remains, was done with a Nikon ECLIPSE LV100N POL polarising microscope.

Plant remains identification

Plant remains identification was organised by the author. Wood species determination of the 20 waterlogged wooden piles taken for dendrochronology was performed by PhD student Alba Ferreira Gomez at the Centre Camille Jullian for Mediterranean and African archaeology’s dendrochronological laboratory at Aix-Marseille University in France in November 2017. Plant remain analysis was performed by PhD student Luke Andrews at the Department of Environment and Geography at the University of York, UK, in May 2019.

Wood species determination or wood anatomy is a subdiscipline of dendrochronology which focuses on tree species determination by looking at cell structures of the sampled trees (Kaennel and Schweingruber 1995:397). The method is composed of slicing three thin sample sections – transversal, tangential and radial, from each pile with a cutter blade (**Figure 114**). The species was determined by visual interpretation through an Olympus Electron microscope.

Figure 114 Slicing a wood sample with a cutter blade (Photo: K. Jerbić).

A sample of plant epidermis from ZAM-7 148–149 cm was sent for radiocarbon dating (described further in Chapter 6). A similar remain was found in ZAM-7 146–147 (**Figure 115**), which was retained for plant fossil identification. The sample was washed through a 63 µm sieve and stored in de-ionised water in a refrigerated storage room below 4°C to prevent desiccation and decay. The analysis consisted of mounting the sample on a microscope slides in water and identified under high power microscopy at 100–400x magnification. The identification to the closest taxonomic resolution was possible by referring to the Grosse-Brauckmann (1974) identification guide.

Figure 115 Leaf remain from ZAM-7 146–147. The leaf is 4 cm long and 1.5 cm wide (Photo: K. Jerbić).

Dendrochronology

The dendrochronological analyses of wooden pile samples were performed by PhD student Alba Ferreira Gomez and Dr Lisa Shindo at the Centre Camille Jullian for Mediterranean and African archaeology's dendrochronological laboratory at Aix-Marseille University in France in November 2017 (**Appendix XI**).

Dendrochronology is the study of the growth rings of trees (Kaennel and Schweingruber 1995:91), Dendrochronology is based on correlating the tree-ring sequences of one sample with the sequences from previously built databases. Since the remains of trees are made of organic material and contain carbon, the same sample used for dendrochronology can be used for radiocarbon dating (Kaennel and Schweingruber 1995:273). Cross-referencing the two dating techniques gives more accurate results, and it allows for other radiocarbon dates from the same site to be calibrated (Berger 1983; Kromer 2009; Roberts 1998:18). Using dendrochronology is a well-established dating method in the field of environmental archaeology (Berger 1983; Reitz and Shackley 2012:253) and pile-dwelling research, simply because of the vast quantities of wood preserved in a wetland anaerobic environment (Billamboz 2004:117; Menotti 2012:14). The limitations of this method lie in the fact that a tree master-sequence for the particular area has to exist in order to correlate with the sample (Menotti 2012:20). Dendrochronology is used not only as a dating method but also as a tool for paleo-environmental and socio-economic studies linked to building technology, occupational patterns and the studies that investigate the impact that humans have on the landscape. Traces of wood technology on archaeological wooden artefacts enable the recognition of the settlement's genesis, development and organisation. Wood remains can lead to exploring even further into the social components of the community, by studying the organisation of used wood for different types of buildings (Menotti 2012:20).

Initial preparations of the wooden samples were undertaken on site in Zambratija (see fieldwork methods described previously in this chapter), and sent to the laboratory, where they were photographed and prepared for determining the tree ring measurements (**Appendix XII**). For the tree-ring sequences, ring widths (**Figure 116**) were measured using the incremental measuring table LINTAB with 0.01 mm (**Figure 117**). The measurements were automatically digitally transferred into the TSAP-Win software (Rinntech Company, Heidelberg, Germany). Cross-dating was carried out by means of DENDRON IV software, developed with RunRev LiveCode, Edinburgh, Scotland, by G.-N. Lambert CNRS, University of Franche-Comté, Besançon, France and the University of Liege, Belgium (Version: 20150221).

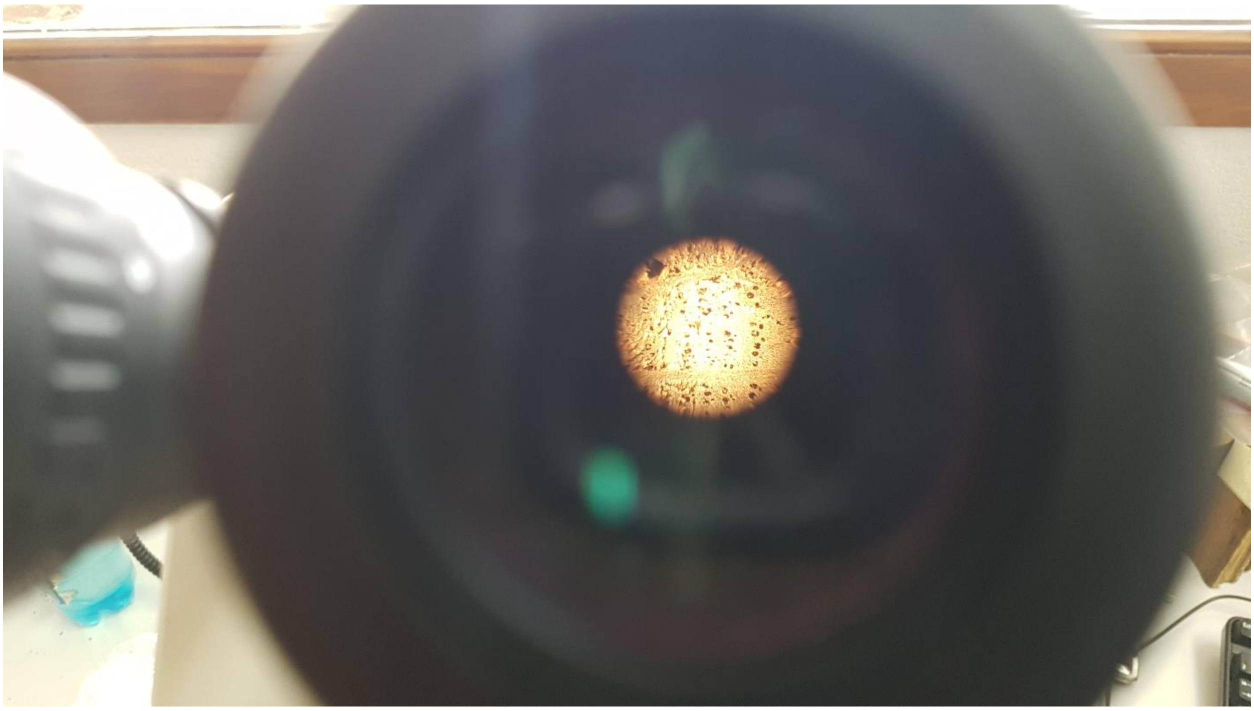


Figure 116 Pile 19 tree-rings through the microscope lense (Photo: K. Jerbić).

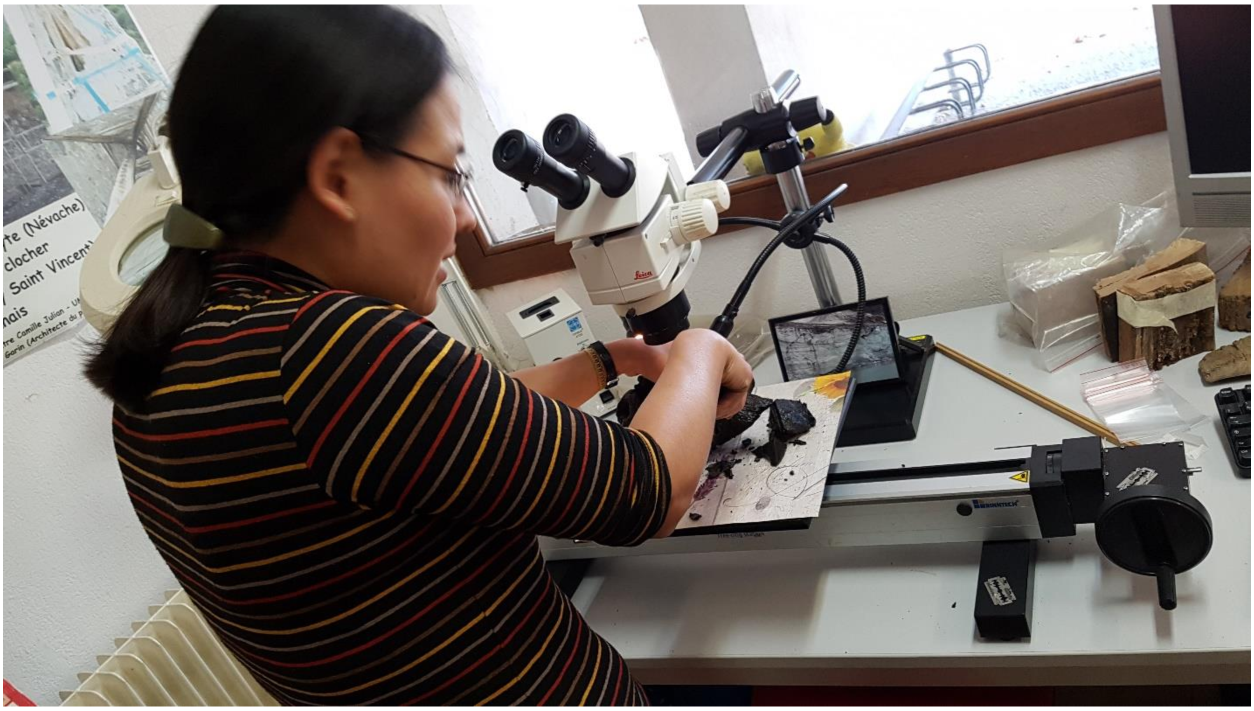


Figure 117 Dr Shindo performing the tree-ring measurements (Photo: K. Jerbić).

Radiocarbon dating

The Radiocarbon dating of samples collected during the PhD research fieldwork was performed by the Scottish Universities Environmental Research Centre (SUERC) in East Kilbride, Scotland, UK, between January and September 2018. Dating by radiocarbon determination can be applied to all organic materials. When an organism dies, it can no longer exchange carbon and at that moment the carbon begins the process of its radioactive decay (Gillespie 1984:3). The unstable carbon isotope ^{14}C changes at a known fixed rate through time, and eventually becomes a stable ^{14}N. The remaining radioactivity in the element indicates the time passed since the last exchange of carbon in the organism and gives a measurable age of the sample. The Accelerator Mass Spectometer (AMS) allows the radioactive dating of smaller sized samples, such as seeds. The radioactive dates of samples older than 2500 years underestimate the actual age, but it is possible to apply calibration factors, such as dendrochronology, to turn them into true dates (Roberts 1998:15).

Eleven samples were sent to radiocarbon dating and nine were successful (**Figure 118**), because two unsuccessful samples did not contain sufficient amounts of carbon for radiocarbon determinations (**Appendix XIII**). All radiocarbon dates were calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4. The date ranges have been calibrated using the Marine 13 calibration curve, and a regional marine offset (ΔR) of 105 ± 47 years for the SUERC-76718 sample. All other successful samples were calibrated using the IntCal13 atmospheric calibration curve. The methods used for radiocarbon dating at SUERC are thoroughly described by Dunbar et al. (2016).

#	Sample context	Sample type	Lab code	Successful	Figure
1	ZAM-1, 151–154 cm	Shell	SUERC-76718 (GU46016)	Yes	**119**
2	ZAM-1, 266–268 cm	Unknown material	(GU46017)	No	**120**
3	ZAM-1, 420–421 cm	Fibrous peat	SUERC-76722 (GU46018	Yes	**121**
4	ZAM-2, 31–33 cm	Shells and snails	SUERC-76723 (GU46019)	Yes	**122, 123**
5	ZAM-2, 81–82 cm	Unknown material	(GU46020)	No	**124**
6	ZAM-2, 109–111 cm	Shells and snails	SUERC-76724 (GU46021)	Yes	**125, 126**
7	ZAM-7, 95–96 cm	Charcoal	SUERC-81648 (GU48799)	Yes	**127**
8	ZAM-7, 148–149 cm	Leaf	SUERC-81649 (GU48800)	Yes	**128**
9	ZAM-7, 260–261 cm	Plant macrofossils	SUERC-81653 (GU48801)	Yes	**129**
10	Pile 18	Waterlogged wood	SUERC-77772 (GU46526)	Yes	**130**
11	Pile 29	Waterlogged wood	SUERC 77773 (GU46527)	Yes	**131**

Figure 118 A list of all samples sent for radiocarbon dating.

Figure 119 Radiocarbon dating sample 1 (Photo: K. Jerbić).

Figure 120 Radiocarbon dating sample 2 (Photo: K. Jerbić).

Figure 121 Radiocarbon dating sample 3 (Photo: K. Jerbić).

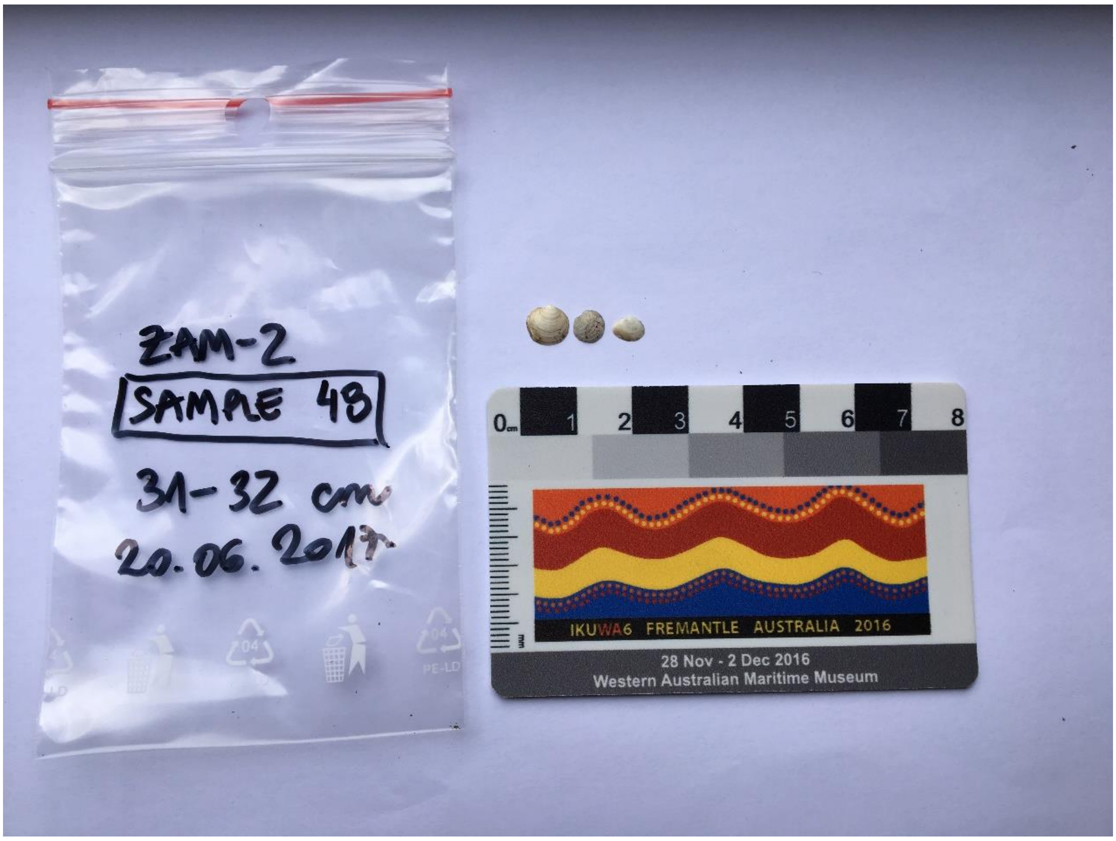


Figure 122 Part 1 of 2 of radiocarbon dating sample 4 (Photo: K. Jerbić).

Figure 123 Part 2 of 2 of radiocarbon dating sample 4 (Photo: K. Jerbić).

Figure 124 Radiocarbon dating sample 5 (Photo: K. Jerbić).

Figure 125 Part 1 of 2 of radiocarbon dating sample 6 (Photo: K. Jerbić).

Figure 126 Part 2 of 2 of radiocarbon dating sample 6 (Photo: K. Jerbić).

Figure 127 Radiocarbon dating sample 7 (Photo: K. Jerbić).

Figure 128 Radiocarbon dating sample 8 (Photo: K. Jerbić).

Figure 129 Radiocarbon dating sample 9 (Photo: K. Jerbić).

Figure 130 Radiocarbon dating sample 10 (Photo: K. Jerbić).

Figure 131 Radiocarbon dating sample 11 (Photo: K. Jerbić).

Desk-based methods

All desk-based work was performed by the author at the Flinders University Digital Archaeology Laboratory between June 2017 and June 2019. The sea-level marker data of the Northern Adriatic has been extracted from Vacchi et al. (2016) and presented in Chapter 2.

Digital photography data processing

Three software used for the digital processing of the data collected on fieldwork and in the laboratory, listed here in alphabetical order: Adobe Lightroom, Adobe Photoshop and Agisoft Photoscan Pro 1.3. Adobe Lightroom is a software developed for the organisation and manipulation of a large number of digital images (Adobe 2018). It was used here for the colour correction of underwater photographs with a blue-green cast, for the purposes of creating a 3D photogrammetric model of the 2017 investigation trench. Adobe Photoshop was used for combining photographs or cores ZAM-1, ZAM-2 and ZAM-7 taken during the initial core description. Once removed from their original context, the characteristics of sediment and soil samples start to change very quickly (Reitz and Shackley 2012:145). This is why it is very important to collect and document as much information possible on the field or, in the case of core samples, immediately after they are split in two halves (See pages 14 and 15 of this chapter). One of the most indicative characteristics of environmental changes, the sources of which vary from physical, chemical, post-depositional etc., is the soil colour. Together with sediment structure and texture, the colour of the sediment may indicate the kinds of agents which contributed to these changes (Reitz and Shackley 2012:142). That is why the cores were described and digitally documented within 30 minutes after they were cut in half. As seen on **Figure 81**, total lengths of successfully taken Zambratija cores varies from 136 to 577 centimetres. In order to have a high-resolution visual representation of each examined core, photographs of the working core halves were taken in 5 cm intervals, and later connected in Adobe Photoshop to create a continuous photomosaic. The photomosaic of each core was then used as a descriptive part in graphs as evidence of changes in soil colour. This practice is a very useful for showing parallel sets of data of a sediment column (eg. Benjamin et al. 2017:6). Agisoft Photoscan Pro 1.3[21] was used for creating a photomosaic of the seabed area where wooden samples were taken for further analyses. Even though it was not as practical and low-cost as today (McCarthy and Benjamin 2014:95; Yamafune 2016:89), 3D photogrammetry has been used and recognised as a valuable tool for understanding sites from the very start of the development of underwater archaeological recording techniques (Bass 1966:112-118). The early 21st century technical development of compact high-resolution digital cameras, in conjunction with software programs that use trigonometry and geometry to simultaneously generate multiple images, have both contributed to photogrammetry becoming a standard method for accurate archaeological data site planning and interpretation. 3D photogrammetry has previously been used to accurately record and analyse submerged Prehistoric and pile-dwelling sites. The site was recorded by video footage with a GoPro Hero 3 digital camera, which was later transformed into video frame photogrammetry, following the method described by Yamafune (2016:89-93). The digital processing was performed by following the method described by McCarthy and Benjamin (2014:98-100).

Site mapping and data overlay

While describing archaeological excavations undertaken on Lake Biel in Switzerland, Hafner (2004) states that diver archaeologists sometimes argue that underwater fieldwork (referring to shallow lake environments) is a straightforward job, and significant problems start to occur when the large collected datasets have to be contextually joined together (Hafner 2004:182). In order to avoid an overload of data and to minimise errors, it is therefore crucial to carefully develop a project plan before starting any archaeological project (Green 2004:13). For Zambratija, two different sets of data were initially collected to accurately visualise the research context material. The first one was through archival work in collaboration with AMI and Flinders University, by gathering all the available published and unpublished data created before presenting the Research Proposal, presented in Chapters 1–4. After synthesizing that preliminary data

[21] Agisoft changed the name of the software to Agisoft Metashape in December 2018.

and designing the research questions in mind, a fieldwork and laboratory-based research, presented in the methods above, was designed to collect the second set of data. By combining these two sets, it became possible to create the necessary digital visualisations used in the thesis. This action involved the processing of all collected information so far, by creating graphs, maps and models to better understand and further compliment the thesis discussion and conclusions. Two software programs were used: Autodesk AutoCAD and ArcGIS.

Since some of the analyses were performed by other individuals and not the author, and a part of the data used for interpretation came from desk-based research, the collected information came in various digital formats. The compiled graphs and information were therefore digitally traced and appropriately scaled in Autodesk AutoCAD by the author for the purposes of a uniformed representation of all data in this thesis.

The possibility of layering multiple numerical, text-based and graphical information into digital visualisation environments (Green 2004:210) has made Geographical Information Systems (GIS) one of the essential image-making tools in archaeology (Connoly and Lake 2006). In other words, GIS makes it possible to place information like GPS coordinates, sonar traces, excavation site plans, artefacts etc. into a real-life georeferenced space (Green 2004:211). In maritime archaeology, GIS is most commonly used in survey, excavation and site distribution (Green 2004:212), which makes it possible to visualise, manage, analyse and present the data in the form of digital maps (Connoly and Lake 2006:16). For Zambratija, the ArcGIS online mapping tool was used to combine multi-beam, GPS and total station data collected by archival and fieldwork, to produce a series of visualisations of the bay and the broader areas used for comparative research.

CHAPTER 7: ORIGINAL RESULTS

The following paragraphs represent the core findings of the fieldwork and laboratory research obtained at the time of the PhD candidature. The hypothesis that the submerged site in Zambratija Bay is a 6,000-year-old pile-dwelling will be supported here with consideration of the prior data (2008–2015) and the original research included in this thesis, including new radiocarbon dates as well as geophysical, environmental and archaeological evidence. Original results will be presented here in the order of fieldwork and laboratory methods performed on individual cores and wooden samples. After presenting the original data, the results obtained by desk-based work will be synthesized in the discussion (Chapter 8).

Sub-bottom profiles

Fieldwork consisted of sub-bottom profiling, seabed coring and underwater archaeological research. The sub-bottom track lines and sediment thickness served as a guideline to select the most suitable positions for seabed cores with long stratigraphy. The survey area was concentrated above the submerged karstic depression filled with soft sediments.

A total of 21 profiles were recorded (**Appendix XIV**), covering a combined total length of 9 km (**Figure 132**). Out of the 21 profiles, 13 were configured in a grid formation directly over the submerged depression. The results of the survey performed above the karstic depression were interpreted as a 5-deep-sediment stratigraphy layered over a surface of limestone bedrock (**Figure 133**). The full Harpha Sea d.o.o. fieldwork report and the profiles can be seen in **Appendix V**. The sub-bottom profiles revealed the most suitable areas for a successful collection of vertical sediment samples in the bay. After an assessment of all the track lines and acoustic signals, eight positions were selected for seabed coring (**Figure 134**).

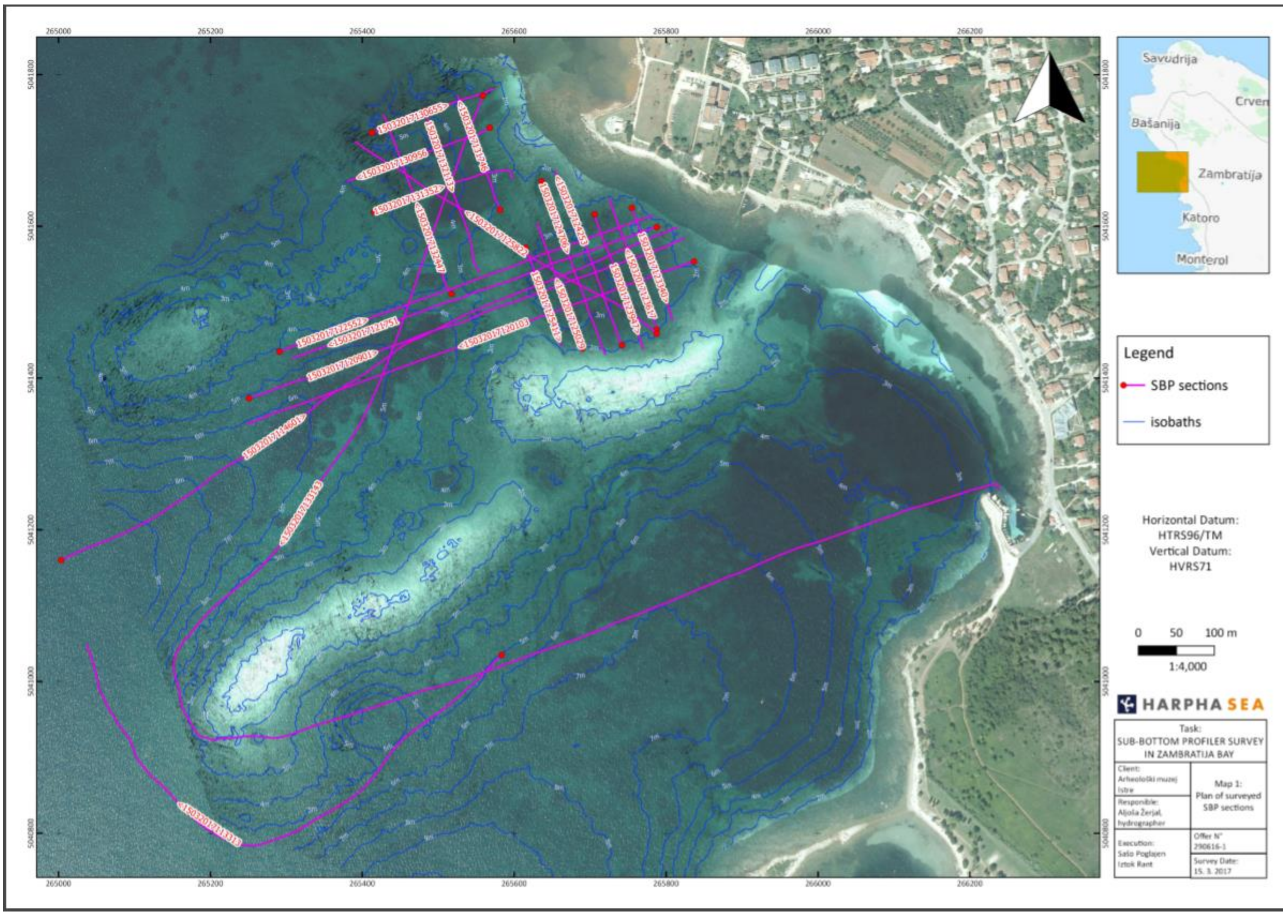


Figure 132 Sub-bottom profile track lines (Author: Harpha Sea d.o.o.).

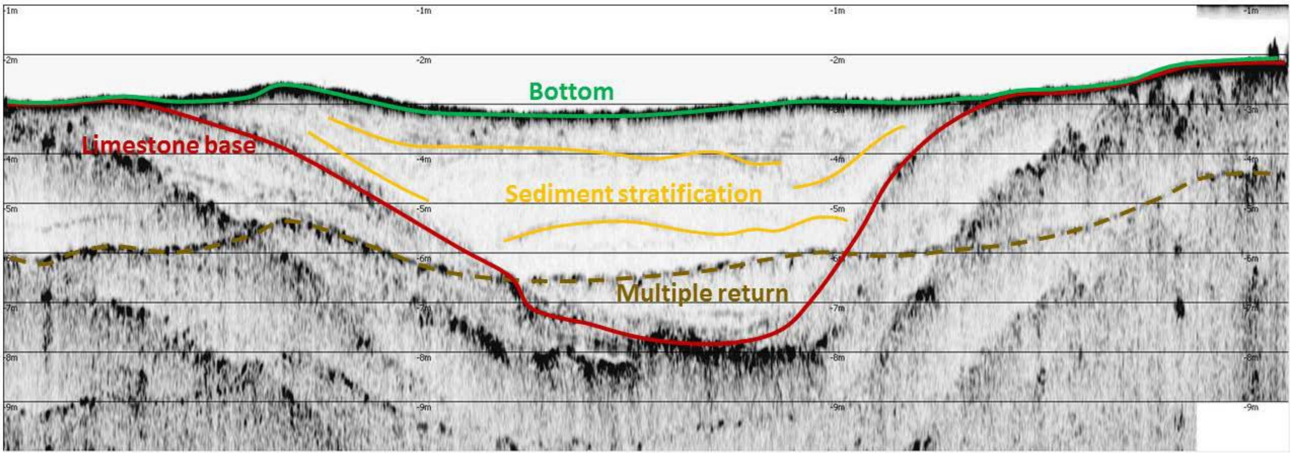


Figure 133 A rough interpretation of sub-bottom profile track line 1503207123947 (Author: Harpha Sea d.o.o.).

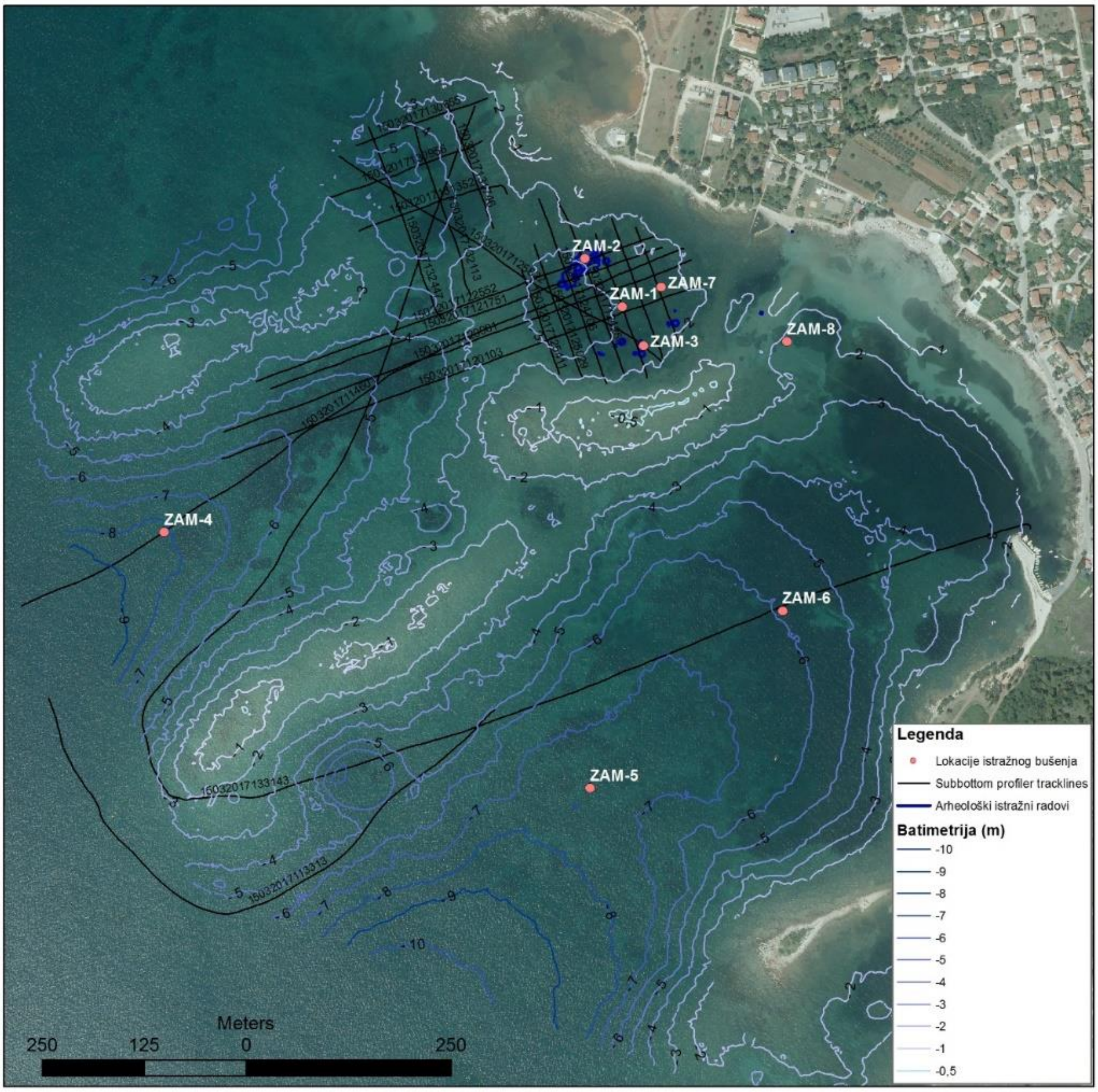


Figure 134 The positions of the cores (red dots) in relation to the sub-bottom profile track lines (black lines), the archaeological features (blue lines) and the georeferenced coordinates of the 2011 bathymetric survey (Image: O. Hasan).

Sediment cores

As seen on **Figure 134**, cores ZAM-1, ZAM-2 and ZAM-3 were sampled inside the natural boundaries of the submerged sinkhole and positioned on the sub-bottom profile track lines 15032017123947, 15032017122552 and 15032017125822. Core ZAM-4 was unsuccessful due to the sampled sediment being loose and unable to stay in the PVC core lining. It was positioned outside the natural boundaries of the submerged sinkhole on the sub-bottom profile track line 15032017133143. Although not analysed in the thesis, cores ZAM-5 and ZAM-6 were sampled outside the natural boundaries of the submerged sinkhole, for the purposes of extracting valuable knowledge of the submerged landscape in the broader area of the bay in future HGI projects. After the sampling of the first 6 cores, they were assessed according to their positions and lengths which lead to the decision of taking one more sample inside the natural boundaries of the submerged sinkhole on the sub-bottom profile track line 15032017123340, marked as core ZAM-7, and a core positioned in the near the Bronze Age boat marked ZAM-8, taken for the Underwater Archaeology department in AMI to reconstruct the site formation processes of the boat in their future projects.

The total number of the cores taken inside the natural boundaries of the submerged sinkhole is four, which are cores ZAM-1, ZAM-2, ZAM-3 and ZAM-7 (**Figure 135**). After the assessment of their lengths and positions, as well as the PhD project timeline and budget calculations, the first two cores chosen for further laboratory analyses in 2017 were cores ZAM-1 and ZAM-2. After initial laboratory analyses and consultation with supervisors, it was decided that the evidence from these two cores were sufficient for an in-depth analysis of the environmental and sea-level assessment of the submerged landscape but not for an archaeological interpretation. However, the candidate received an external research grant in 2018 which allowed for the analysis of one more core. Two cores were considered for further analyses, cores ZAM-3 and ZAM-7 which were both positioned inside the natural boundaries of the submerged sinkhole. Due to a longer stratigraphical sequence, which implied a possibility of reaching the peat sediments similar to the ones found in core ZAM-1, the additional core that was selected in 2018 was ZAM-7. The peat sediments were visible in the first segment of the core, which was 268 centimetres long, and after an assessment and consultation with the environmental scientists from HGI it was decided that this length was sufficient for an archaeological assessment and the second segment of the core was not analysed.

Cores inside the submerged sinkhole	Sub-bottom profile track line	Total core length measured on site	GPS coordinates	Laboratory analyses
ZAM-1	15032017123947	(2 segments) 577 cm	45°28'27.65" 13°30'13.55"	Yes
ZAM-2	15032017122552	136 cm	45°28'29.40" 13°30'11.35"	Yes
ZAM-3	15032017125822	190 cm	45°28'26.13" 13°30'14.85"	No
ZAM-7	15032017123340	(2 segments) 426 cm	45°28'28.47" 13°30'15.70"	Yes

Figure 135 A table with the four cores positioned inside the natural boundaries of the submerged sinkhole.

Since the GPS coordinates were taken in the degrees, minutes and seconds format, they were converted to the latitude and longitude format to be compatible with the data from the sub-bottom profiles. The converted coordinates for ZAM-1, ZAM-2 and ZAM-7 are presented on **Figure 136**.

Cores inside the submerged sinkhole	Sub-bottom profile track line	GPS coordinates		HTRS coordinates	
		X	Y	X	Y
ZAM-1	15032017123947	45°28'27.65"	13°30'13.55"	265738.74	5041526.74
ZAM-2	15032017122552	45°28'29.40"	13°30'11.35"	265693.08	5041585.32
ZAM-7	15032017123340	45°28'28.47"	13°30'15.70"	265786.38	5041550.31

Figure 136 The converted coordinates for ZAM-1, ZAM-2 and ZAM-7.

ZAM-1 results

As seen on **Figure 137**, ZAM-1 was positioned over the 15032017123947 trackline (original trackline in **Appendix XI**). **Figure 138** shows the position of the core on the sub-bottom profile (X 265738.74; Y 5041526.74). The seabed surface depth for ZAM-1 (-3.05 RSL) was calculated according to the position on the profile.

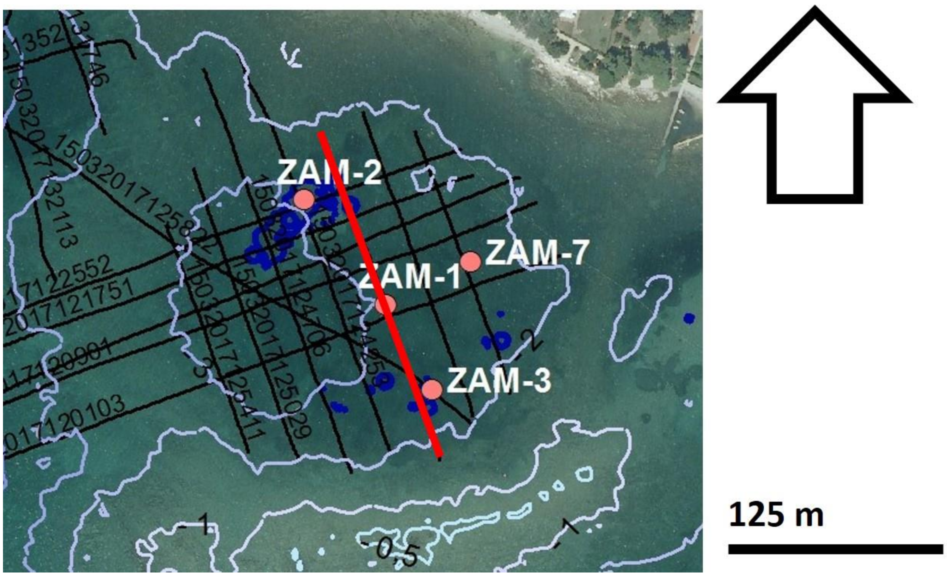


Figure 137 Trackline 15032017123947 (in red).

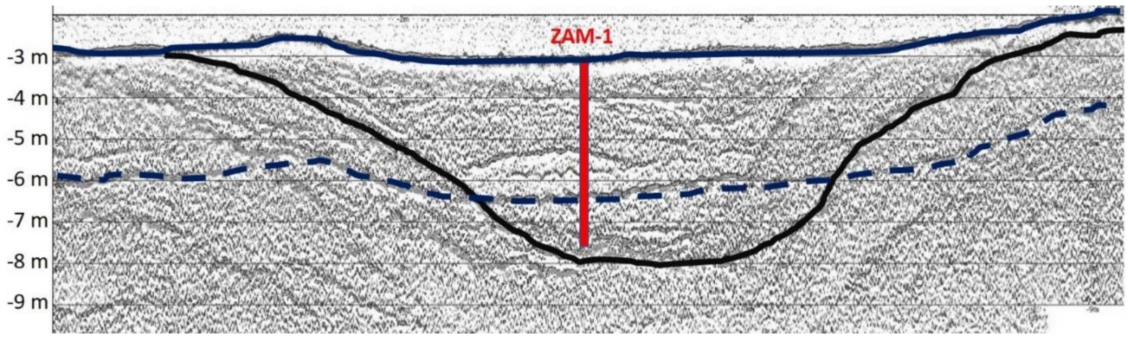


Figure 138 The position of ZAM-1 (red) on the sub-bottom profile 15032017123947. The seabed is outlined in blue solid line. The blue dashed line is the multiple return signal. Bedrock is outlined in black.

As the known length of ZAM-1 (577 cm) was only a preliminary fieldwork measurement, it had to be reviewed after splitting in half during the initial core description protocol. ZAM-1 was therefore photographed in its full length composed of two separate core segments combining a corrected total length of 559 cm (**Figure 139**). Since ZAM-1 was longer than the 3 m corer PVC tube, it was composed of two segments. The thickness of the sediment sections trapped in the core catcher was calculated into the total core length and is demonstrated on Figure 141 as a gap.

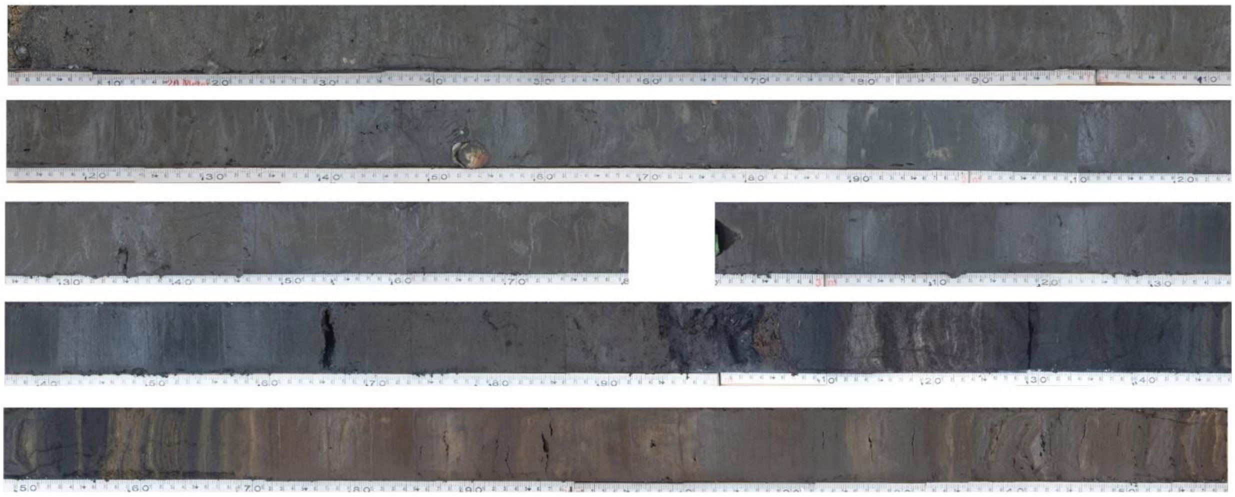


Figure 139 Sediment core ZAM-1 presented in 112 cm sequences left to right (Image: K. Jerbić).

According to the Munsell soil colour chart (Munsell Color Co. 1992) and the Troels-Smith standard system for describing unconsolidated sediments (Troels-Smith 1955), the sediment colours and texture were appearing throughout the core as demonstrated in **Figure 140**. Sediments start with a thin layer of seabed yellow coarse sand with a sharp transition to a bluish grey clay at 4 cm below ground level (bgl). The bluish grey clay continues down to 365 cm bgl, when it gradually transitions to a darker colour and the sediments begin to have visible traces of organic components down to 395 cm bgl. At 395 cm bgl, the sediments are black, dry and almost exclusively composed of organic peat with visible wooden components until 411 cm bgl. At 411 cm bgl, a sharp transition changes the sediments to a laminated sequence until 471 cm bgl, from where it changes to yellowish brown mud and continues down to the end of the core at 559 cm bgl.

Magnetic susceptibility and colour spectrometry showed the start of significant changes at around 260 cm bgl (**Figure 141**). Foraminifera were identified in two segments. They were present at 37–38 cm bgl, indicating a marine environment, and not present at 421–422 cm bgl, indicating a freshwater environment.

Interval (cm)	Munsell	Characteristics					Components
		Nig.	Strf.	Elas.	Sicc.	Lim.	
0–4	2.5Y 6/3 light yellowish brown	1	0	3	1	-	Gs2 Gg2 Ga+
4–255	GLEY 2 5/5B bluish gray	2	2	0	1	4	Sh1 As1 Ag2 Ga+
255–294	GLEY 2 4/5B dark bluish gray	3	1	0	2	1	Sh1 As1 Ag2
294–365	5Y 3/1 very dark gray	4	2	1	3	1	Sh1 As1 Sh2 Dg+
365–395	5Y 2.5/1 black 5Y 5/1 gray	4 1	2	2	3	3	Th4 Tl3 Sh2 Dh1 Dl4 Dg+
395–411	5Y 2.5/1 black	4	2	4	4	2	Sh4 Dl2 Dg1 As1
411–471	5Y 3/1 very dark gray 10YR 5/8 yellowish brown	4 2	4	2	3	4	Dg2 As2 Ag2
471–566	10YR 5/8 yellowish brown 5Y 5/1 gray	2 1	3	0	2	3	Dg3 As3 Ag2

Figure 140 A vertical composition of sediment colours and texture throughout ZAM-1.

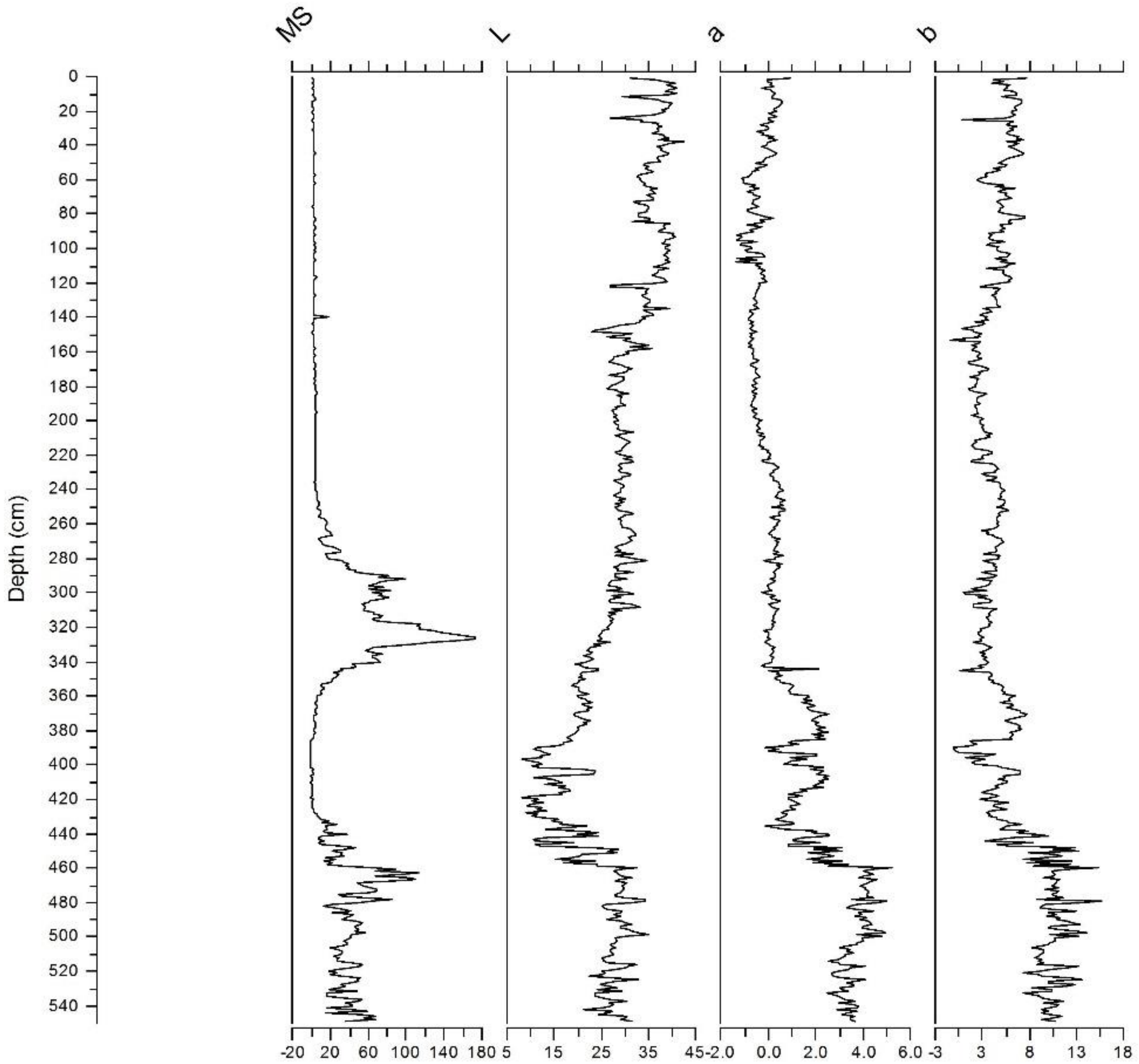


Figure 141 Magnetic susceptibility and colour spectrometry values in the core ZAM-1.

Grain size analysis (**Figure 142**) shows that with an 77.7% average, silt is the dominant particle size throughout ZAM-1. Very coarse silt and coarse silt, as well as sand particles, increase in the upper part of the core down to approximately 170 cm bgl. Other than at the surface, sand appears only in intervals between 405 and 430 cm bgl, where it reaches almost 100 %. This was explained as the result of peat containing plant residue, while the rest of the sediment is made of the remains of the shell molluscs. Intervals between 450 and 470 cm bgl show a highest content of clay at 28 to 35.3 %, after which at 490 to 550 cm bgl clay averages down to 23.3 %.

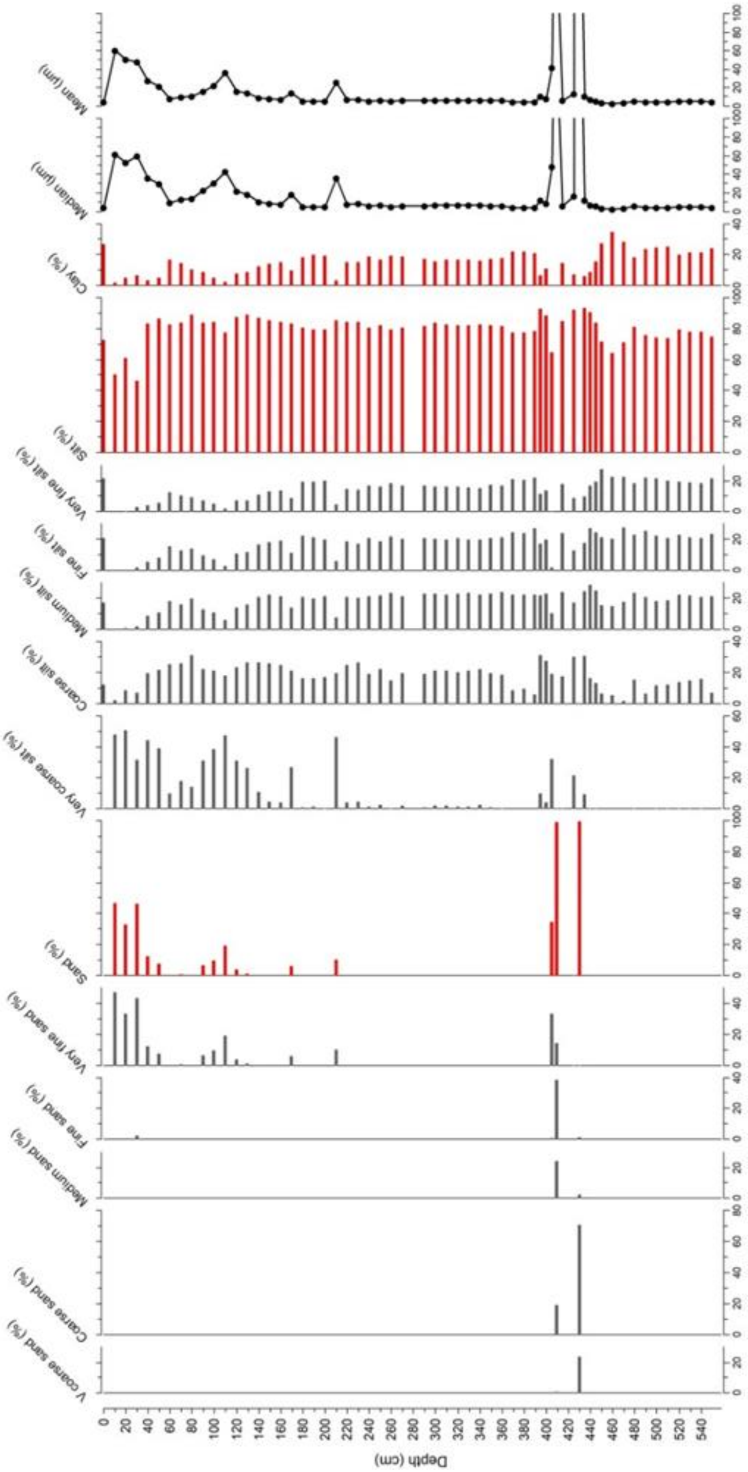


Figure 142 Grain-size variation for ZAM-1.

Nitrogen and carbon results in sediments include total nitrogen (TN), total carbon (TC), total organic carbon (TOC), total inorganic carbon (TIC) and total organic carbon to total nitrogen ratio (TOC/TN), and subsequently insoluble residue content. The most valuable results provide total nitrogen (TN) and total organic content (TOC), as well as its ratio. TN and TOC in sediment core ZAM-1 (**Figure 143**) are higher between 395 and 460 cm bgl, with the highest values between 395 and 410 and 425 and 440 cm bgl for TN (1.04 to 1.46 % and 1.63 to 2.85 %, respectively) and for TOC (18.13 to 32.64 %). TOC/TN ratio shows a stability throughout the core with average values around 12 (11.85), except between 370 and 430 cm bgl, where it reaches values higher than 12 (14.10 and 22.75). The organic matter in this interval is result of the presence of terrestrial vascular plants, while the source of organic matter from the rest of the core is algal phytoplankton. Total inorganic carbon (TIC) indirectly indicates carbonate content in the sediments. TIC levels are higher in the lower part of the core, between 395 and 510 cm bgl, as well as in the upper part of the core down to 170 cm bgl.

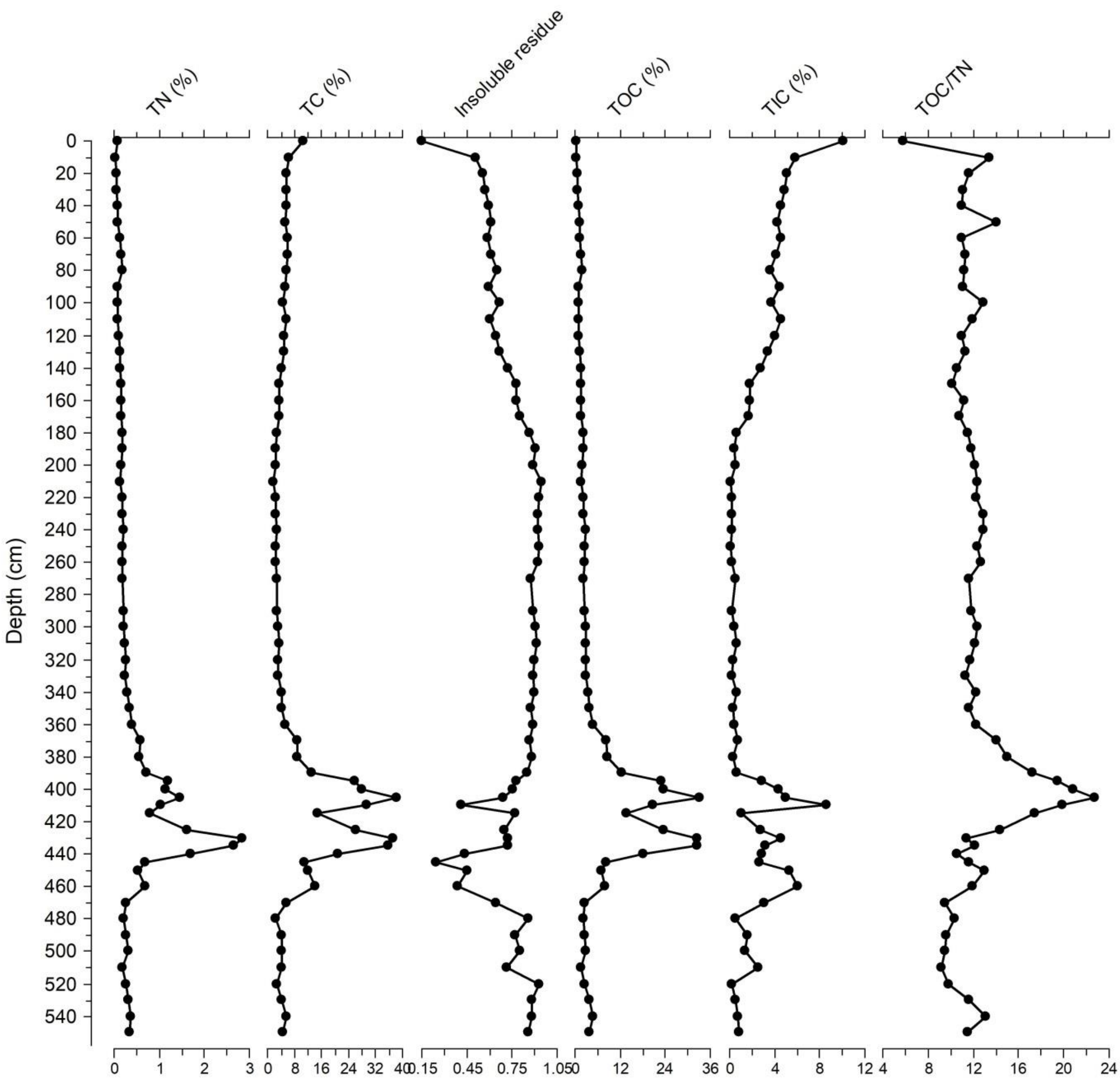


Figure 143 Variation of nitrogen and carbon content with depth in the sediment core ZAM-1.

The dominant mineral phase in ZAM-1 (**Figure 144**) is quartz in almost all samples, except between 390 and 460 cm bgl. The sediment between 390 and 460 cm bgl is organic, evident in the dark colour and sediment components as well as a high organic carbon content. Calcite, Dolomite and Aragonite appear in the upper part of the core. Almost all samples contained Halite, which is the consequence of the drying of marine sediments after core splitting. Feldspars (Plagioclase and Potassium Feldspar) appear in most intervals except in the lower parts of the core.

ZAM-1	**Mineral phases**	
	Main minerals	**Accessory minerals**
10-11	Qtz	Dol, Cal, Arg, Pl, Kfs, Ms/I, Kln, Hl
50-51	Qtz	Cal, Dol, Arg, Pl, Kfs, Ms/I, Kln, Hl
100-101	Qtz	Dol, Cal, Arg, Pl, Ms/I, Hl
150-151	Qtz	Cal, Dol, Py, Pl, Kfs, Ms/I, Kln
190-191	Qtz	Pl, Kfs, Hl, Ms/I, Kln, Gp, Dol, Cal
200-201	Qtz	Pl, Kfs, Cal, Hl, Ms/I, Kln
210-211	Qtz	Pl, Ms/I, Kln, Py
240-241	Qtz	Py, Pl, Ms/I, Hl
250-251	Qtz	Pl, Py, Hl, Ms/I, Kln
270-271	Qtz	Py, Pl, Gp, Ms/I, Cal, Hl
290-291	Qtz	Py, Pl, Gp, Ms/I, Hl
300-301	Qtz	Py, Hl, Pl, Ms/I, Kln
303-304	Qtz	Py, Hl, Pl, Ms/I, Kln, Pyrrhotite
310-311	Qtz	Py, Hl, Pl, Ms/I, Kln
320-321	Qtz	Py, Hl, Pl, Ms/I, Kln
330-331	Qtz	Pl, Py, Hl, Gp, Ms/I, Kln
340-341	Qtz	Py, Hl, Pl, Ms/I, Kln
350-351	Qtz	Pl, Hl, Ms/I, Kln
360-361	Qtz	Py, Hl, Pl, Ms/I, Kln
380-381	Qtz	Py, Hl, Pl, Ms/I, Kln
390-391	Qtz, Py	Hl, Pl, Ms/I, Kln
400-401	Qtz, Hl	Py
410-411	Hl, Gp	
415-416	Qtz	Hl, Py
440-441	org	Qtz, Cal
445-446	org	Vivianite, Qtz
450-451	org	Hl, Qtz
460-461	org	Hl, Qtz
480-481	Qtz	Pl, Hl, Ms/I, Kln
510-511	Qtz	Hl, Ms/I, Kln, siderite
530-531	Qtz	Hl, Ms/I, Kln
540-541	Qtz	Hl, Ms/I, Kln
550-551	Qtz	Hl, Ms/I, Kln

Figure 144 The mineralogical composition of sediments from core ZAM-1. Abbreviations: Qtz-quartz, Cal-calcite, Dol-dolomite, Arg-aragonite, Pl-plagioclase, Kfs-potassium feldspar, Ms/I-muscovite/illite, Kln-kaolinite, Hl-halite, Py-pyrite, Gp-gypsum.

Pyrite is present between 150 and 415 cm bgl, almost always associated with Gypsum, except at 190-191 cm bgl where Gypsum occurs without Pyrite. At 303–304, near the high magnetic susceptibility peak, there are traces of Pyrrhotite. At 410-411 cm, Halite and Gypsum are the only mineral phases. Dominant material in sediments between 440 and 460 cm bgl is organic material, in association with Quartz, Halite and Calcite. Surface spots with a violet-blue hue were noticed throughout the core at 443, 445, 460, 540 and 550 cm (**Figure 145**), however the collected amounts were insufficient for XRD identification. Finally, at 445–446 cm the collected sample was sufficient for the analysis and the violet-blue spots were determined as Vivianite. The sample was also documented with a scanning electron microscope (SEM) (**Figure 146**).

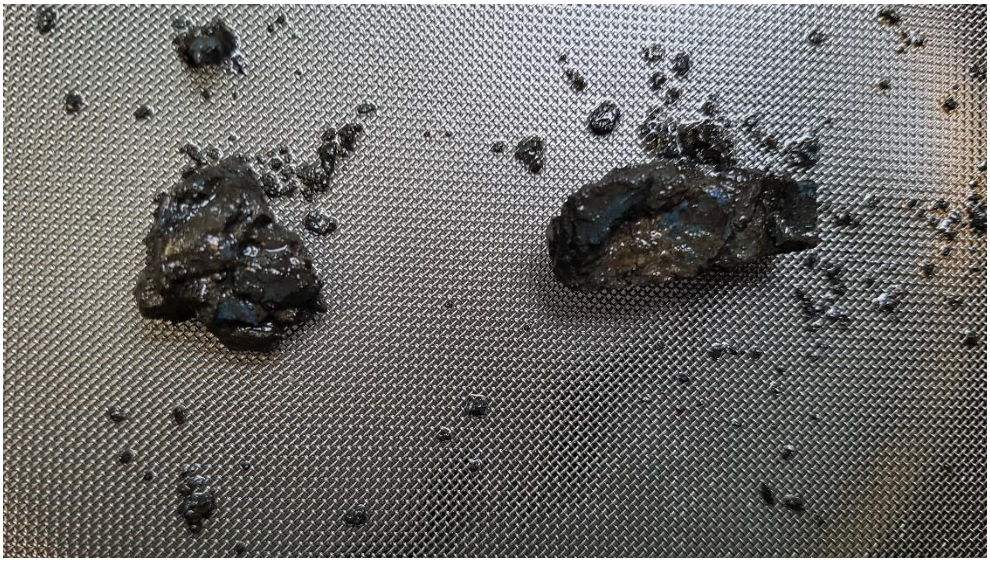


Figure 145 Traces of Vivianite in a discrete sample taken from 443–444 cm (Photo: K. Jerbić).

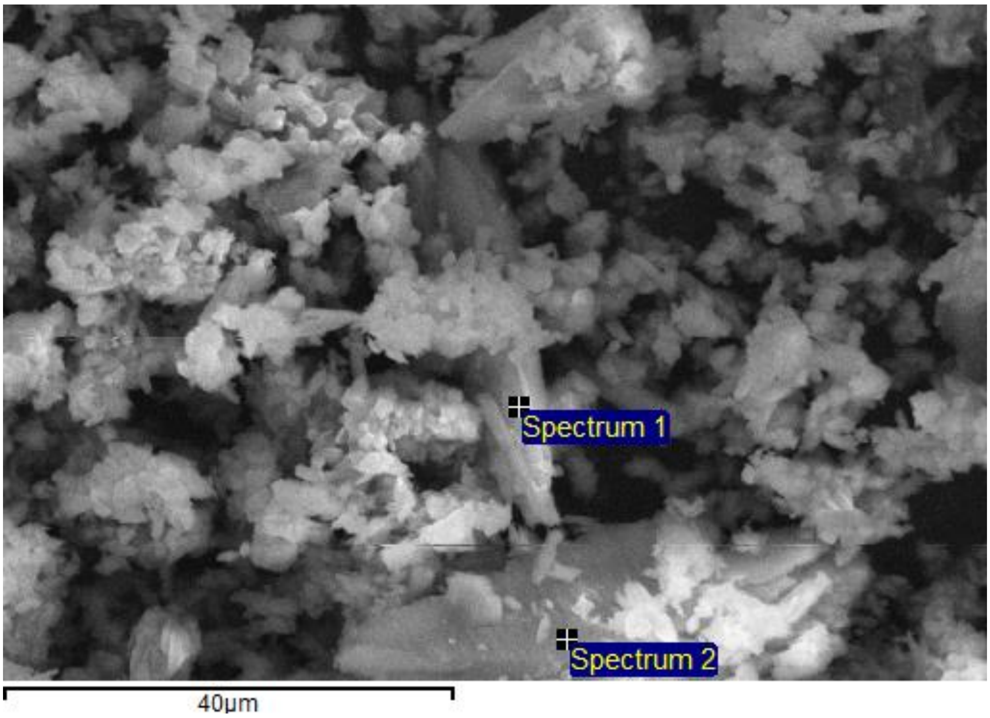


Figure 146 SEM image of Vivianite from 445–446 cm. Spectrum graphs in Appendix XV (Image: O. Hasan).

The µ-XRF analysis yielded geochemical results for ZAM-1 in a 1 cm resolution for the following elements: Al, Si, Ti, K, Fe, Br, P and S (**Figure 147**) and Ca, Sr, Ba, Rb, Zr, Mn and Mo (**Figure 148**).

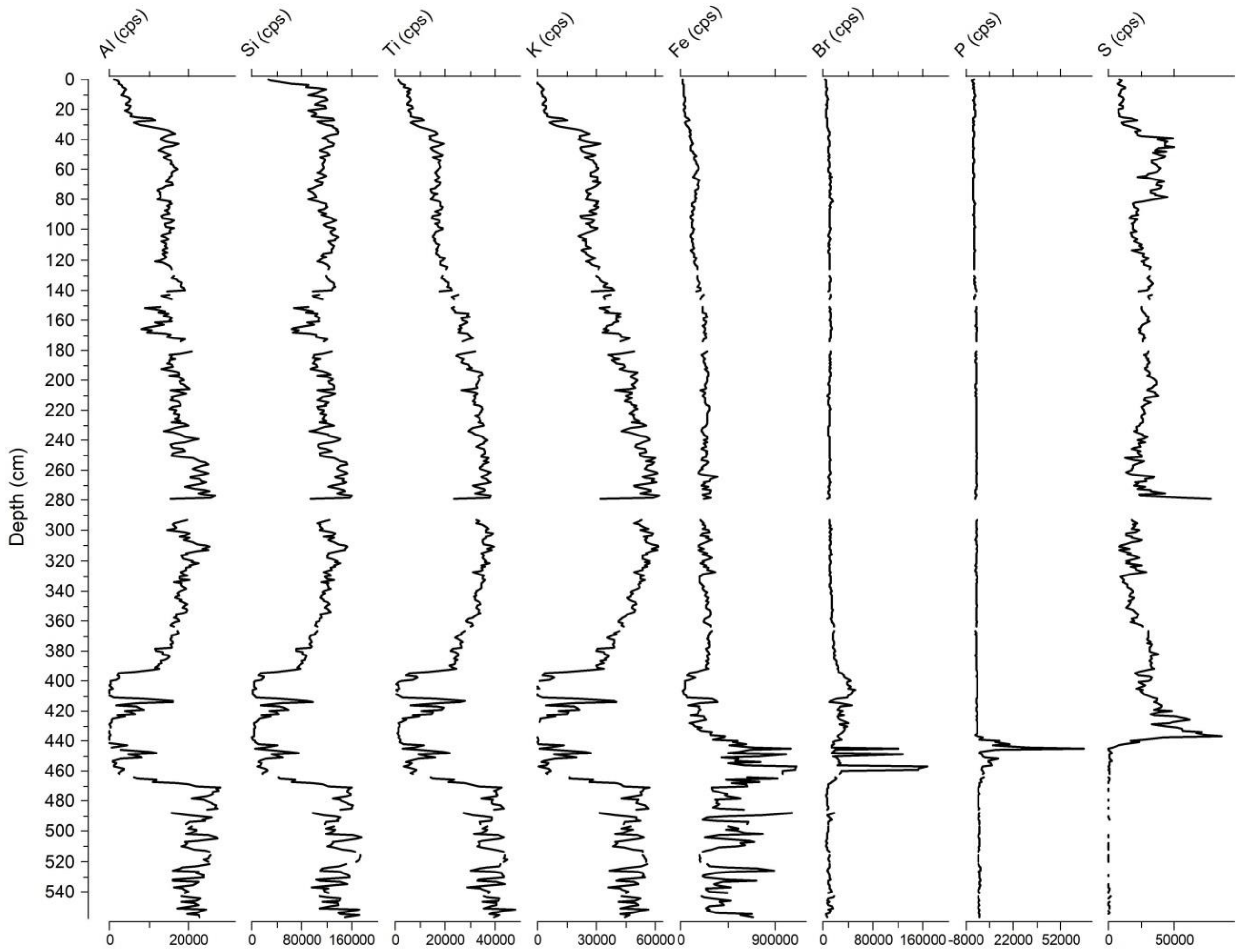


Figure 147 Down-core variations of Al, Si, Ti, K, Fe, Br, P and S elements for ZAM-1.

As XRF results are semi-quantitative and relative, they are not comparable between cores and the specific elements rather show a considerable trend in each core. In ZAM-1, Al, Si, Ti and K, as well as other lithogenic elements, are higher in lower part of the core, from 470 cm bgl downwards, following the appearance of brown mud. Their content decreases in black fine-grained and peaty sediments between 395 and 470 cm bgl, with instances of increased values at 450–443 cm bgl and 425–412 cm bgl. Values are relatively constant from 35 to 395 cm bgl, somewhat decreasing between 150 and 170 cm bgl down to 210 cm bgl. Values of siliciclastic lithogenic elements considerably decrease in the upper 35 cm of the core, where the highest values of elements Ca and Sr occur. The same segment is associated with carbonate mineral phases for Calcite, Aragonite and Dolomite (see **Figure 148**). Calcium and Sr are low in the lower and middle part of the core, except at 440–445 cm bgl. Iron content differs from the mentioned lithogenic elements;

higher values are observed in bottom part of the core, in the brown mud (440–559 cm bgl), with the highest values between 440 and 470 cm. In this interval, high values of P, Mo, Br and Mn refer to redox sensitive elements. In addition to these elements, the Vivianite phase also occurs here, which gives valuable information for phosphorus (P) retention in aquatic ecosystems. Sulfur shows high values down to 440 cm bgl, with the highest values between 410 and 440 cm bgl, while it is very low in the lower part of the core, in the brown clay.

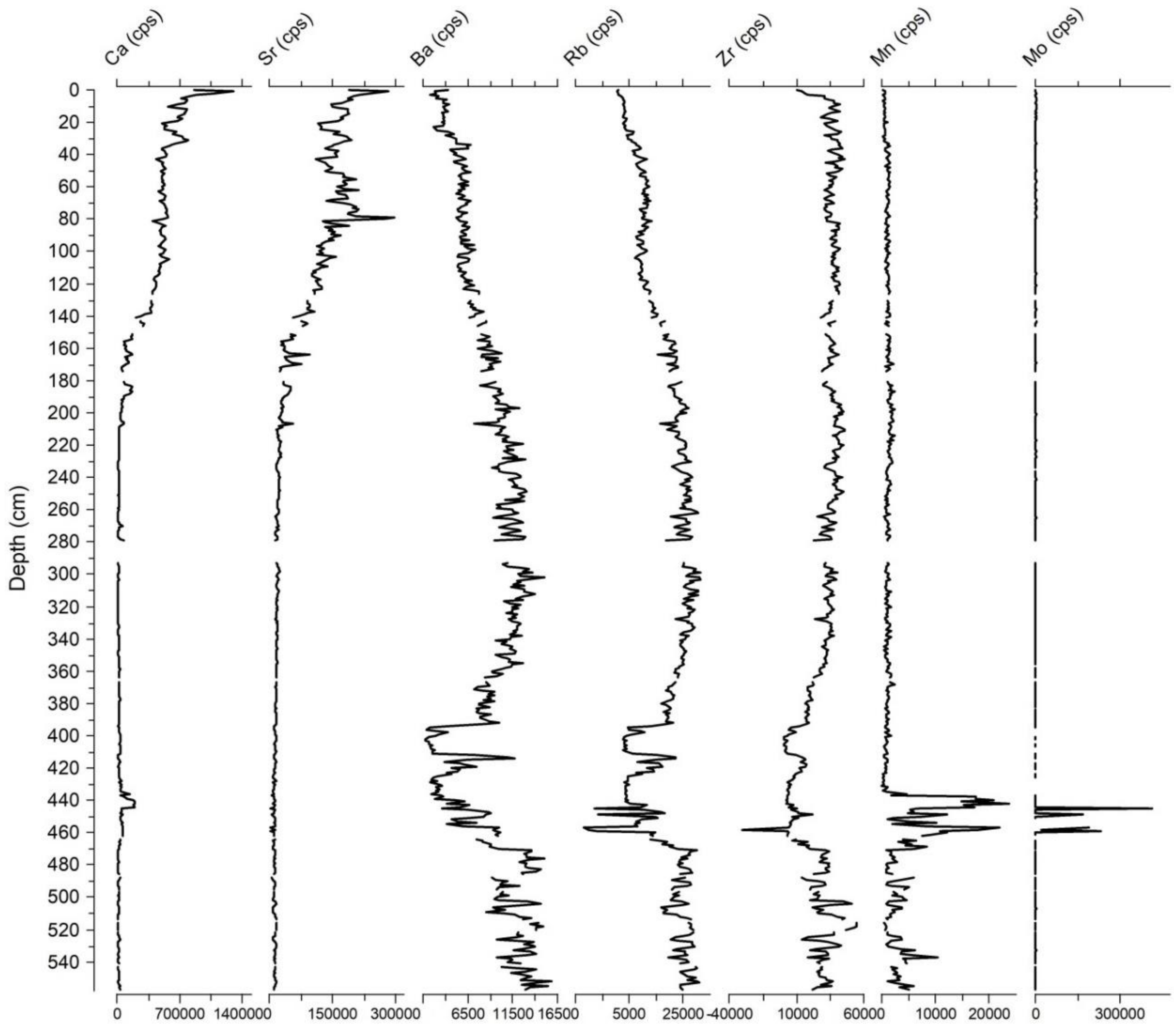


Figure 148 Down-core variations of Ca, Sr, Ba, Rb, Zr, Mn and Mo in ZAM-1.

Radiocarbon dating analyses for the successful samples from ZAM-1 yielded a 3246–2882 Cal BC date for the shell in the marine sediments at 151–154 cm and 3632–3375 Cal BC date range for the fibrous peat at 420–421 cm (**Figure 149**). All results for core ZAM-1 showed promising evidence for a paleoenvironmental reconstruction of the bay, presented in Chapter 8.

Lab Reference	Uncalibrated ^{14}C Age	Calibrated Age	Probability	Location	Sample description
SUERC-76718	4836 ± 32 BP	3246–2882 Cal BC	95.4%	ZAM-1 core, 151–154 cm	Shell
SUERC-76722	4714 ± 32 BP	3632–3375 Cal BC	95.4%	ZAM-1 core, 420–421 cm	Peat (fibrous)

Figure 149 Radiocarbon dates from ZAM-1.

ZAM-2 results

As seen on **Figure 150**, ZAM-2 was positioned over the 15032017122552 trackline (original trackline in **Appendix XI**). **Figure 151** shows the position of the core on the sub-bottom profile (X 265693.08; Y 5041585.32). The seabed surface depth for ZAM-1 (-3.15 RSL) was calculated according to the position on the profile. ZAM-2 was deliberately sampled inside the limits of the submerged peat platform, the outline of which can be seen on **Figure 152**.

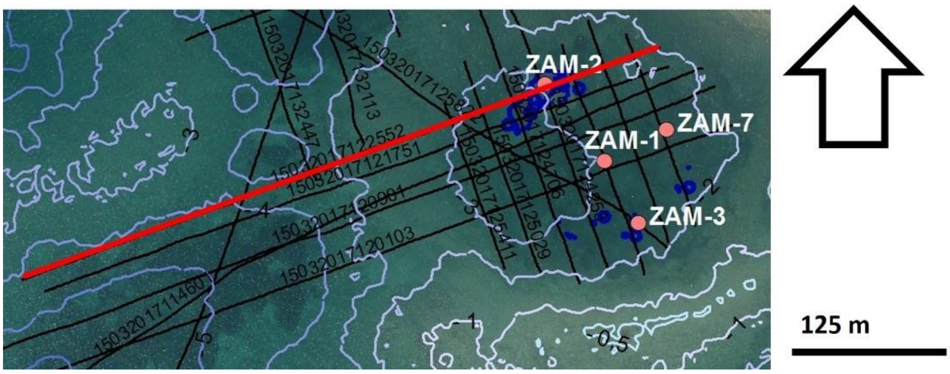


Figure 150 ZAM-2 on trackline 15032017122552 (in red).

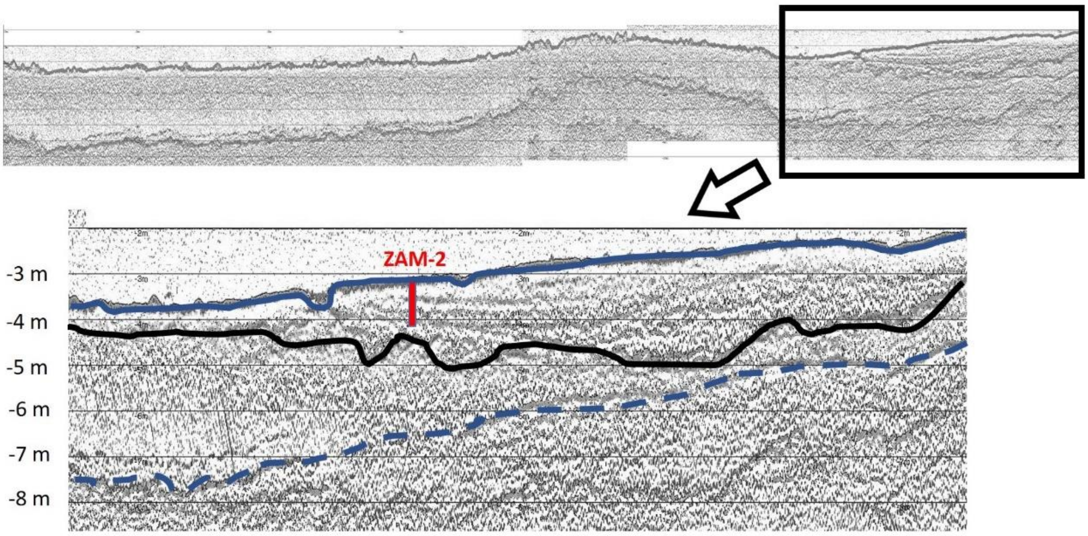


Figure 151 The position of ZAM-2 (red on lower image) on the sub-bottom profile 15032017122552 (upper image). The seabed is outlined in blue solid line. The blue dashed line is the multiple return signal. Bedrock is outlined in black.

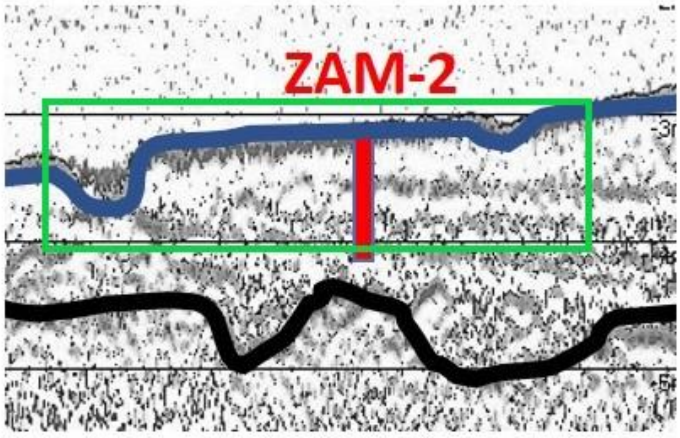


Figure 152 Outlines of the peat platform (green square).

As the known length of ZAM-2 (136 cm) was only a preliminary fieldwork measurement, it had to be reviewed after splitting in half during the initial core description protocol. ZAM-2 was therefore photographed in its full length in its full corrected total length of 123.5 cm (**Figure 153**). According to the Munsell soil colour chart (Munsell Color Co. 1992) and the Troels-Smith standard system for describing unconsolidated sediments (Troels-Smith 1955), the sediment colours, texture were appearing throughout the core as demonstrated in **Figure 154**. The layers start with a dark peaty sediment with splatters of grey sand. At 26 cm bgl, the peat sharply transitions a very dark grey clay containing organic matter and some sand. The very dark grey clay continues down to 73 cm bgl, when it gradually transitions to a dark bluish grey clay.

Figure 153 Full length (0–123.5 cm) of core ZAM-2 left to right.

Interval (cm)	Munsell and description	Characteristics					Components
		Nig.	Strf.	Elas.	Sicc.	Lim.	
0–26	5Y 2.5/1 Black	4	1	4	3	-	Th3 Tl+ Sh1 Gs2 DhDlDg+
26–73	5Y 3/1 Very dark grey	3	1	3	3	4	Th1 Sh1 Ag2
73–123.5	GLEY 2 4/5B Dark bluish grey	1	1	0	2	1	Th1 Sh1 Ag2

Figure 154 A vertical composition of sediment colours and texture throughout ZAM-2.

Magnetic susceptibility and colour spectrometry (**Figure 155**) showed a significant increase at around 75 and 105 cm bgl. Based on the changes seen in the magnetic susceptibility and colour throughout the core, eleven samples were chosen for foraminifera count. The presence of foraminifera was identified and showed some inconsistencies in appearance, making it difficult to distinguish marine from brackish and/or freshwater phases (**Figure 156**).

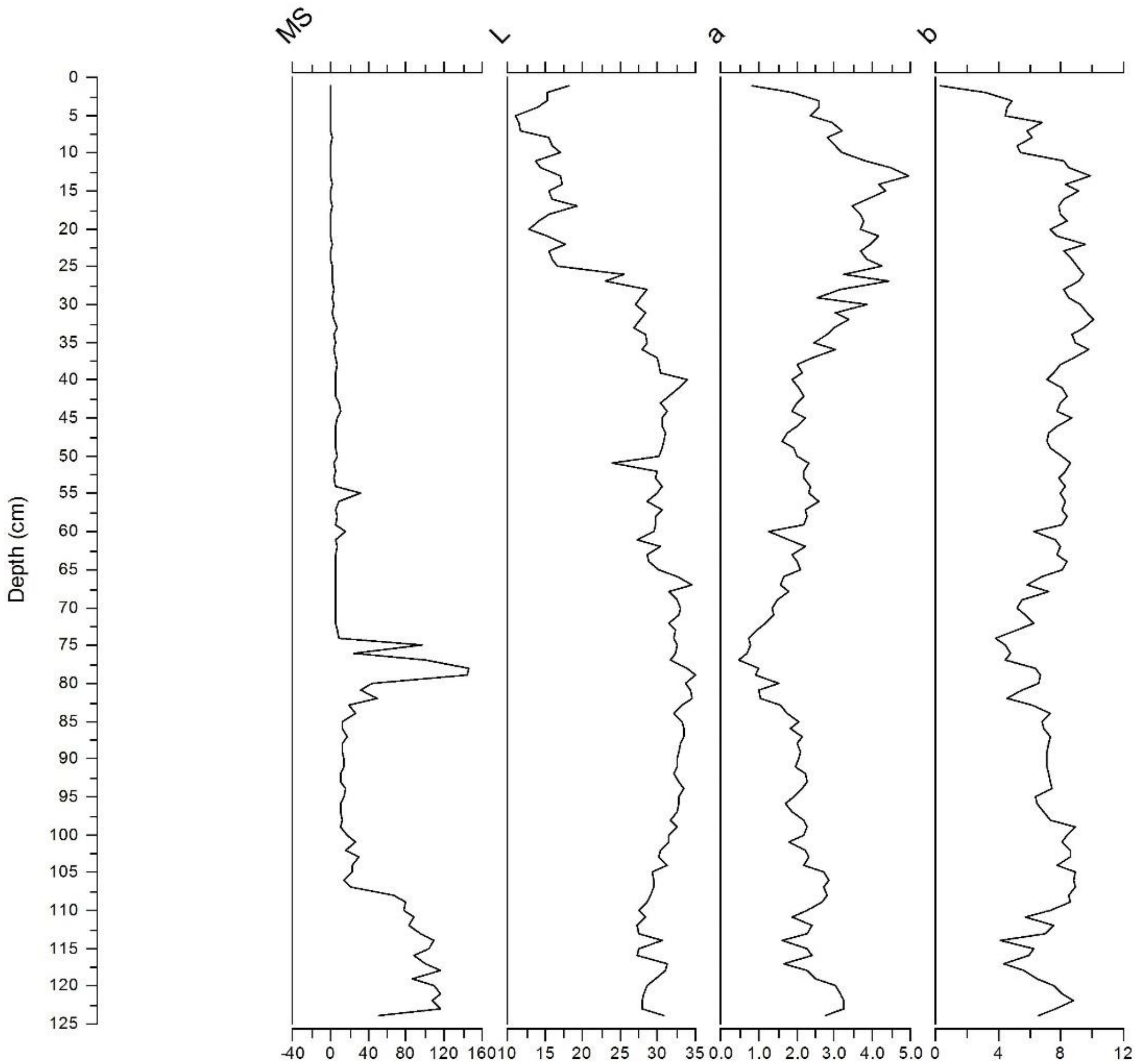


Figure 155 Magnetic susceptibility and colour spectrometry values of core ZAM-2.

13–14 cm	20–21 cm	29–30 cm	75–76 cm	76–77 cm	82–83 cm	83–84 cm	106–107 cm	108–109 cm	110–111 cm	115–116 cm
YES	NO	YES	NO	NO	NO	YES	YES	YES	YES	NO

Figure 156 Foraminifera presence in ZAM-2.

Grain size analysis (**Figure 157**) showed the dominant particle size throughout the core ZAM-1 is silt, with a 66.2 % average throughout the core. A slight decrease in silt content is visible at the 40 and 90 cm bgl. Silt coarseness is evenly distributed throughout the core. Sand only appears only in the upper layers, at 0 and 20 cm bgl, where it reaches almost 100%. Upper layers are mostly composed of loose sandy seabed sediment with plant residues and mollusk remains. Clay is evenly distributed throughout the core with an average 18.7 %. At the 40 and 90 cm bgl the clay content increases proportionally with silt decreasing at the same positions.

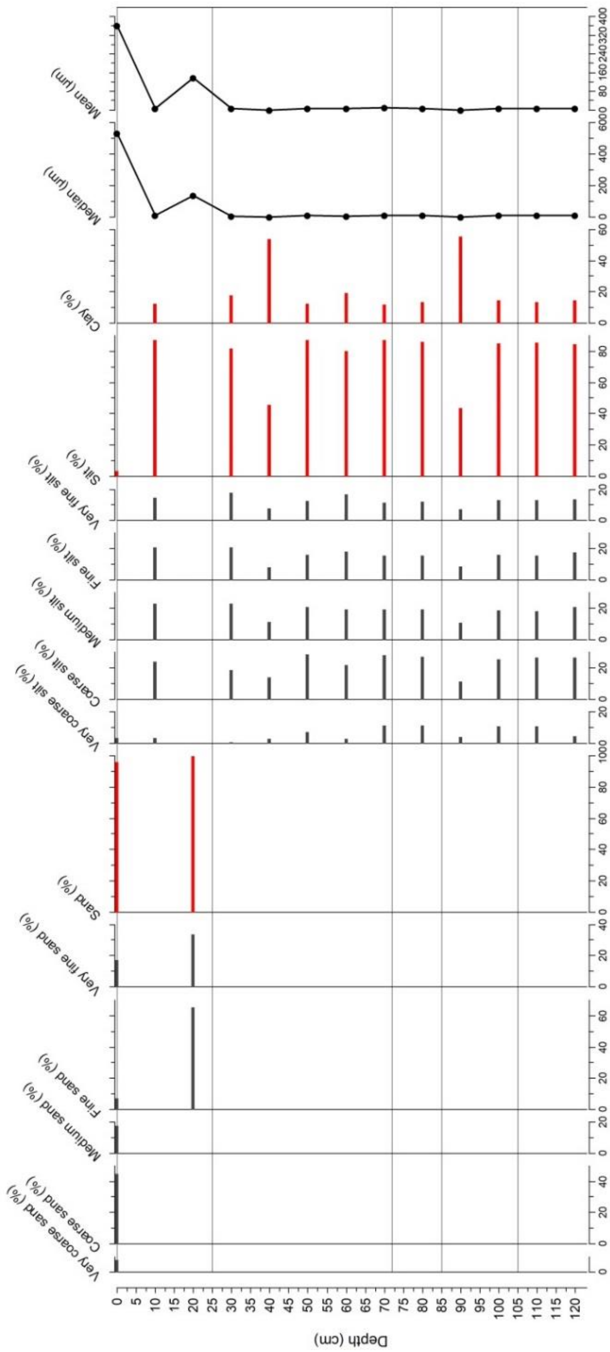


Figure 157 Grain-size variation with depth in the sediment core ZAM-2.

The highest values of TN and TOC in ZAM-2 are in the upper 20 cm of the core, 1.17 % and 17.29 % in average, respectively (**Figure 158**) where the TOC/TN ratio is approximately 15. The ratio shows lower values at approximately 14 between 30 and 70 cm bgl, and 12 between 60 and 120 cm bgl. Sediment organic matter comes mainly from vascular plants in the upper parts of the core, possibly connected to the peat platform inside which the core is located.

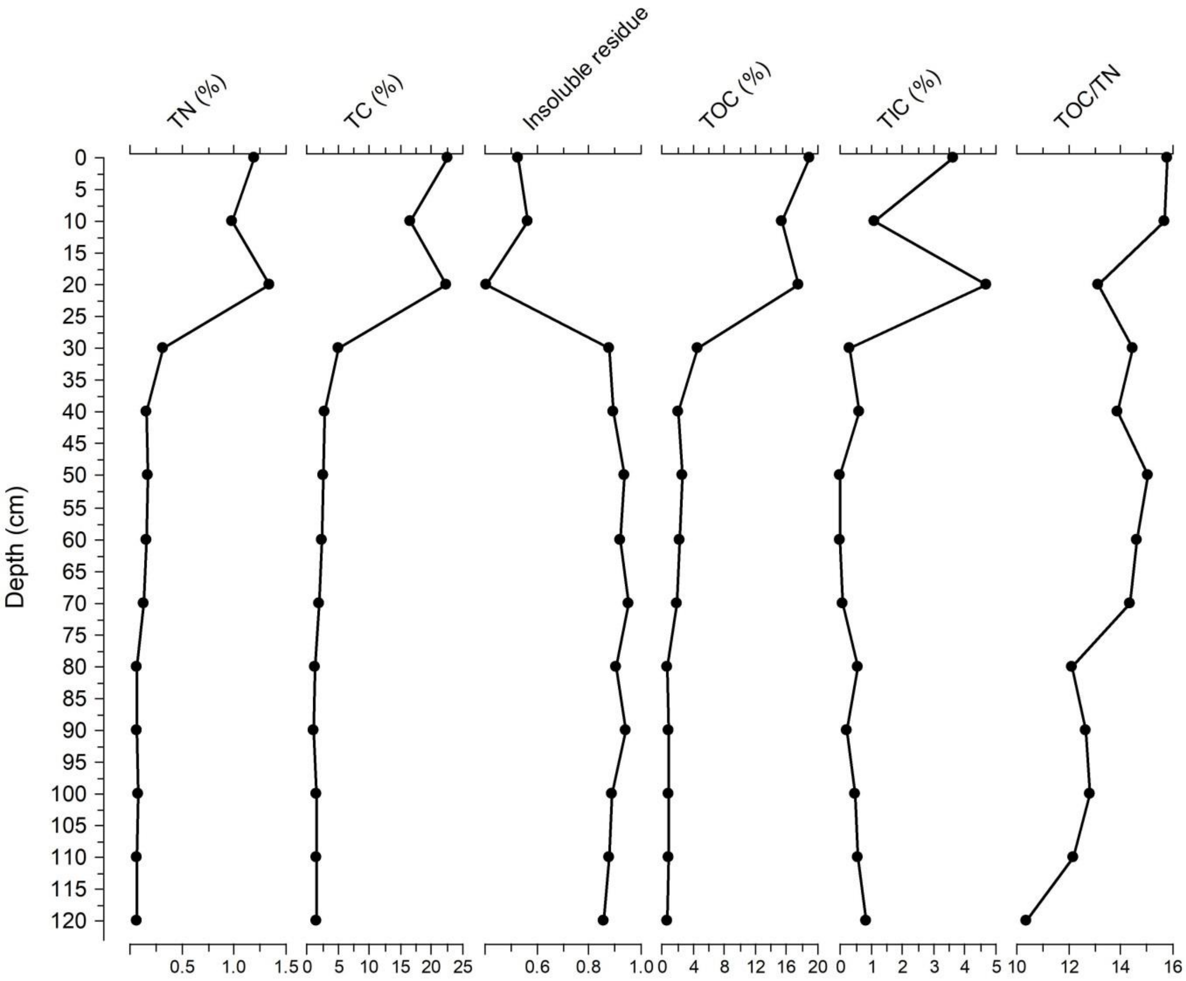


Figure 158 Variation of nitrogen and carbon content in ZAM-2.

The dominant mineral phase in ZAM-2 (**Figure 159**) is quartz in almost all samples, except between 10 and 30 cm bgl. Calcite and Gypsum only appear in the upper part of the core. Only two samples at 20 and 30 cm bgl, contained Halite. Feldspars (Plagioclase and Potassium Feldspar) appear in all except one position, at 20 cm bgl. Pyrite and Gypsum appear only at the very top of the core. There were no visible traces of Vivianite detected in ZAM-2.

ZAM-2	Main minerals	Accessory minerals
10-11	Qtz, Hl	Cal, Gp, Py, Pl, Kfs
20-21	Hl	Qtz, Cal
30-31	Qtz	Hl, Pl, Kfs, Ms/I, Kln
60-61	Qtz	Pl, Kfs, Ms/I, Kln
80-81	Qtz	Pl, Kfs, Ms/I, Kln
100-101	Qtz	Pl, Kfs, Ms/I, Kln
120-121	Qtz	Pl, Kfs, Ms/I, Kln

Figure 159 Mineralogical composition of sediments from core ZAM-2. Abbreviations: Qtz-quartz, Cal-calcite, Pl-plagioclase, Kfs-potassium feldspar, Ms/I-muscovite/illite, Kln-kaolinite, Hl-halite, Py-pyrite, Gp-gypsum.

Radiocarbon dating analyses for the successful samples from ZAM-2 yielded a 2026–1781 Cal BC date for the shells and snails in the sediments at 31–33 cm and 70–227 Cal AD date range for the shells and snails at 109–111 cm (**Figure 160**). Although at first showing potential to include the peat platform into the environmental and archaeological study of Zambratija Bay, ZAM-2 showed many inconsistencies in the results. At this stage, combined with the upside-down radiocarbon dates showed on Figure 158, ZAM-2 is considered as having disturbed sediments insufficient for further interpretations. ZAM-2 did, however, show stratigraphical similarities to the archaeological excavations from 2008–2015 excavations.

Lab Reference	Uncalibrated ^{14}C Age	Calibrated Age	Probability	Location	Sample description
SUERC-76723	3575 ± 32 BP	2026–1781 Cal BC	95.4%	ZAM-2 core, 31–33 cm	Shells, snails
SUERC-76724	1873 ± 32 BP	70–227 Cal AD	95.4%	ZAM-2 core, 109–111 cm	Shells, snail

Figure 160 Radiocarbon dates from ZAM-2.

ZAM-7 results

As seen on **Figure 161**, ZAM-7 was positioned over the 15032017123340 trackline (original trackline in **Appendix XI**). **Figure 162** shows the position of the core on the sub-bottom profile (X 265786.38; Y 5041550.31). The seabed surface depth for ZAM-7 (-2.70 RSL) was calculated according to the position on the profile.

As the known length of ZAM-7 (426 cm) was only a preliminary fieldwork measurement, it had to be reviewed after splitting in half during the initial core description protocol. Since ZAM-7 was longer than the 3 m corer PVC tube, it was composed of two segments. After an assessment of the core at the CGS laboratories, it was decided that the first, upper segment of ZAM-7 was sufficient for an archaeological interpretation. Therefore, only the first segment at a length of 268 cm was photographed (**Figure 163**).

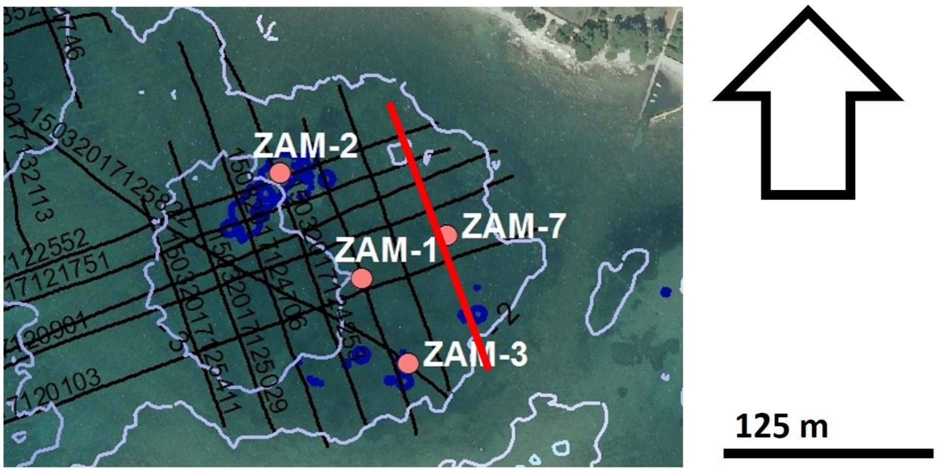


Figure 161 ZAM-7 on trackline 15032017123340 (in red).

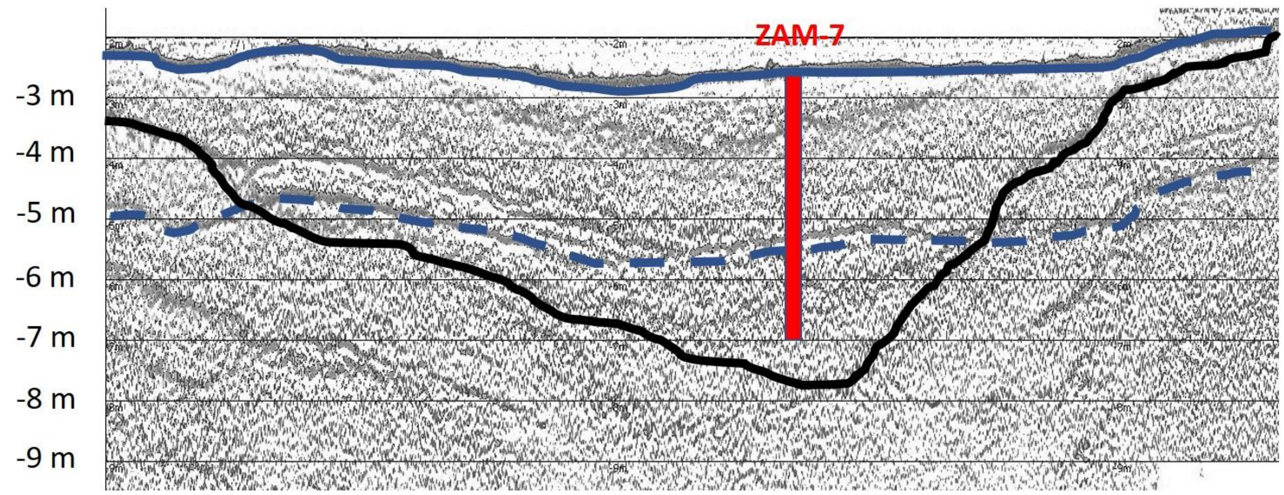


Figure 162 The position of ZAM-7 on the sub-bottom profile 15032017123340. The seabed is outlined in blue solid line. The blue dashed line is the multiple return signal. Bedrock is outlined in black.

Figure 163 The first 268 cm of ZAM-7. Upper section 0–149 cm, lower section 0–268.

Magnetic susceptibility and colour spectrometry (**Figure 164**) show a change in signal at around 75 to 90 cm bgl. Several smaller peaks occur in the magnetism until around 145 cm bgl with a very high signal. The signal is undisturbed until 170 cm bgl from where it shows multiple peaks until 195 cm bgl, after which it is stable down to the bottom of the first segment of ZAM-7 at 268 cm bgl.

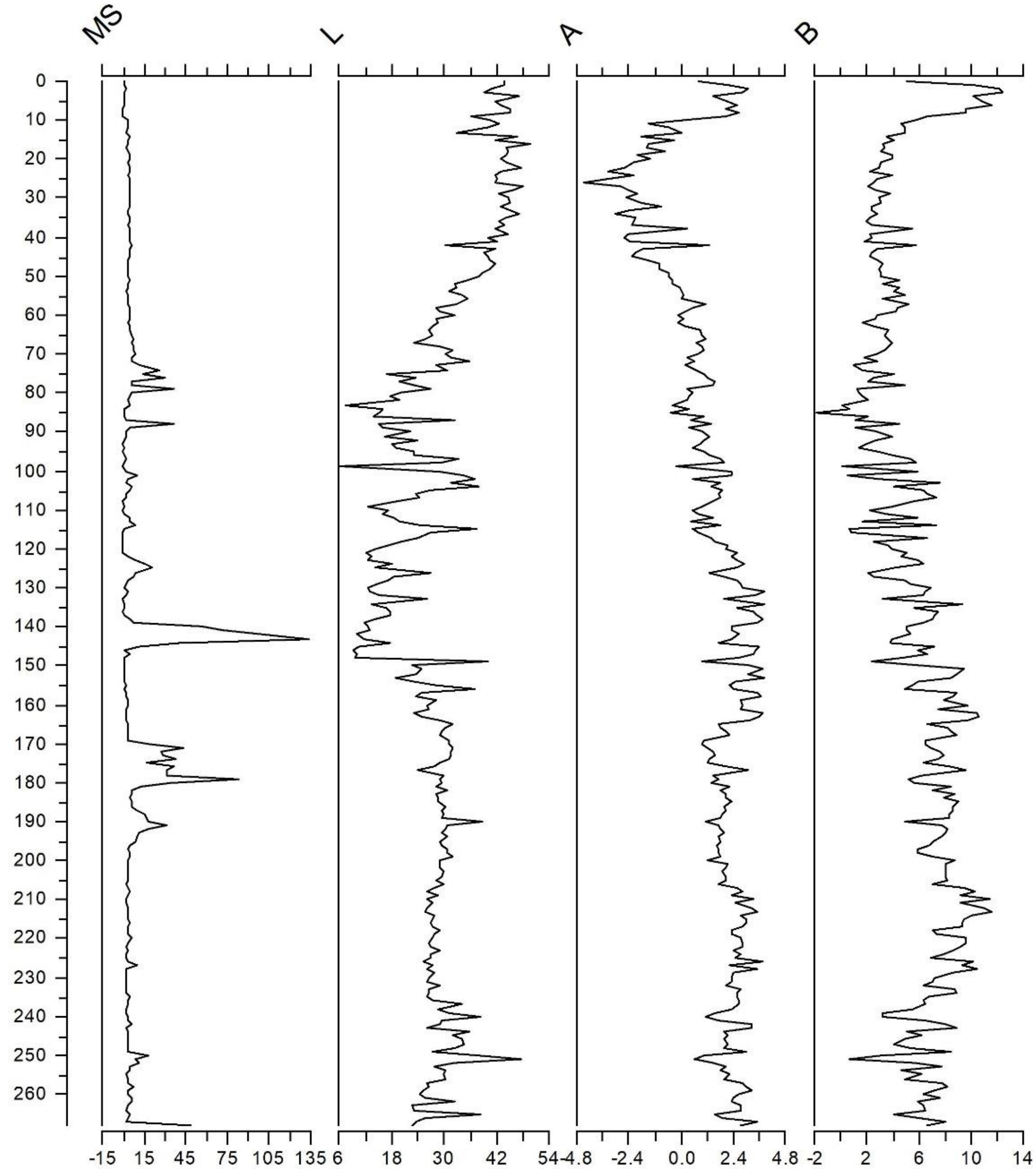


Figure 164 Magnetic susceptibility and colour spectrometry values of core ZAM-7.

The results presented above indicated potential for finding stratified cultural remains in the core, which is why a microarchaeological excavation, or archaeology of the core, was undertaken on ZAM-7.

According to the Munsell soil colour chart (Munsell Color Co. 1992) and the Troels-Smith standard system for describing unconsolidated sediments (Troels-Smith 1955), sediment colours, texture and components were appearing throughout the core as demonstrated in **Figure 165**.

Interval (cm)	Munsell	Characteristics					Components
		Nig.	Strf.	Elas.	Sicc.	Lim.	
0–10	2.5Y 6/3 light yellowish brown	1	0	3	1	-	Gs2 Gg2 Ga+
10–43	GLEY 2 5/5B bluish gray	3	2	2	1	4	Sh+ As1 Ag2 Ga+
43–67	GLEY 2 4/5B dark bluish gray	3	1	0	2	1	Sh1 As1 Ag2
67–97	5Y 3/1 very dark gray	4	2	1	3	1	Sh1 As1 Sh2 Dg+
97–99	5Y 5/1 gray 5Y 2.5/1 black	1 3	0	-	4	4	Gg4
99–115	5Y 5/1 gray	2	2	0	1	4	Dg+ As4 Gg3
115–149	10YR 2/2 very dark brown	3	0	3	4	2	Th2 Tl4 Sh4 Dh4 Dl4 Dg3
149–180	5Y 3/1 very dark gray 10YR 5/8 yellowish brown	3 2	4	2 1	2	3	Sh 1 Dd+ Dl+ Dg1 As2
180–268	10YR 5/8 yellowish brown	2	3	1	1	2	Dh3 As4 Ag1

Figure 165 A vertical composition of sediment colours and texture throughout ZAM-7.

Sediments start with a thin layer of seabed yellow coarse sand with a sharp transition to a bluish grey clay at 10 cm bgl. The bluish grey clay continues down to 43 cm bgl, when it gradually transitions to a darker colour and the sediment begins to have visible traces of organic components and molluscs (**Figure 166**).

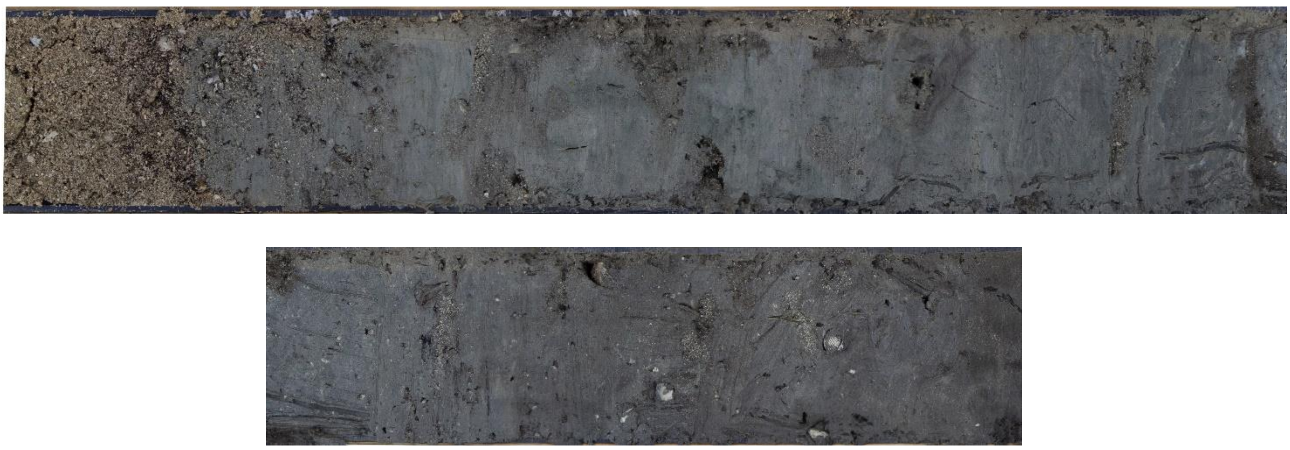


Figure 166 ZAM-7, sediments from 0–43 cm (up) and 43–67 (down) cm bgl.

At 67 cm bgl, the sediment is almost black, but not dry, down to 97 cm bgl (**Figure 167**), where it is abruptly stopped by two burnt stones (**Figure 168**), sitting at 97–99 cm bgl. After sharp transition at 99 cm bgl (**Figure 169**) to a very fine, dense layer filled with ash, large pieces of charcoal and organic remains down to 115 cm bgl (**Figure 170**). The sediments between 115 and 149 cm bgl is very dry, compact and laminated, composed of organic peat, fragments of waterlogged wood and other plant macrofossils and charcoal.

Figure 167 ZAM-7, sediments from 67–97 cm bgl.

Figure 168 Burnt stone found in ZAM-7 at 97 – 99 cm bgl (Photo: K. Jerbić).

Figure 169 ZAM-7, sediments from 97–149 cm bgl.

Figure 170 Ash layer inside the core ZAM-7 during excavation (Photo: K. Jerbić).

A fragment of dark burnished ceramic rim with finger impressions was found just above the rocks, at 95–97 cm bgl (**Figures 171:1, 172**). A fragment of charcoal from the same position was sent for radiocarbon dating. One more ceramic fragment was found in the ash at 102–103 cm bgl (**Figure 171:2**), and two at the very beginning of the peaty sediments with large quantities of wooden remains (**Figure 173**) at 115–116 cm bgl (**Figure 171:3**) and 116–117 cm bgl (**Figure 171:4**).

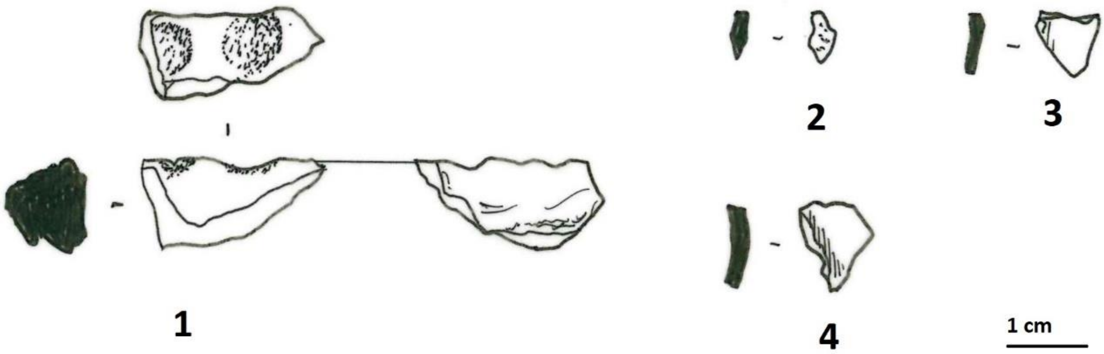


Figure 171 Ceramics found in ZAM-7. A fragment of a rim with finger impressions from 95–97 cm bgl (1), small fragment from 102–103 cm bgl (2), thin ceramic fragments from 115–116 cm bgl (3) and 116–117 cm bgl (4) Drawings: K. Jerbić).

Figure 172 Fragment of a ceramic rim with finger impressions found at 95 – 97 cm bgl (Photo: K. Jerbić).

Figure 173 A detail of the transition from ash with a large piece of charcoal, to the organic peat with visible organic plant fibres and wooden fragments. Pottery fragments were found between 115–117 cm bgl (Photo: Dr O. Hasan).

At 146–147 cm bgl and 148–149 cm bgl, two fully preserved plant fossil leaves were found intact. One was sent for radiocarbon dating (see **Figure 128**), and the other was analysed for species determination (discussed further in text). The sediments at 149 interchange from dark grey to yellowish brown clay until around 180 cm bgl, when they gradually become more wet, muddy and evenly brown down to 268 cm bgl (**Figure 174**). Plant macrofossils were sent to radiocarbon dating from 260–261 cm bgl.

Figure 174 ZAM-7 sediments from 149–180 cm bgl (up) and 180–268 cm bgl (down).

The plant epidermis from a leaf found at from 146–147 cm bgl compared favourably with Grosse-Brauckmann (1974) as being *Phragmites australis* (**Figure 175**) or the common reed, a plant most often found in wetland systems (Grosse-Brauckmann 1974).

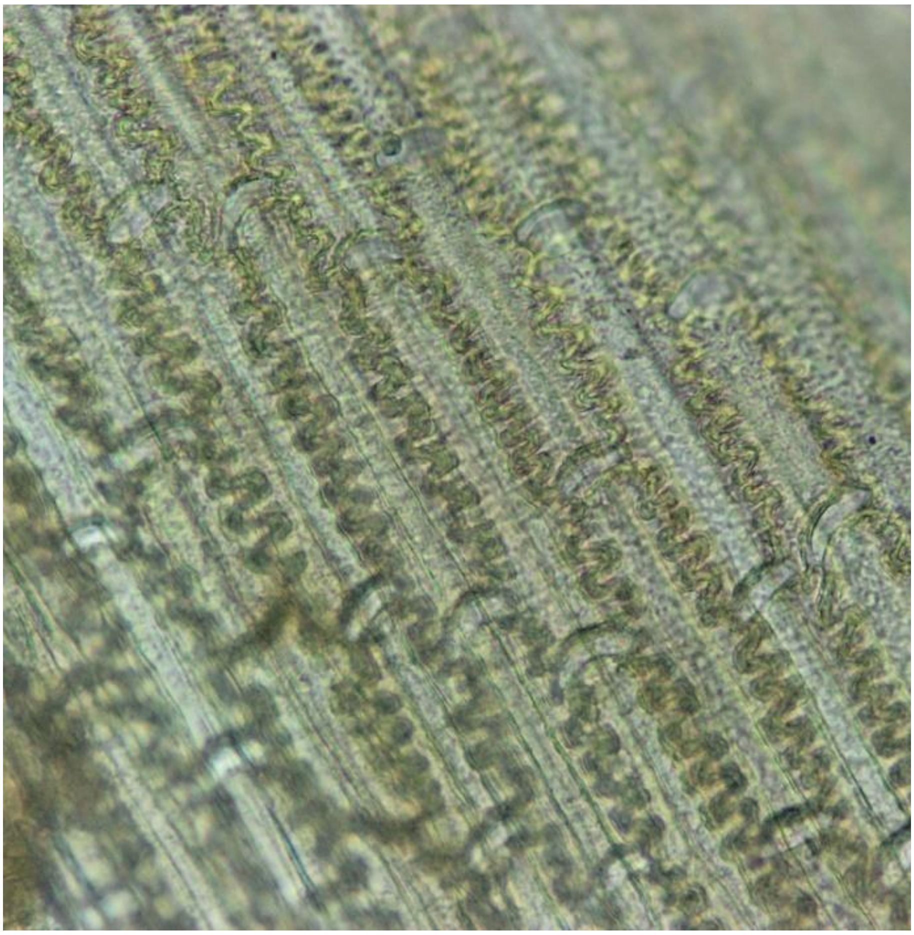


Figure 175 Epidermal cells of plant macrofossil sent for identification at 200x (Photo: L. Andrews)

The presence of foraminifera in ZAM-7 was identified as presented in **Figure 176**. Foraminifera were present in the bluish grey marine sediments, as well as at 170–171 cm below surface level. There were no foraminifera identified at 190–191 cm, where sediments were mostly brown, clayey and laminated.

40–41 cm	**50–51 cm**	**60–61 cm**	**170–171 cm**	**190–191 cm**
YES	YES	YES	YES	NO

Figure 176 Foraminifera presence in ZAM-7.

Six samples from ZAM-7 between 55 and 180 cm below surface level were sent for microflotation analysis (**Appendix XVI**). Layers contained microscopic particles resembling ceramics (**Figure 177**), the amount of which was expressed in density values. The density of ceramic particles was low in layers above 80 cm, and high above 106 cm below surface level. There were no ceramic particles present at 179–180 cm below surface level (**Figure 178**). Although similar to natural flisch, the microscopic particles were interpreted as ceramics, due to the irregularity of their appearance within the samples, as well as the fact that some fragments were sealed around microcrystalline chert (**Figure 179**), which would not be the case had they been deposited naturally.

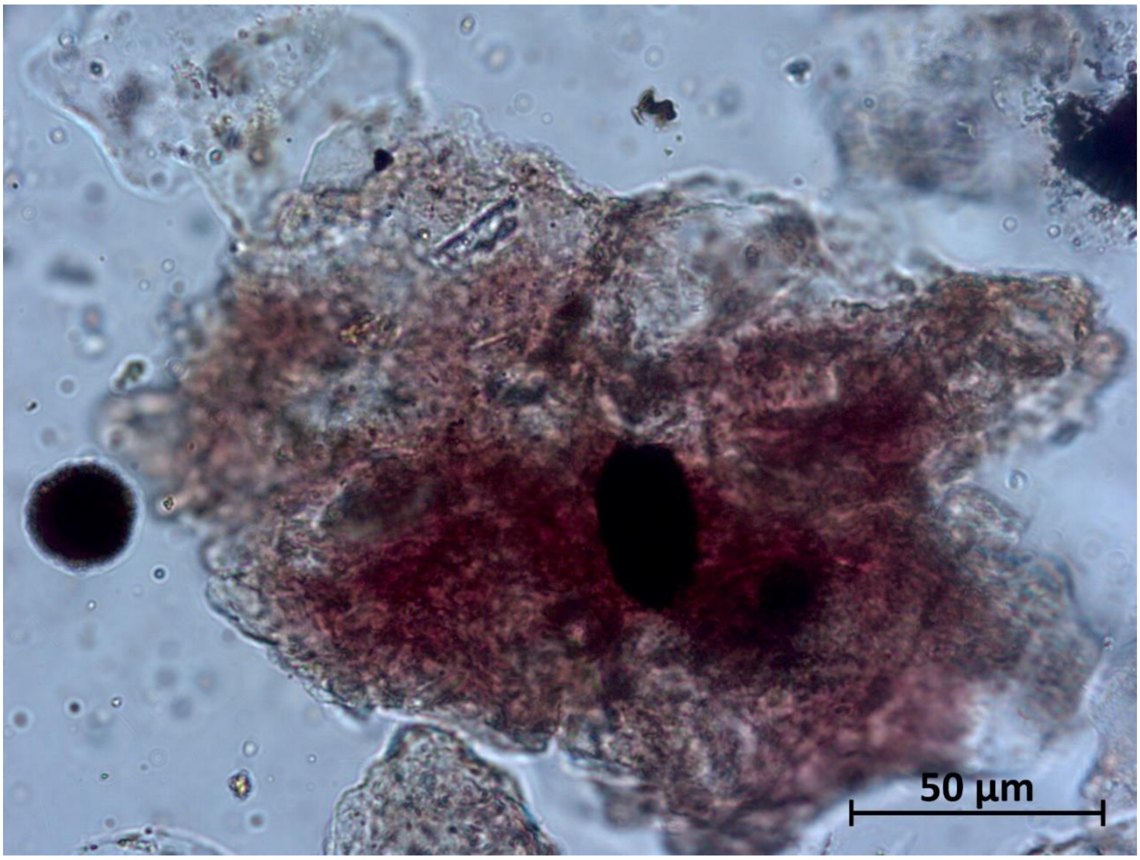


Figure 177 Clay particle (Photo: Dr I. Razum).

#	ZAM-7	Sample size	Presence of microceramics
1	55–56 cm	2 cm^3	Small density
2	74–75 cm	2 cm^3	Small density
3	80–81 cm	2 cm^3	High density
4	99–100 cm	2 cm^3	High density
5	105–106 cm	2 cm^3	High density
6	179–180 cm	2 cm^3	Not present

Figure 178 The density of microceramics throughout core ZAM-7.

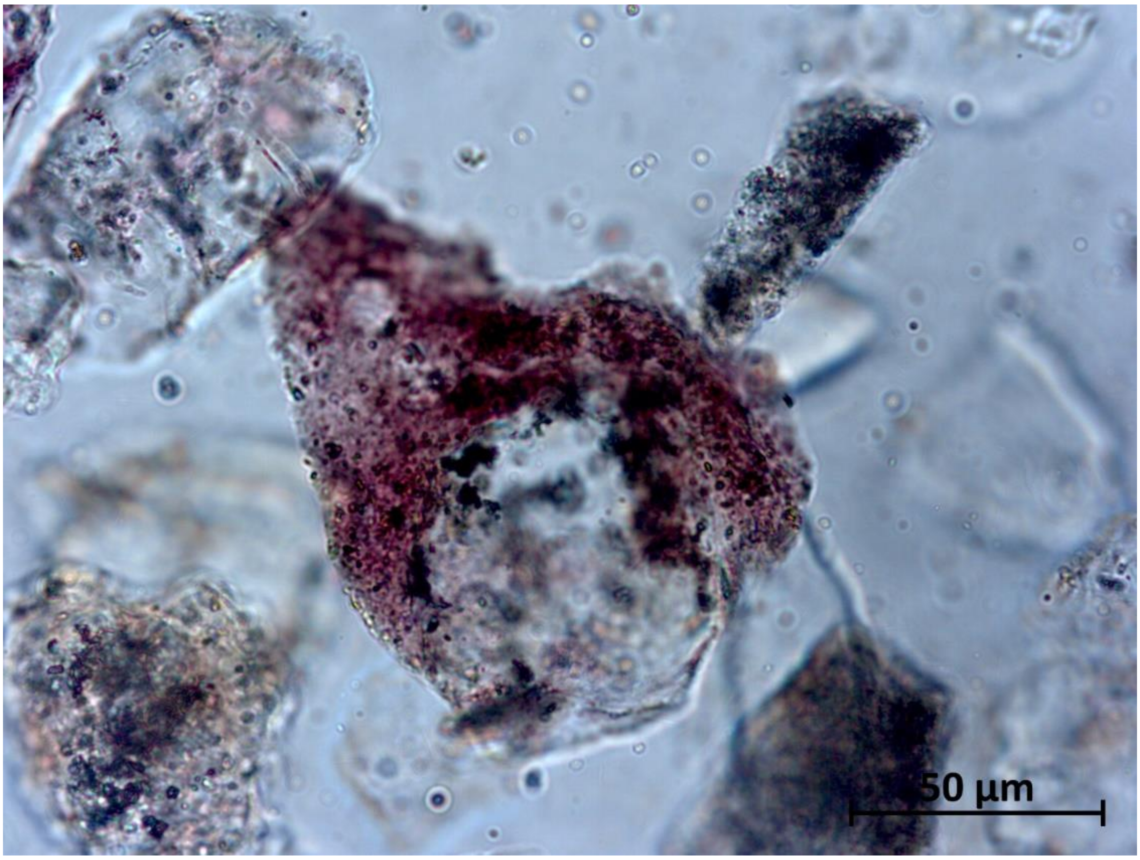


Figure 179 Clay particle surrounding a fragment of microcrystalline chert (Photo: Dr I. Razum)

Radiocarbon dating analyses for the successful samples from ZAM-7 yielded a 4041–3819 Cal BC date for the charcoal found at 95–96 cm, 4461–4354 Cal BC for a leaf found at 148–149 cm and 5669–5560 Cal BC date range for plant macrofossils found at 260–261 cm (**Figure 180**).

Lab Reference	Uncalibrated ^{14}C Age	Calibrated Age	Probability	Location	Sample description
SUERC-81648	5157 ± 28 BP	4041–3819 Cal BC	95.4%	ZAM-7 core, 95–96 cm	Charcoal
SUERC-81649	5583 ± 28 BP	4461–4354 Cal BC	95.4%	ZAM-7 core, 148–149 cm	Leaf
SUERC-81653	6703 ± 28 BP	5669–5560 Cal BC	95.4%	ZAM-7 core, 260–261 cm	Plant macrofossils

Figure 180 Radiocarbon dates from ZAM-7.

Underwater archaeology

The 2017 trench was positioned on the southwestern edges of the karstic sinkhole (**Figure 181**). Underwater archaeological investigations revealed two sets of results. The first set is combined of 3D photogrammetry and georeferenced site plan, and the second set is composed of a floating oak tree-ring sequence with limiting radiocarbon dates.

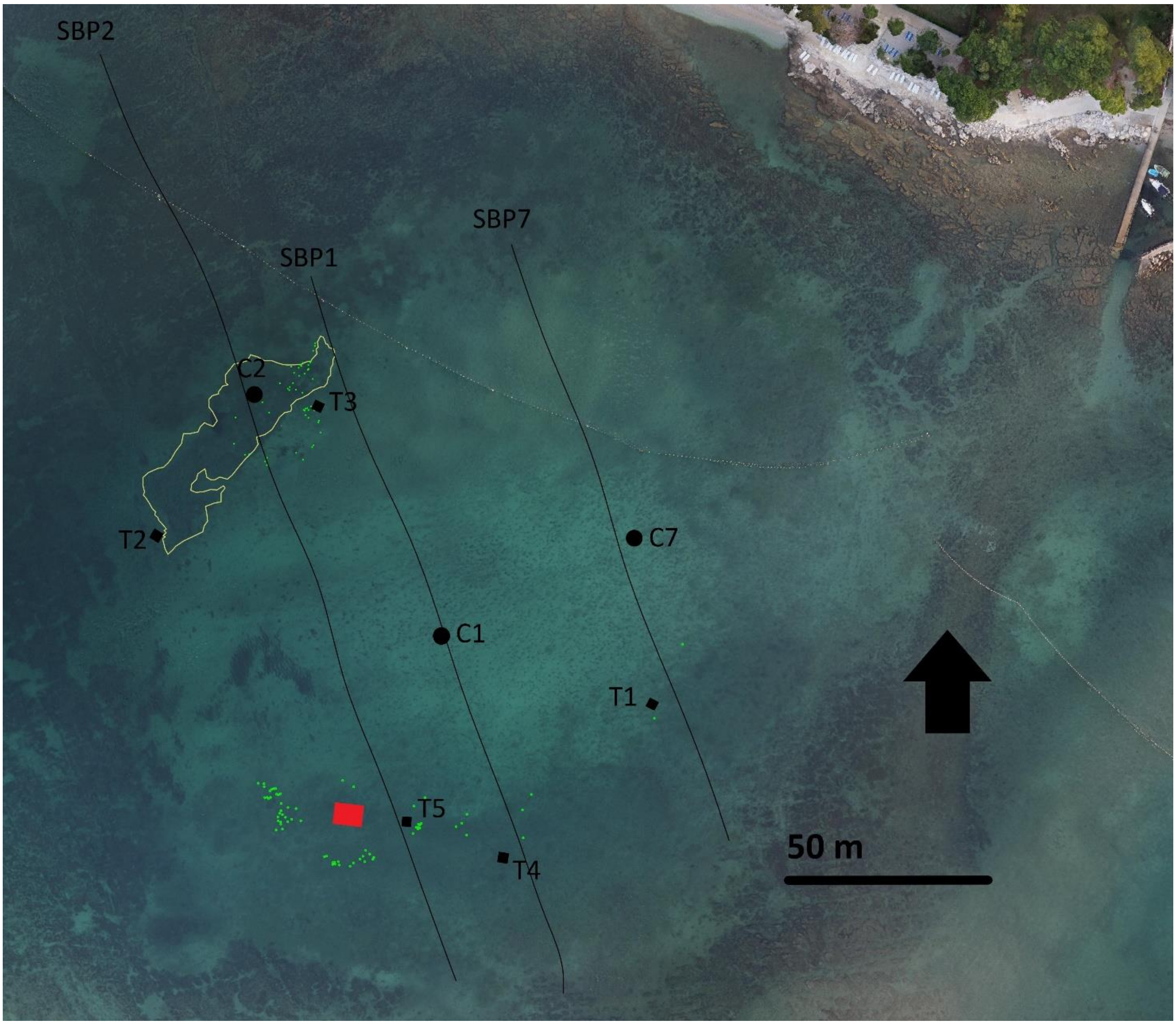


Figure 181 The position of the 2017 investigation trench (red) in relation to the five excavation units from 2008–2015 (T1–5), and cores ZAM-1 (C1), ZAM-2 (C2), ZAM-7 (C3) and their sub-bottom profiles (SBP1, SBP2 and SBP3). The green dots are clusters of georeferenced wooden piles.

3D photogrammetry model and a georeferenced site plan

The 3D photogrammetry model (**Figure 182**) provided with high-resolution digital data for further archaeological interpretations. The investigation area was placed on a slightly sloping seabed, which was documented in the form of two opposite side-views, A to the South (**Figure 183**) and C to the North (**Figure 184**). The side views indicate that the wooden piles do not protrude enough out of the seabed for them to be detected in the sub-bottom profiles but are more likely *Pinna nobilis* (**Figure 185**). Wooden piles, as well as *Pinna nobilis* and trepangs are clearly visible in the enlarged details (**Figure 186**).

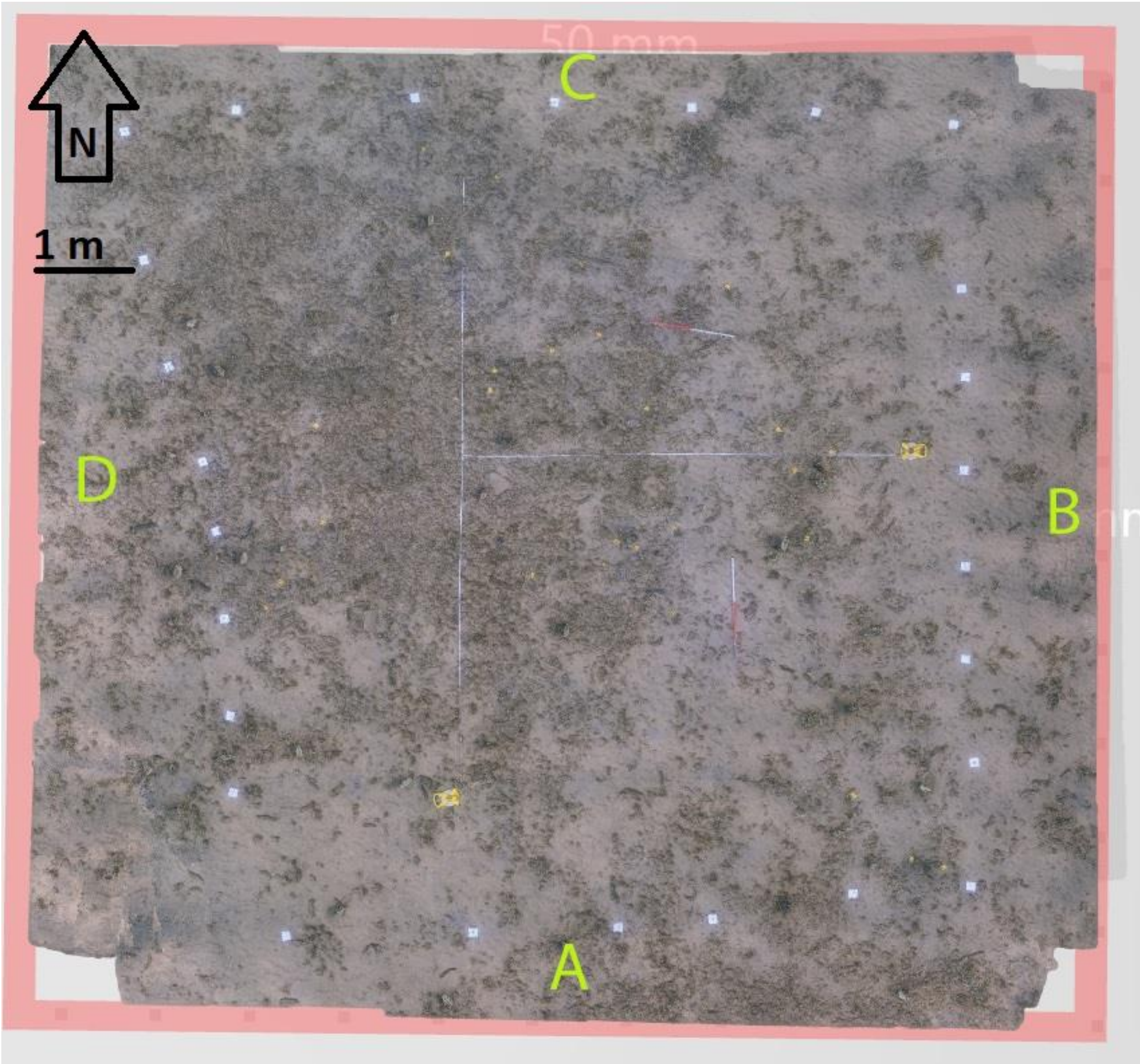


Figure 182 Photogrammetry model top view (Image: K. Jerbić).

Figure 183 Side view of section A (Image: E. Aragon Nuñez).

Figure 184 Side view of section C (Image: E. Aragon Nuñez).

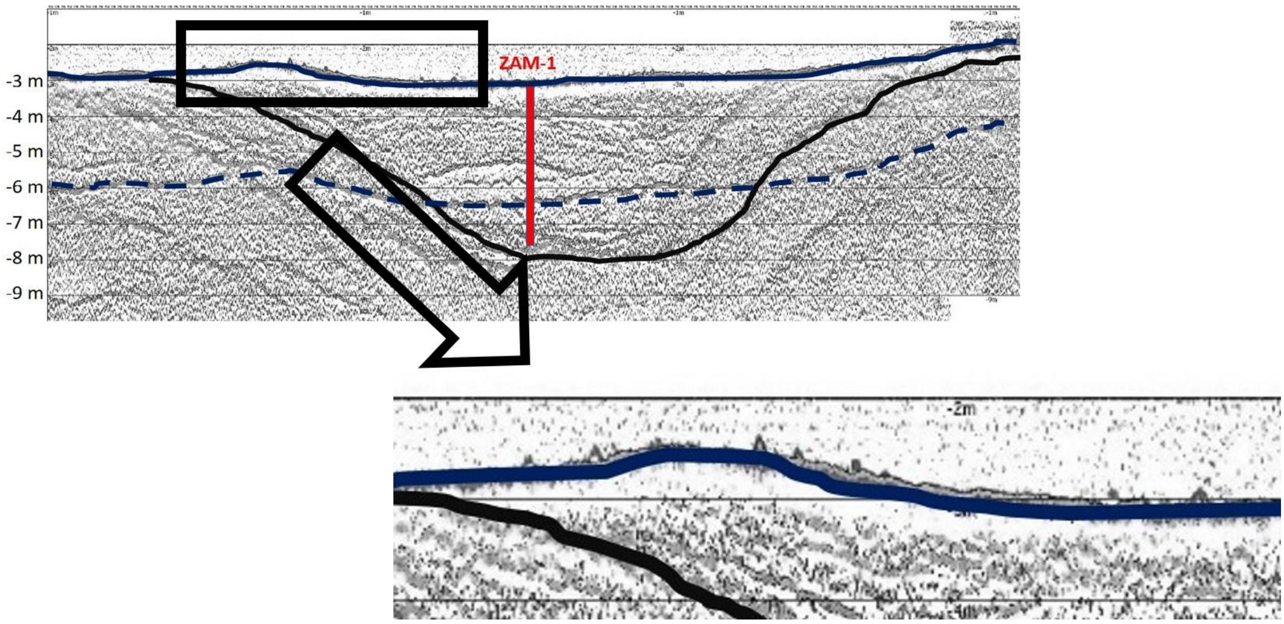


Figure 185 Sub-bottom profile 15032017123947 detail with protruding features which are more likely *Pinna nobilis* rather than wooden piles.

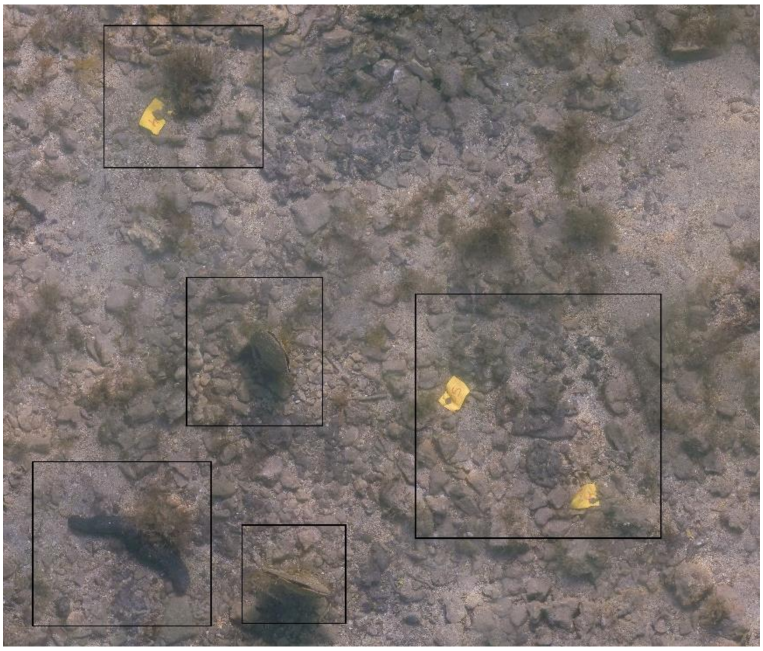


Figure 186 A photogrammetry detail with wooden piles, trepang and *Pinna nobilis*.

Tree-ring sequence with radiocarbon dates

Twenty samples from Zambratija were taken for dendrochronology (**Figure 187**) (**Appendix XIV**). Since tree rings can only be compared from the same tree species, the samples were first taken for tree species determination. The species was determined by observing microscopic varieties taken from the transversal (**Figure 188**), tangential (**Figure 189**) and radial (**Figure 190**) section of each sample. The samples were compared to Schweingruber (1993) and all showed to be oak (*Quercus sp.*). Out of the 20 oak samples, 19 showed a sufficient amount of tree rings for performing a tree-ring analysis (**Figure 191**). The wood structure of sample ZAMB 28 was extremely damaged and weakened by seaworms, and it was not included in further measuring.

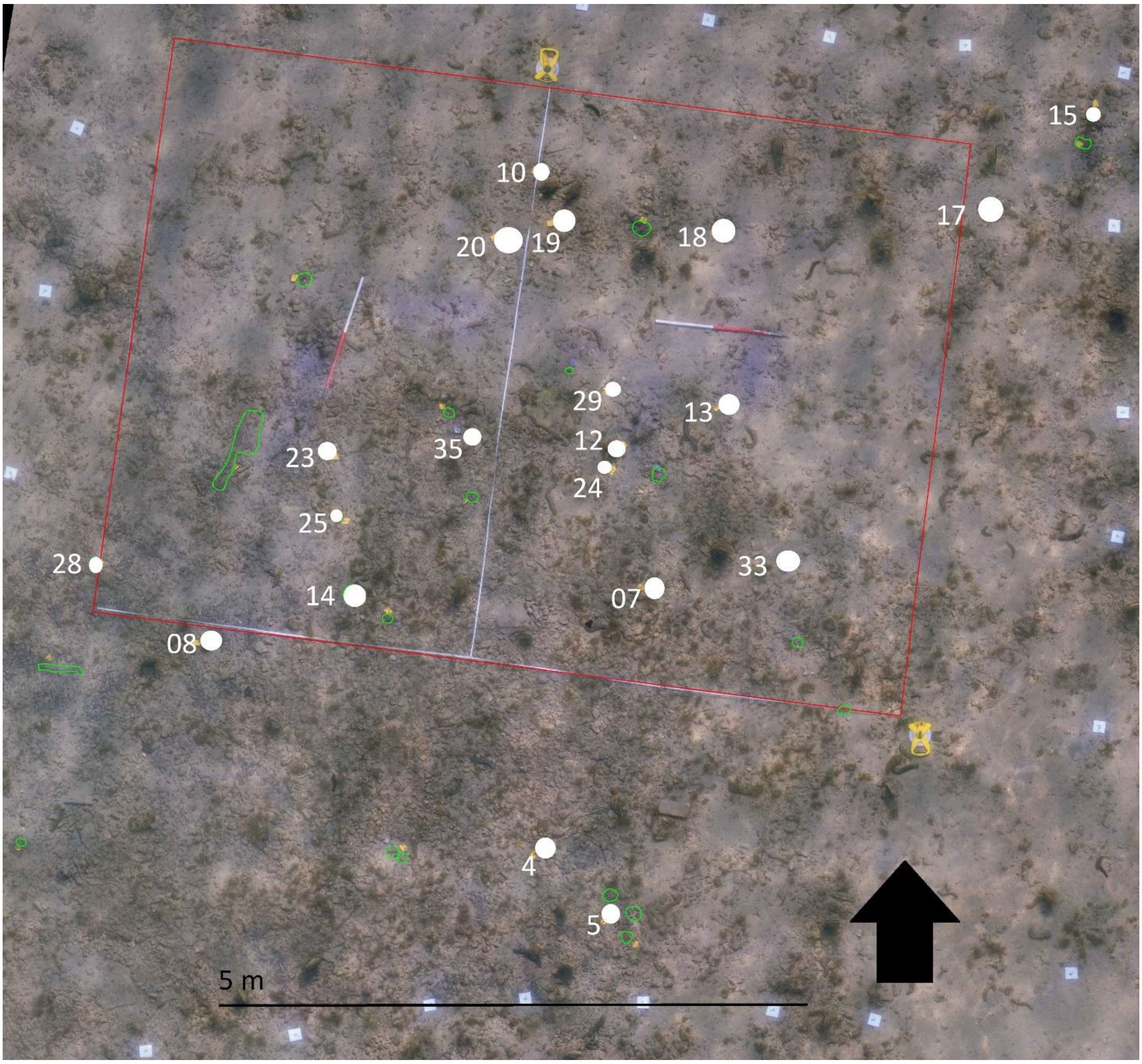


Figure 187 Photogrammetry of the 2017 trench. The wooden samples taken for dendrochronology are marked with white. Other marked piles are outlined in green. The red lines are the official limits of the trench, however piles were also marked outside these parameters and the marks were there mostly for orientation.

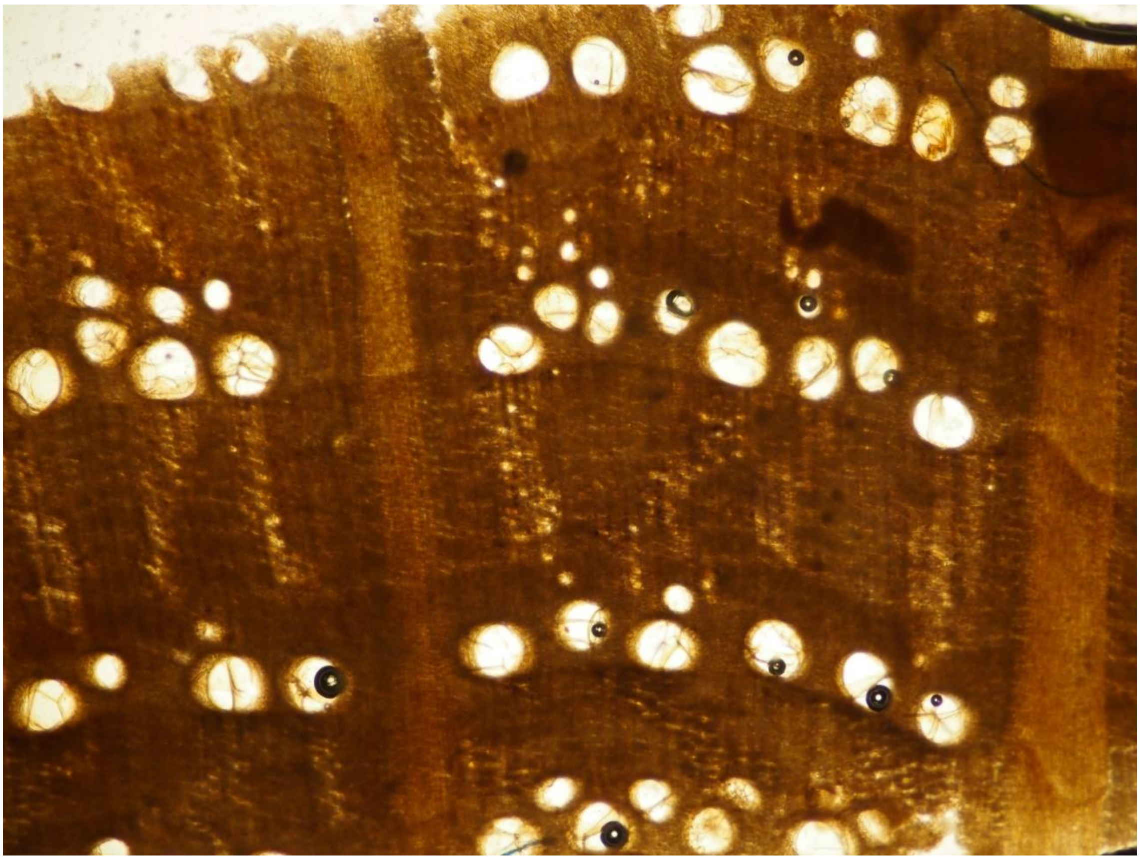


Figure 188 Transversal sections of Pile 23 (*Quercus sp.*).

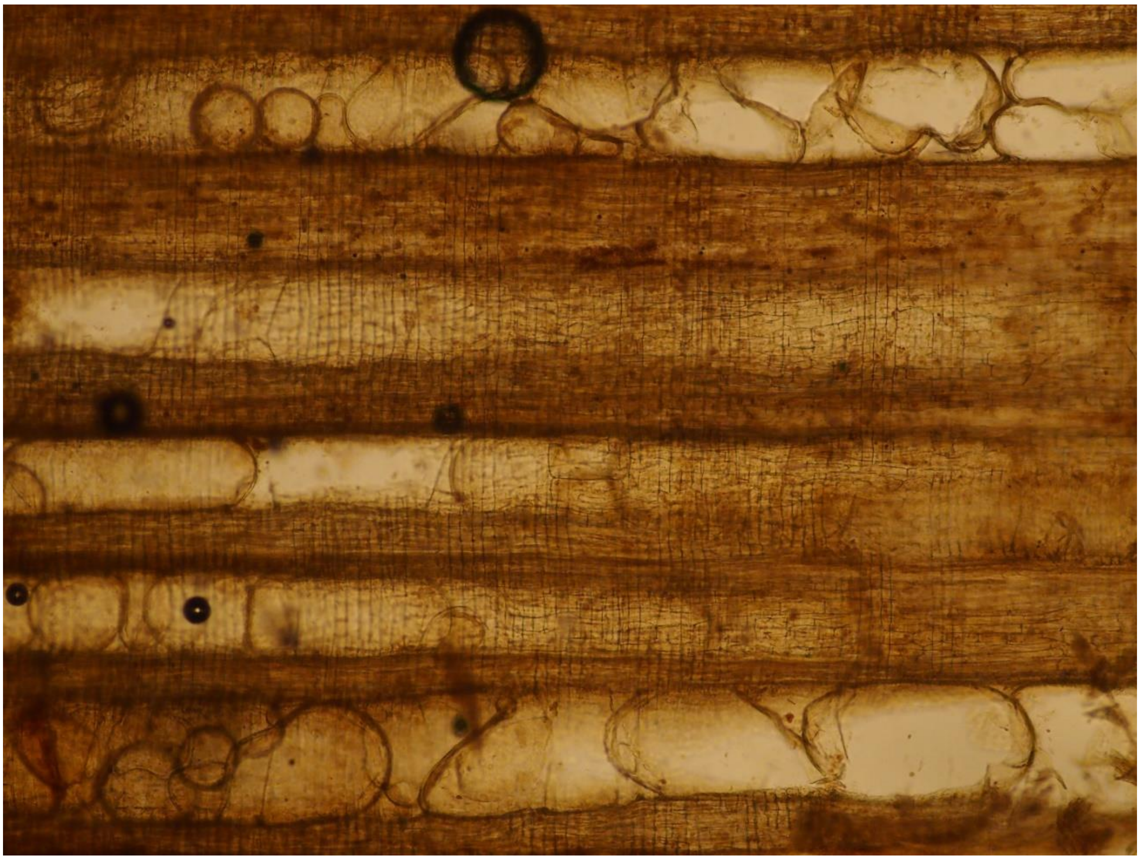


Figure 189 Tangential section of Pile 23 (*Quercus sp.*).

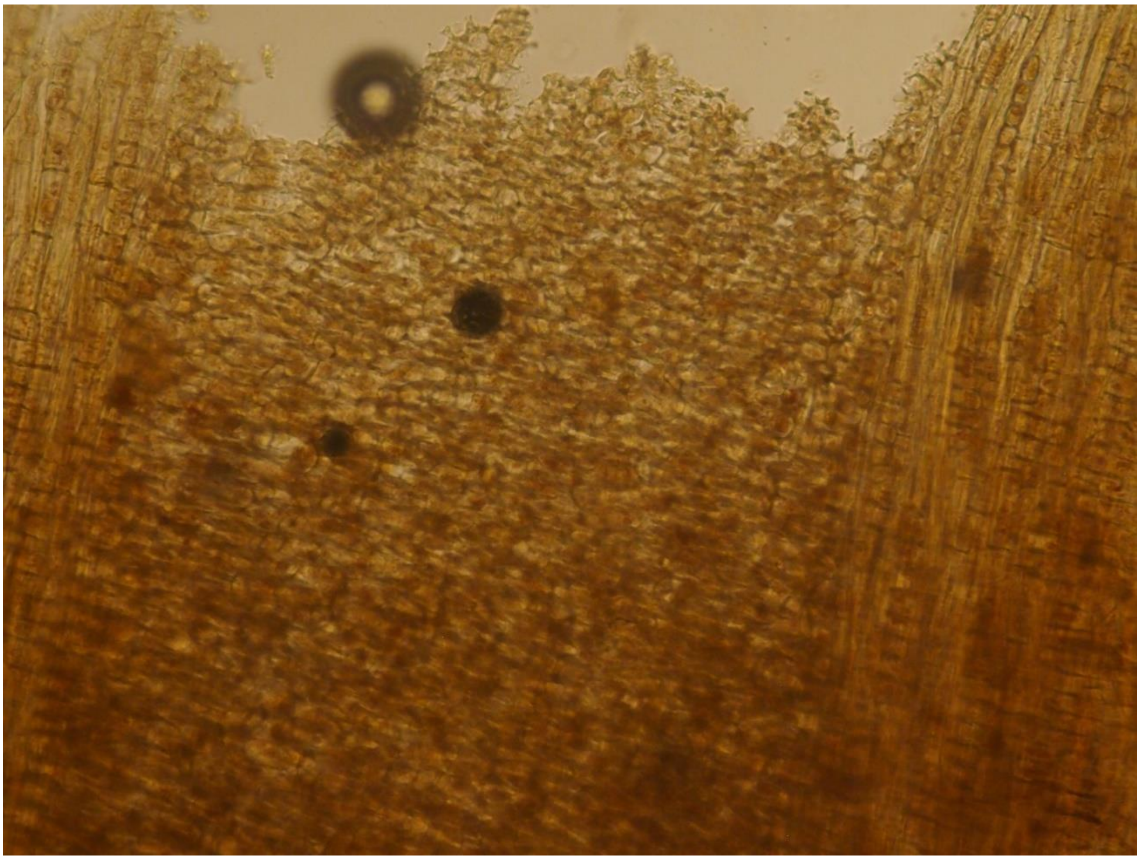


Figure 190 Radial section of Pile 23 (*Quercus sp.*).

#	Pile	Number of tree rings	Included in 62-year average
1	ZAMB 04	28	YES
2	ZAMB 05	26	YES
3	ZAMB 07	7	NO
4	ZAMB 08	39	NO
5	ZAMB 10	40	NO
6	ZAMB 12	13	NO
7	ZAMB 13	28	YES
8	ZAMB 14	11	NO
9	ZAMB 15	33	NO
10	ZAMB 17	16	YES
11	ZAMB 18	24	YES
12	ZAMB 19	15	YES
13	ZAMB 20	29	YES
14	ZAMB 23	56	YES
15	ZAMB 24	20	YES
16	ZAMB 25	28	NO
17	ZAMB 28	/	/
18	ZAMB 29	43	YES
19	ZAMB 33	27	YES
20	ZAMB 35	8	NO

Figure 191 A list of dendrochronology samples from Zambratija. Samples in red were sent for radiocarbon dating.

Out of the 19 measurable samples, 11 were successfully synchronised into a 62-year-old average sequence (**Figure 192**), whereas the remaining eight samples did not correlate either to the 62-year average, or to one another. The results were sent this to Service de l'Archéologie de l'Office du Patrimoine du Canton de Neuchâtel (OPAN) in Switzerland and Dendrodata s.a.s. in Italy for possible correlations with long pile-dwelling Oak sequences, but it could not be successfully matched to any known database.

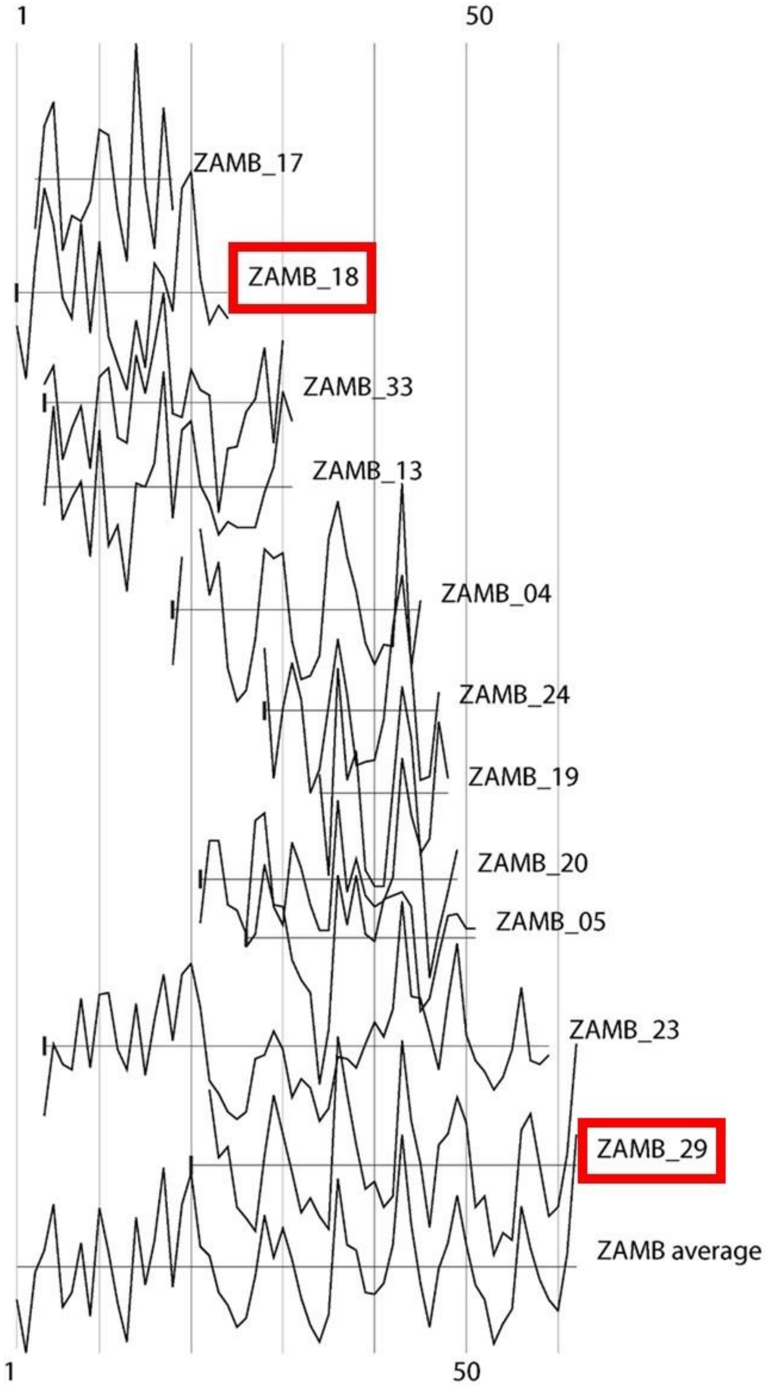


Figure 192 The synchronisation of the 11 correlated growth chronologies (Corridor indexing). The average chronology is represented at the bottom. The red squares mark the samples sent for radiocarbon dating.

Two samples, one from the beginning and one from the end of the sequence were sent for radiocarbon dating. Sample 18 from the beginning of the sequence yielded a 4240–4044 Cal BC date. Sample 29 from the end of the sequence yealded a 4034–3801 Cal BC date (**Figure 193**).

Lab Reference	**Uncalibrated ^{14}C Age**	**Calibrated Age**	**Probability**	**Location**	**Sample description**
SUERC-77772	5310 ± 32 BP	4240–4044 Cal BC	95.4%	Dendro sample #18	Wood
SUERC-77773	5129 ± 34 BP	4034–3801 Cal BC	95.4%	Dendro sample #29	Wood

Figure 193 Radiocarbon dates derived from the dendrochronological samples from Zambratija Bay.

Zambratija Bay: original results summary

The original results provided from the research obtained in Zambratija Bay in 2017 and used in this thesis can be summarised as follows:

1. Fieldwork
    a. 21 sub-bottom profiles
    b. 8 sea bed sediment cores, out of which 3 were used for further analyses – ZAM-1, ZAM-2 and ZAM-7
    c. 20 waterlogged wooden pile samples from the sea bed
2. Laboratory analyses
    a. Colour spectrometry, magnetic susceptibility and detailed photography indicating changes in the stratigraphic composition of the cores
    b. Foraminifera findings separating lacustrine from marine and brackish sediments of the cores
    c. Grain size analysis indicating larger fractions in sediments brackish sediments
    d. Total Organic Carbon (TOC) and Total Nitrogen (TN) content indicating organic content in brackish sediments
    e. Pyrrhotite indicating a marine transgression and the start of marine sediments
    f. Vivianite indicating large amounts of P (phosphorous) in brackish sediments which is an indicator of human interactions with the landscape

g. Archaeology of the core ZAM-7 revealed ash layers filled with microscopic traces of pottery as well as 4 fragments of ceramics
h. Radiocarbon dated sphagnum plant in the lower brackish sediments indicating a wetland environment
i. 62-year-old radiocarbon dated dendrochronological sequence derived from 11 samples of wood
j. 9 successful radiocarbon dates from cores and wooden piles revealing an environmental and cultural history of Zambratija Bay

CHAPTER 8: ENVIRONMENTAL AND ARCHAEOLOGICAL INTERPRETATIONS – A COMPARATIVE STUDY

The presented results demonstrate how important it was to execute the sub-bottom profiling, coring and underwater investigations in the respected order. The results could therefore be built upon and complement each other. The sub-bottom profiling had to be commenced first to obtain knowledge of the seabed sediment thickness and preliminary stratigraphy of the bay. Since sub-bottom profiling was done by the same company that performed the bathymetric survey of the bay in 2012 (Koncani Uhač and Čuka 2015:30), the available raw data made it possible to combine and overlap the existing seabed surface with the new subsurface datasets. According to the sub-bottom results, the coring component could be implemented effectively in order to obtain samples of long vertical stratigraphic sequences from areas of the bay with known geophysical and archaeological evidence implying a submerged landscape and an archaeological site. After sampling the cores, their georeferenced positions, as well as the positions of the previously recorded wooden piles, peat platform and excavated units (Koncani Uhač and Čuka 2015:28), were layered over the ortophoto mosaic of the bay (**Figure 194**).

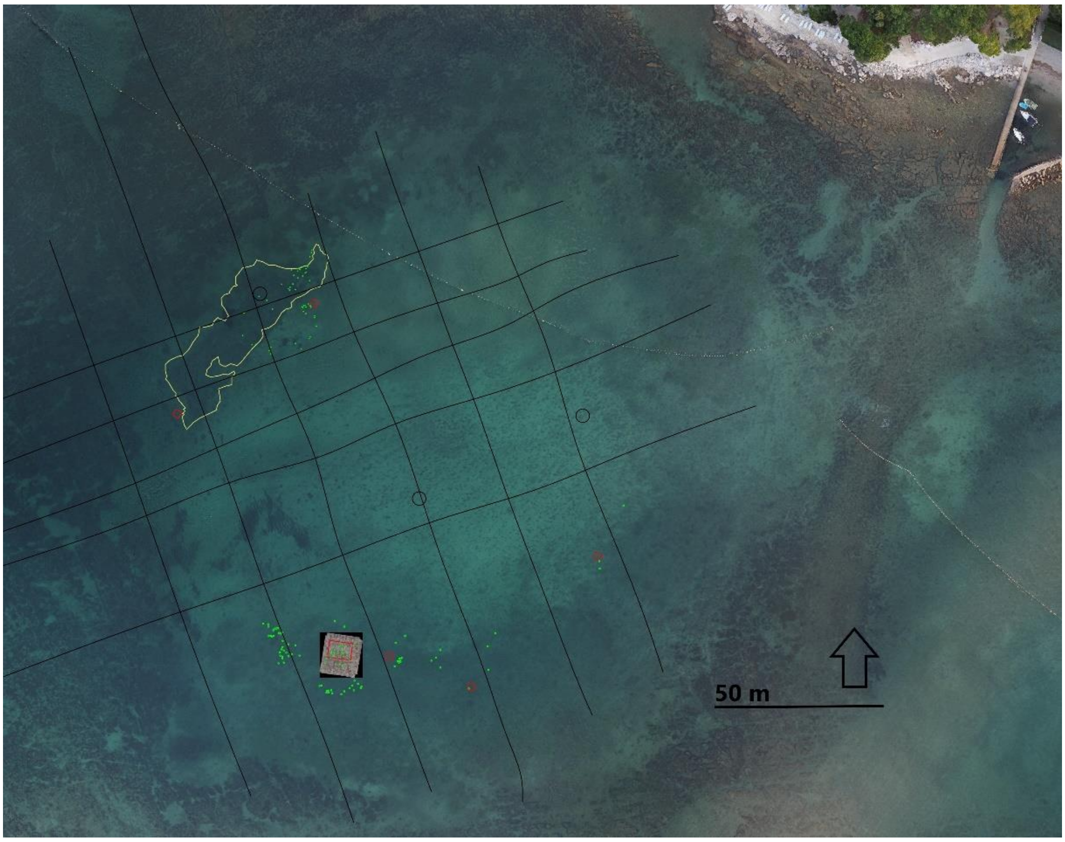


Figure 194 The data used in the thesis.

Furthermore, the combination of radiocarbon dates and the sub-bottom profiles interpreted by analysing the sediments from the cores, gave insight into the environmental and cultural history of the bay. Radiocarbon dates from cultural layers with the radiocarbon dated dendrochronological sequence, in combination with the first radiocarbon date gave insight into the life in the submerged prehistoric pile-dwelling in Zambratija Bay (**Figure 195**). The results gave enough evidence for connecting environmental changes in the bay to the final abandonment of the settlement.

Lab Reference	Uncalibrated ^{14}C Age	Calibrated Age	Probability	Location	Sample description
SUERC-76718	4836 ± 32 BP	3246–2882 Cal BC	95.4%	ZAM-1 core, 151–154 cm	Shell
SUERC-76722	4714 ± 32 BP	3632–3375 Cal BC	95.4%	ZAM-1 core, 420–421 cm	Peat (fibrous)
SUERC-76723	3575 ± 32 BP	2026–1781 Cal BC	95.4%	ZAM-2 core, 31–33 cm	Shells, snail
SUERC-76724	1873 ± 32 BP	70–227 Cal AD	95.4%	ZAM-2 core, 109–111 cm	Shells, snail
SUERC-81648	5157 ± 28 BP	4041–3819 Cal BC	95.4%	ZAM-7 core, 95–96 cm	Charcoal
SUERC-81649	5583 ± 28 BP	4461–4354 Cal BC	95.4%	ZAM-7 core, 148–149 cm	Leaf
SUERC-81653	6703 ± 28 BP	5669–5560 Cal BC	95.4%	ZAM-7 core, 260–261 cm	Plant macrofossils
SUERC-77772	5310 ± 32 BP	4240–4044 Cal BC	95.4%	Dendro sample #18	Wood
SUERC-77773	5129 ± 34 BP	4034–3801 Cal BC	95.4%	Dendro sample #29	Wood
Beta-296187	5260 ± 30 BP	4230–3980 Cal BC	95%	Unit 1, Layer 2	Wood

Figure 195 All radiocarbon determinations undertaken to date. SUERC dates represent new data undertaken for the purposes of this thesis while the BETA date was previously the only absolute date from the submerged prehistoric pile-dwelling in Zambratija Bay.

Vertical stratigraphy

The sediment cores from Zambratija provided evidence for a paleoenvironmental and archaeological assessment. By combining data from ZAM-1 and ZAM-7, the archaeological site could be interpreted by analysing and cross-referencing the microscopic and macroscopic contents of the sediments. Although the radiocarbon dates and the deposition of foraminifera in ZAM-2 (**Figure 196**) showed irregularities, the data is still valuable for confirming that the deposition of marine sediments occurred during the late Holocene.

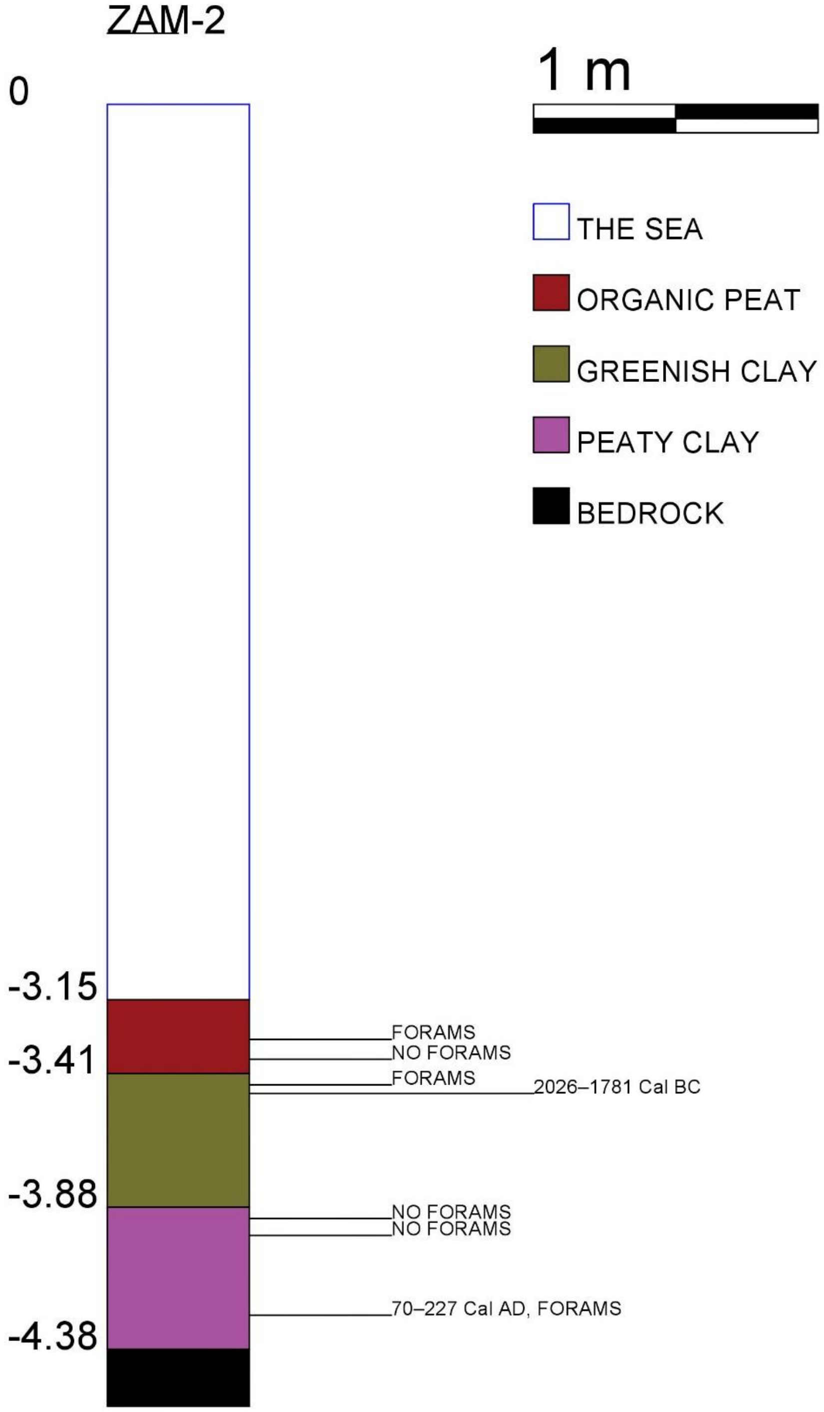


Figure 196 With its irregular radiocarbon dates and deposition of foraminifera, core ZAM-2 represents one of the limitations of this research.

Paleoenvironment

As seen on **Figure 197**, the paleoenvironmental changes throughout the Holocene can be seen in Zambratija Bay with the interpretation of core ZAM-1, located in the centre of the karstic sinkhole. The core starts with marine sediments which are characterised by the occurrence of bluish grey clay carbonate sediments containing marine shells and foraminifera. The bluish grey clay shows succession highly magnetic signal sediments containing pyrrhotite minerals, which are formed under marine influence through karstic underground (Siddal 2018). The pyrrhotite occurs before 3246–2882 Cal BC, which is a radiocarbon date derived from a marine shell. The marine sediments gradually become darker grey, and increasingly containing organic components until the sediment becomes an almost black, organic, dry peat. The fibrous peat from this part of the core yielded a radiocarbon date range between 3632–3375 Cal BC. The almost one-meter thick organic sediments here contain high TOC (15-30 %) and N (1.1-2.8 %) with high P, Fe and Mo levels, as well as reliable indications of vivianite in lower parts of the core towards the next changes in colour and composition.

Vivianite, an authigenic ferrous iron phosphate mineral ($Fe_3(PO_4)_2{\cdot}8H_2O$) usually appears in waterlogged soils and aquatic sediments (Rothe et al. 2016). It occurs on various Quaternary, and modern aquatic systems worldwide, which includes marine, freshwater and terrestrial waterlogged soils. Vivianite regularly occurs in close association with organic remains in iron-rich sediments with significant P content, and it is important indicator of P burial in the lake/marine basins (Rothe et al. 2016). Recent investigation indicate that it acts as an important burial sink for P in brackish coastal environments (Egger et al. 2015), however it also occurs in alluvial deposits (Grizelj et al. 2017). In archaeological contexts it is a common find in cultural stratigraphic layers of peat bogs (Siddal 2018) and has also been recorded as a secondary deposit on archaeological finds which include human remains (Maritan and Mazzoli 2004; McGowan and Prangnell 2006; Tessadri 2000; Thali et al. 2011) and ceramic artefacts (Dillian and Bello 2008), as well as anthropologically influenced muddy wastewater layers settings with higher P levels (Rothe et al. 2016). This implies that the occurrence of vivianite in archaeological contexts represents a secondary refuse and a reliable indicator of human impact on aquatic environments. In the cases of small-scale sediment assessments such as core analysis, the occurrence of vivianite might also imply the presence of cultural remains in the near vicinity of the core location. The end of the organic sediments is characterized by lower values of δ13C and δ15N and a sharp change in colour starting with fine laminations to a yellowish brown clay sediment implying a freshwater environment. Occurrences of vivianite are still visible in underlying brown clay freshwater pond sediments, containing much more siliciclastic material compared to the organic sediment above.

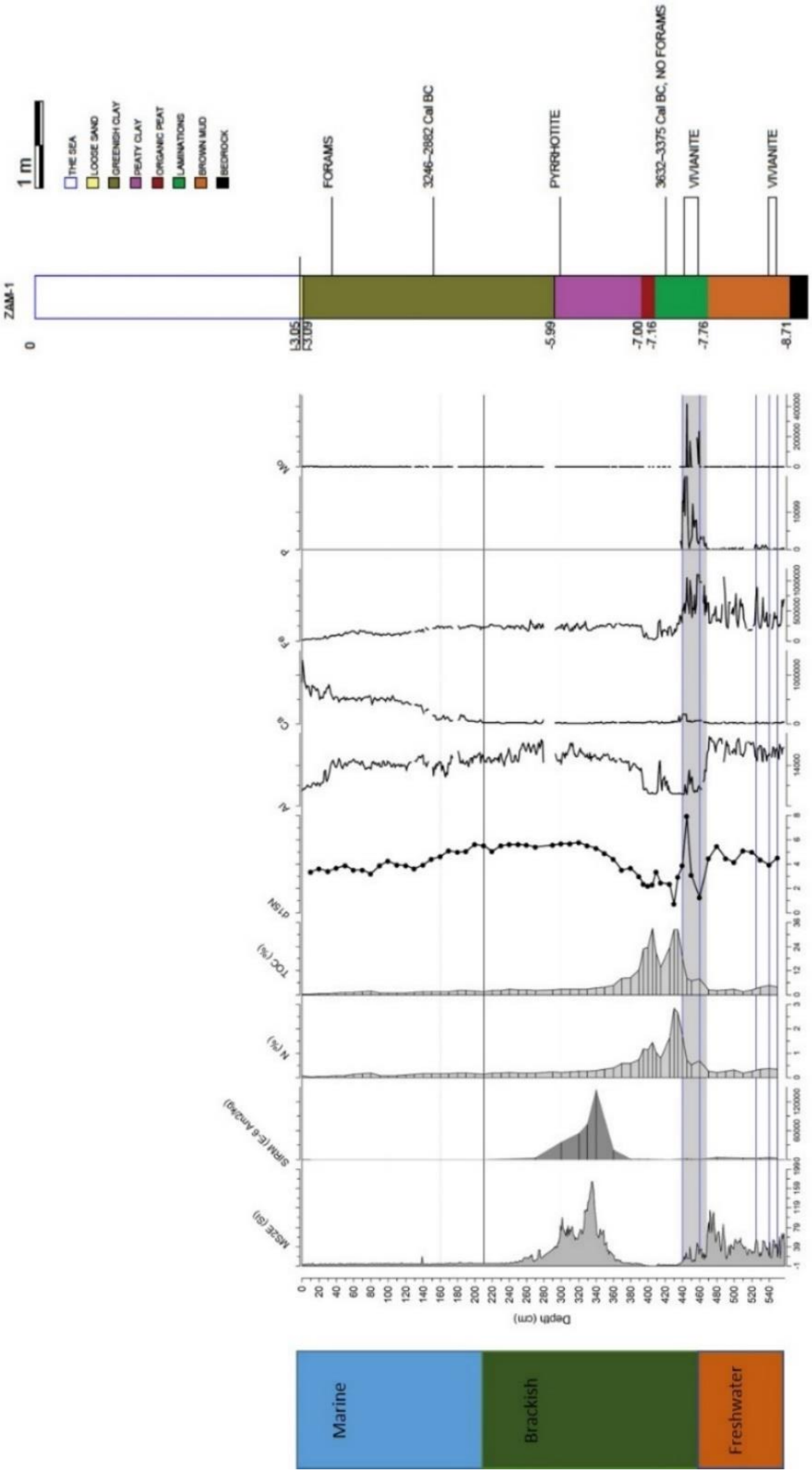


Figure 197 The paleoenvironment of ZAM-1. Detailed images further in text.

The first research question (*How did the physical environment evolve at Zambratija Bay during the Early and Middle Holocene, with special reference to sea-level changes?*) focuses on the global climate events which chronologically overshadowed the cultural and social interactions worldwide since prehistory, and they are still ongoing today. According to comparative research, the process of the glacio-isostatic water melt into the oceans has stopped, and the global sea levels were starting to stabilise at around 5000 BC (Vacchi et al. 2016:173; Benjamin et al. 2017:14). The global climate trends are also present in the Mediterranean at the time, where predictive post-LGM marine transgression calculations show similar sea-level uprise trends (Lambeck and Purcell 2005; Stocchi and Spada 2007). In the Northern Adriatic Sea, the sea-level uplift is inconsistent with these global trends and the local RSL levels were between 4 and 9 metres lower than those for the rest of the Mediterranean at 4000 BC, most likely due to the deglaciation of the Alpine glacier (Lambeck and Purcell 2005:1976; Monegato et al. 2017; Stocchi et al. 2005:140). The Northern Adriatic sea level uplift therefore reached present day levels at around 2000 BC, after which the changes were mostly influenced by tectonic factors made visible in submerged and coastal archaeological sea-level markers (Antonioli et al. 2007; Antonioli et al. 2009; Faivre et al. 2011; Florido et al. 2011; Lambeck et al. 2004b).

According to the sedimentological, mineralogical and geochemical and depositional microfauna results from ZAM-1, the Early and Middle Holocene physical environment and sea level change evolved as presented in **Figure 198**. Lower parts of the core contain brown clay sediments characterized by higher amounts of siliciclastic material. This layer of brown soil considerably rises towards the edge of the sinkhole, based on the geophysical seismic data, and it represents the layer where wooden piles were placed in at the time of the existence of the settlement. The brown clay is overlaid by organic sediments, which are fine-grained in lower part and peaty, with organic plant residues in the upper part. The brown soil is identified as terrestrial freshwater pond/shallow lake environment which gradually transition to a more brackish environment. A high magnetic susceptibility signal between 360 and 300 cm bgl indicates the formation of strongly magnetic mineral, most likely pyrhottite, which forms under marine influence (Larrasoaña et al. 2007). The freshwater to brackish transition is followed by the deposition of marine sediments, which are the result of a marine transgression between 3300 to 3200 Cal BC. This date also correlates to the Northeastern Adriatic trends, where according to (Vacchi et al. 2016) sea level was at -2.9±1.0 RSL at around 3000 BC and reached current level at around 500 AD. According to the radiocarbon dates from ZAM-2, sea-level was rising in Zambratija until at least 70–227 Cal AD, which correlates with the results from the nearby Roman port in Savudrija Bay (Koncani Uhač and Auriemma 2015).

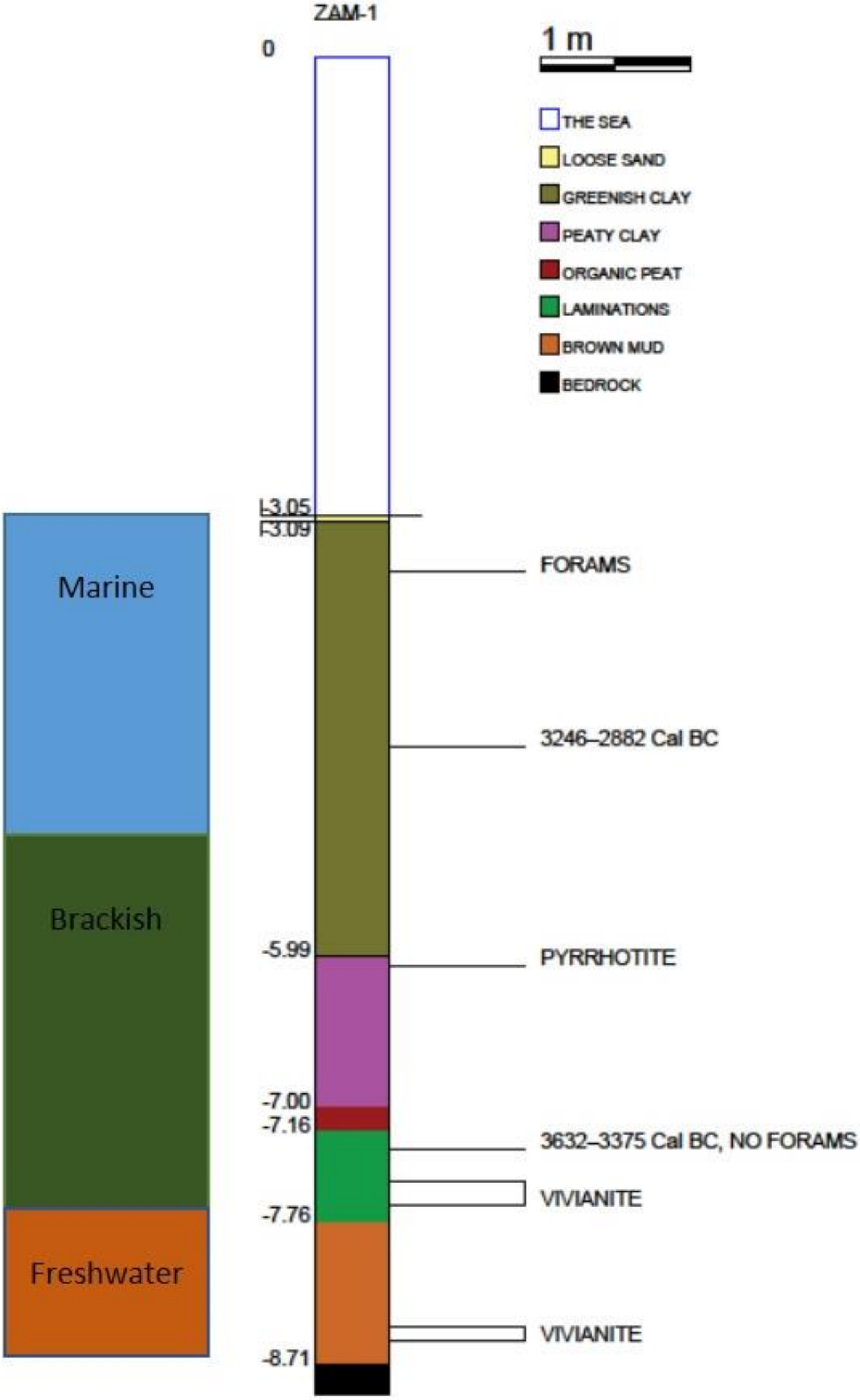


Figure 198 The historical ecology of Zambratija Bay.

Archaeology

As seen on **Figure 199**, core ZAM-7 provides valuable information about the cultural horisons of the seabed stratigraphy in relation to environmental and sea-level changes. Similar to ZAM-1, the core starts with marine sediments which are characterised by the occurrence of bluish grey clay carbonate sediments containing marine shells and foraminifera. There are no cultural remains in this segment of the core.

A low density of microceramics starts around the time when the marine sediments changes to a peaty clay, which also correspondes to higher magnetic signal between 70 and 90 bgl. A similar change was seen in ZAM-1 between 280 and 360 cm bgl with the occurrence of pyrrhotite, indicating marine transgression. The bottom of the peaty clay is marked by archaeological finds – a fragment of a ceramic rim with finger imprints, which was sitting on the top of 2 large rocks with traces of burning. A fragment of charcoal from the same position yielded a radiocarbon date range between 4041–3819 Cal BC. The rocks were covering a 15-cm layer of ashes with more ceramics. The magnetic signal showed a slight peak at the position where the ashes occurred. This position also marks the start of a high density of microceramics in the core. The ashy layers sharply change to an almost black, organic, dry peat, accompanied by one more slight peak in magnetism. Two more fragments of ceramics were found at the transition between the ash and peaty layers, where a large amount of wooden fragments were distinctively visible. The fibrous peat contnues downwards for around 35 cm, when the sediments change to fine laminations.

Two common reed leaves were found at this transition, one of which was radiocarbon dated to 4461–4354 Cal BC. The common reed is an aquatic plant which typically grows in wetlands. The magnetic signal showed a very high peak at this point of the core. In ZAM-1, the sedimentation beneath the organic peat contained traces of Vivianite, an element which occurrs in various waterlogged soils and aquatic environments. Vivianite also often appears in soils and sediments with anthropomorphic influences. After the laminations, the sediments gradually become more muddy and yellowish brown, and the foraminifera deposition, as well as the presence of microceramics, stops somewhere during this gradual transition. One more high magnetic peak appears at the exact moment when the foraminifera deposition dissapears from the core. The plant macrofossils from the very bottom of the core yielded a radiocarbon date range between 5669–5560 Cal BC. Although this is not the end of core ZAM-7, the data obtained from the upper segment was sufficient for an archaeological assessment (**Figure 200**).

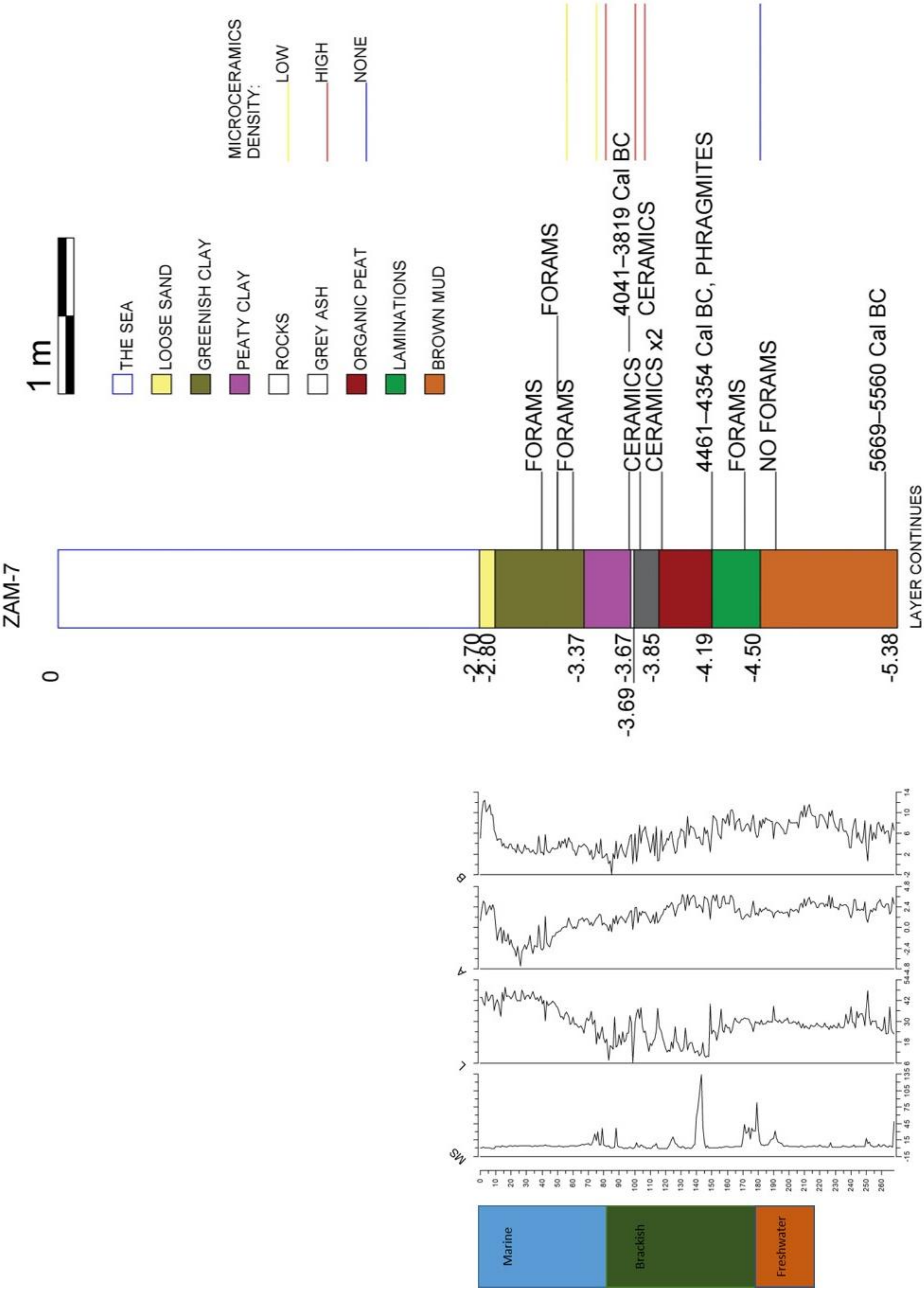


Figure 199 The paleoenvironment of ZAM-7.

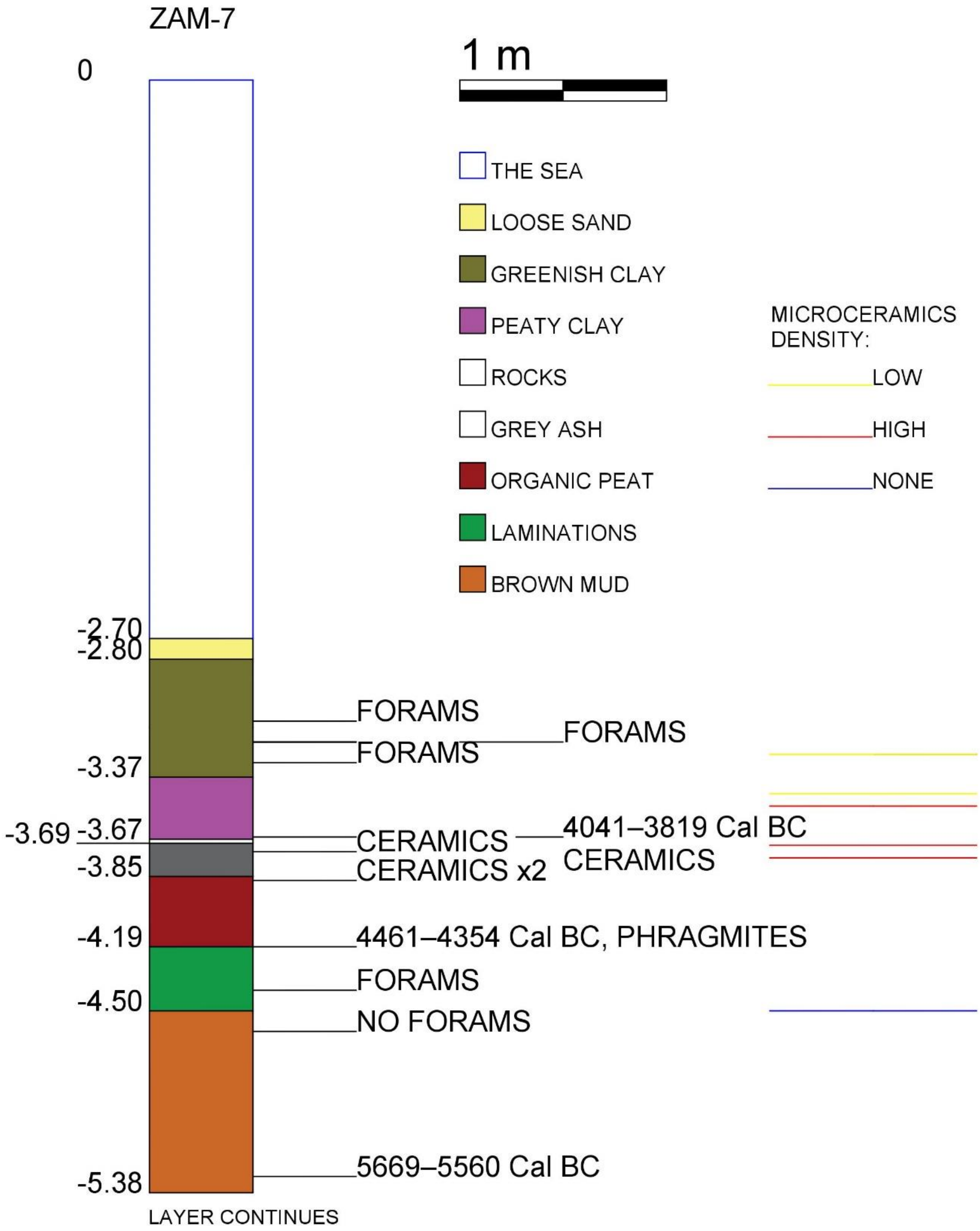


Figure 200 The archaeology of ZAM-7.

ZAM-7 provides stratified evidence of human occupation in the bay. According to the radiocarbon dates, ceramics, microceramics and the ash layer, the cultural horizon in ZAM-7 occurred between at least 4100 and 3800 Cal BC. This hypothesis can be further developed by comparing data from ZAM-1 and ZAM-7 (**Figure 201**), as well as the preliminary radiocarbon date from 2011 and the radiocarbon dated dendrochronological sequence. This comparative study will address the resilience of the Zambratija population to environmental and sea-level changes, therefore providing an answer to the second research question (*What affect did the environmental changes have on the people living at the prehistoric pile-dwelling in Zambratija Bay and on the taphonomy and preservation of the archaeological site left behind?*).

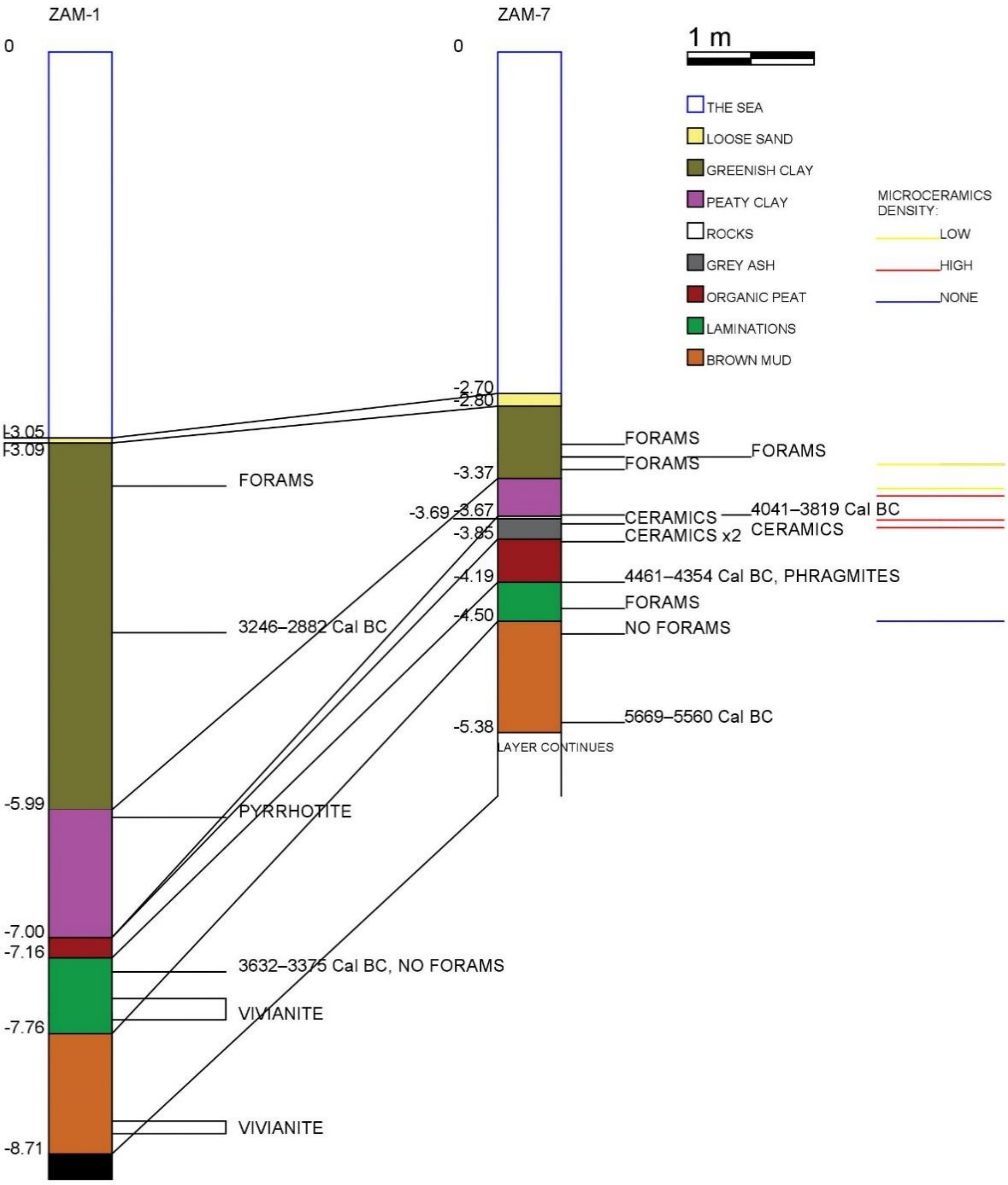


Figure 201 Correlating ZAM-1 and ZAM-7. A working study.

Comparative vertical stratigraphy

Although of varying in length and taken from two different positions in the karstic sinkhole (**Figure 202**), cores ZAM-1 and ZAM-7 showed similarities in their vertical sediment deposition. They have also been assessed from different perspectives – ZAM-1 from a mostly environmental viewpoint, and ZAM-7 from a mostly archaeological viewpoint. Both cores, however, showed that a strictly environmental or a strictly archaeological assessment often include certain aspects of the other. This can be seen in the occurrence and interpretations of Vivianite in the lower segments of ZAM-1, or in the correlation of high magnetic susceptibility peaks in ZAM-7 with the occurrence of ash, indicating a human intervention to the sediments. When looked at side-by-side in the sub-bottom profile 15032017120901, ZAM-1 and ZAM-7 can be analysed as one versatile dataset (**Figure 203**), which will be discussed further in text.

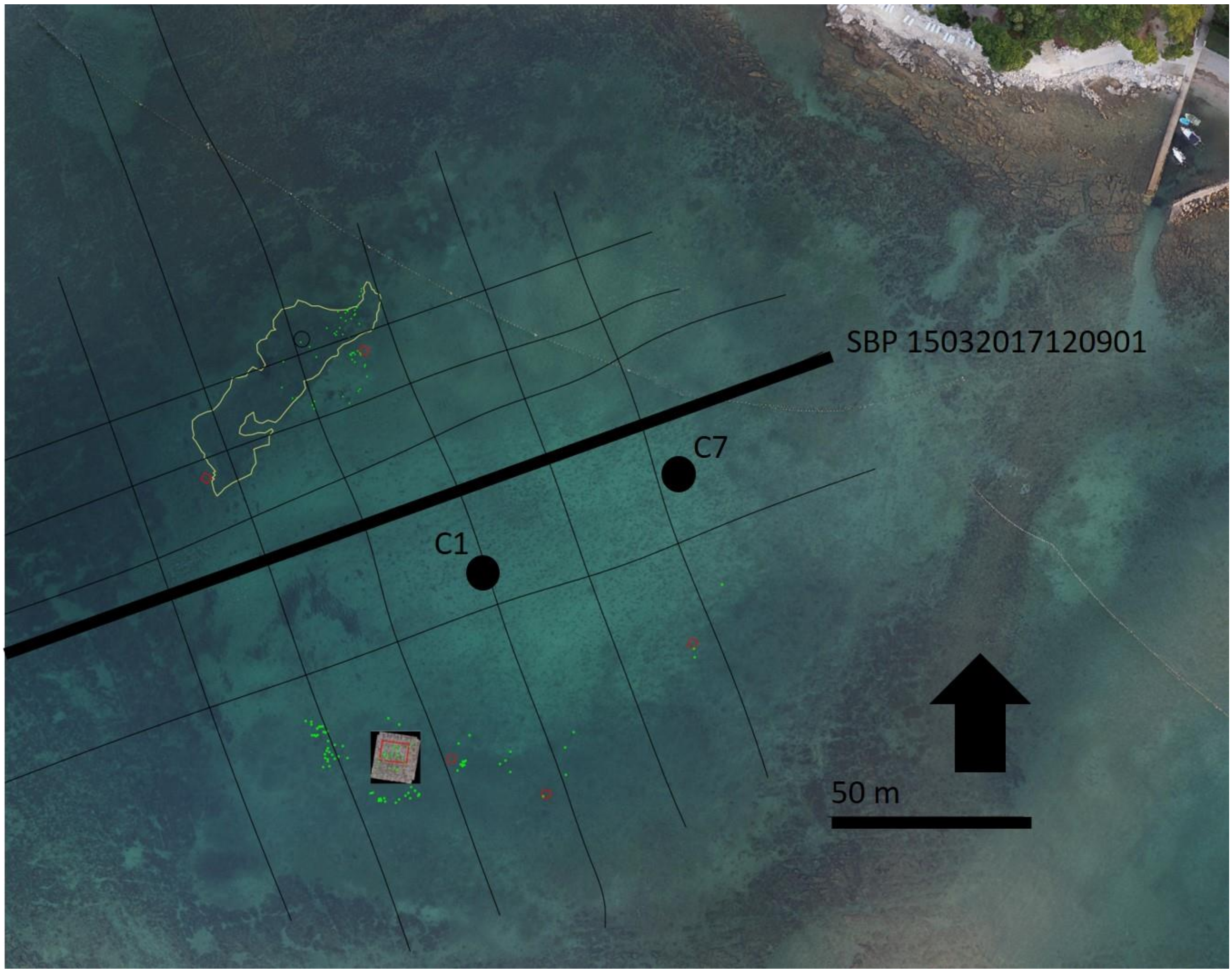


Figure 202 Aerial view of cores ZAM-1 (C1) and ZAM-7 (C7) in relation to sub-bottom profile 15032017120901.

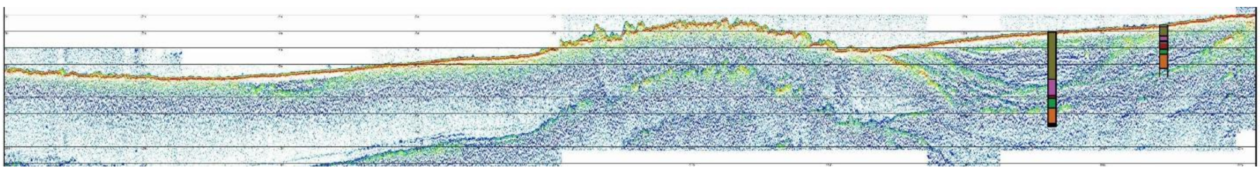


Figure 203 Sub-bottom profile section 15032017120901 and the position of ZAM-1 and ZAM-7 in the karstic sinkhole. Detailed images provided further in text.

As seen in **Figure 204**, ZAM-1 and ZAM-7 also served for ground-truthing of the seismic profiles. According to the deposition of sediments in the centre and on the ridges of the sinkhole, the mentioned possibility of erosion was confirmed (**Figure 205**).

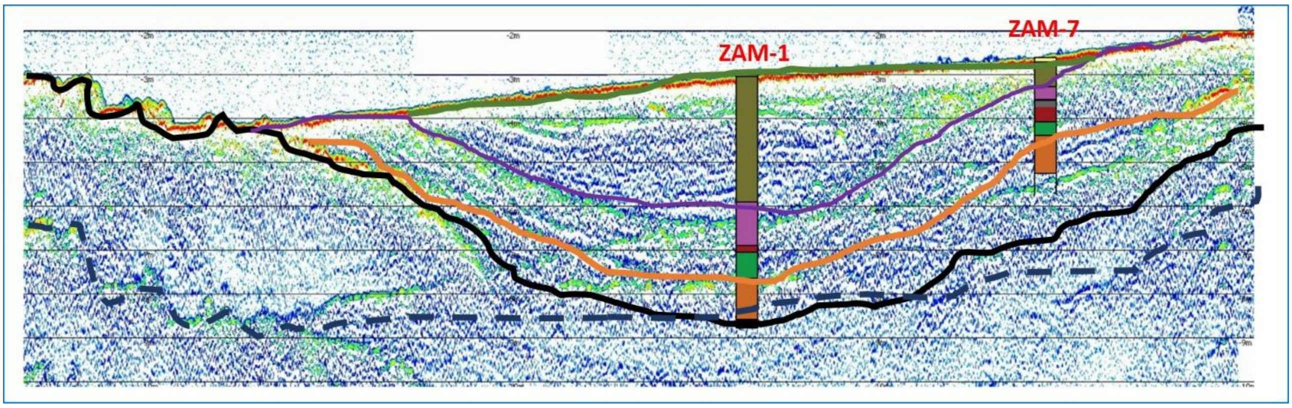


Figure 204 Ground truthing of sub-bottom profile 15032017120901 depicting the accumulation of marine sediments in the centre of the karstic sinkhole.

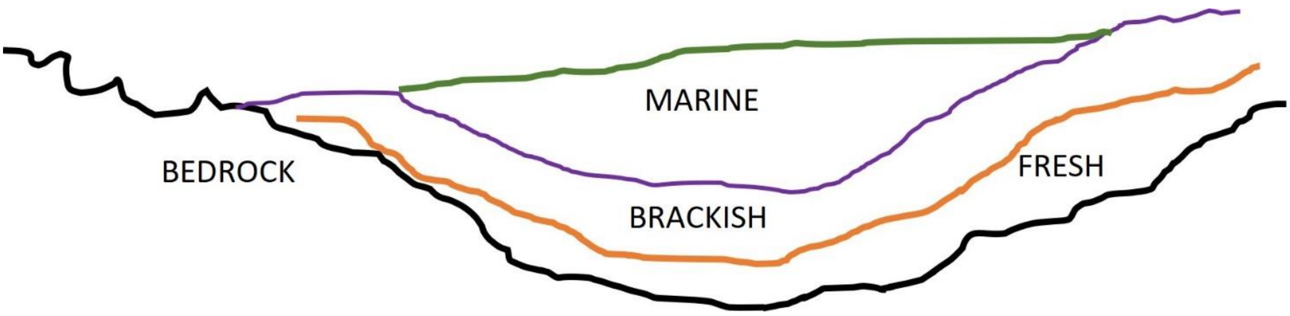


Figure 205 Outlines of the environmental sediments interpreted according to ZAM-1 and ZAM-7 layered over sub-bottom profile 15032017120901.

The marine deposits are gravitating towards the centre of the sinkhole, whereas the brackish and freshwater sediments are following the outlines of the bedrock. This situation might explain the difficulties faced with ZAM-2, as well as other irregularities such as the occurrence of wooden piles around the edges of the sinkhole and the peat platform staying uncovered by marine deposits for thousands of years. According to this data, the outlines of the sinkhole and the visible sediments on the seabed might look like **Figure 206**.

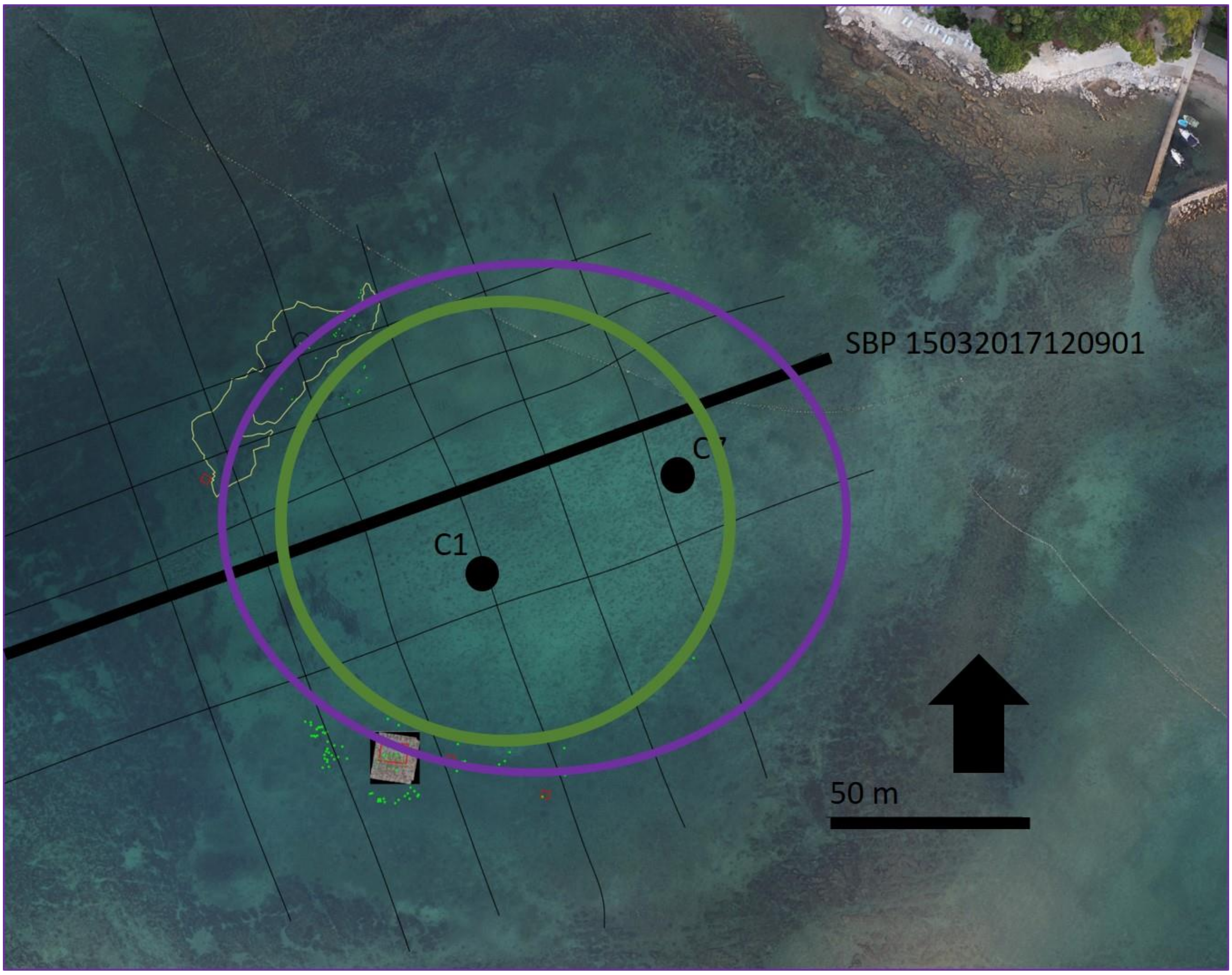


Figure 206 The estimated outlines of the spread of marine (green) and brackish (purple) deposits, according to ZAM-1 and ZAM-7 stratigraphy. The peat platform staying uncovered by marine deposits over time is therefore explained by karstic erosion.

By incorporating the stratigraphy of the cores with the 2008–2015 excavation units, it is possible to perform a site catchment assessment of the submerged archaeological site. After the comparative study of the cores, the stratigraphy of the units was re-evaluated. Due to the ground truthing of the sinkhole and performing an archaeological excavation on ZAM-7, the stratigraphic units originally named in the fieldwork documentation (Koncani Uhač and Čuka 2015), were renamed to 'Marine sand' and Brackish', corresponding with the distinction between marine and brackish sediments in the cores. Since the brackish sediments are chronologically older than the piles (see **Figure 204**), this action was further supported by the fact that the 'Greenish clay' was the layer containing all wooden piles found to date (**Figure 207**).

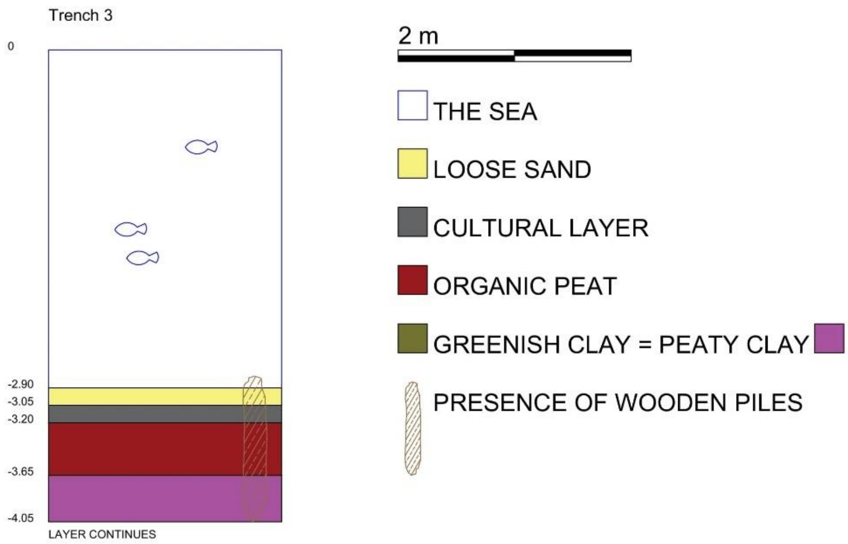


Figure 207 The change from naming 'Greenish clay' sediments in 2008 – 2015 units to 'Peaty clay' is demonstrated on Unit 3. See Figure 35 for reference.

Combined with the data visible in Figure 209, two stratigraphical sequences were made by following this hypothetical change (**Figure 208**). The first sequence connects ZAM-1 and ZAM-7 and the second one connects ZAM-7 and Unit 1 (**Figure 209**).

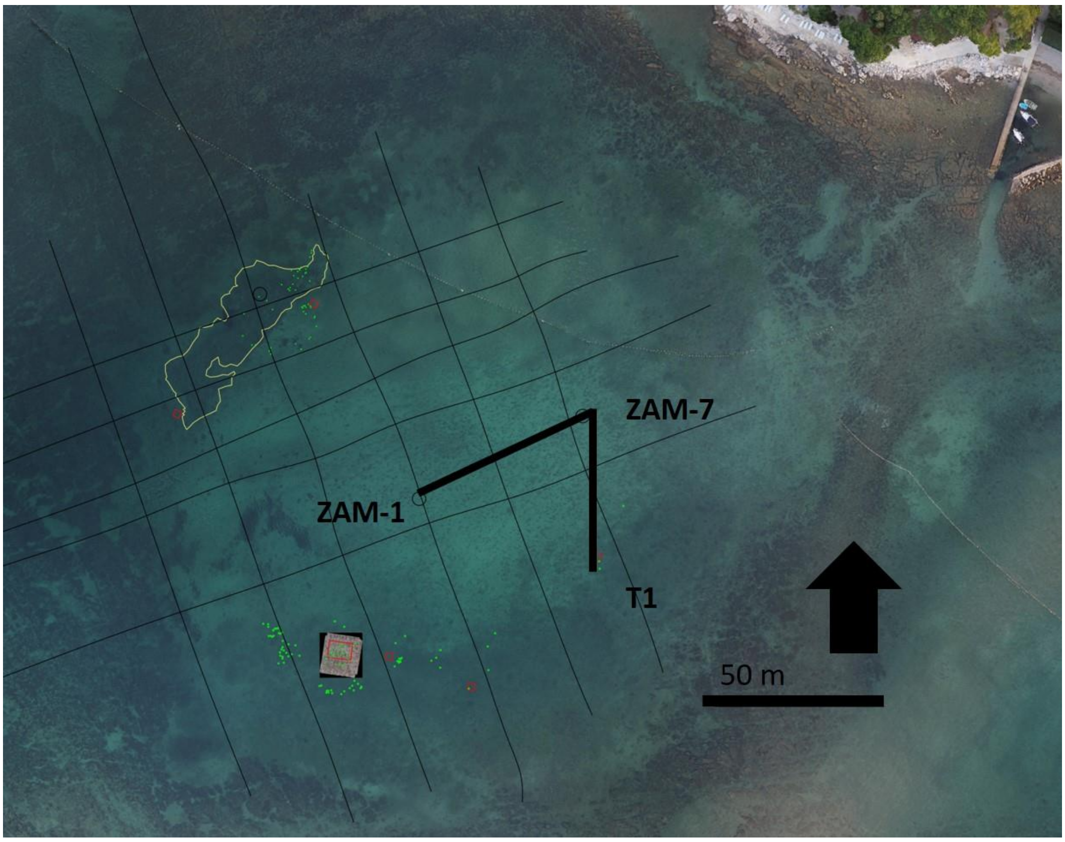


Figure 208 The lines connecting the stratigraphical sequences on figure 213.

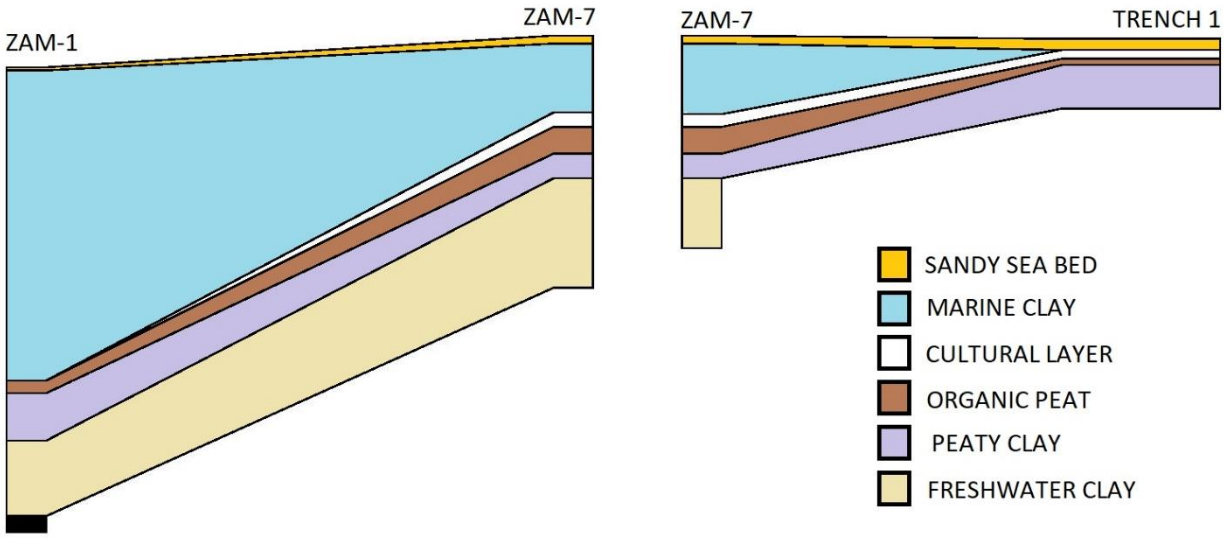


Figure 209 Site catchment stratigraphy according to ZAM-1, ZAM-7 and Unit 1.

Horizontal stratigraphy

As demonstrated on Figure 211, the reason for which the wooden piles and the peat platform are following the outline of the sinkhole is because the deposition of the marine sediments is sliding towards the centre. The 2017 trench was positioned on the southwestern edges of the sinkhole, with a very high density of protruding piles (**Figure 210**).

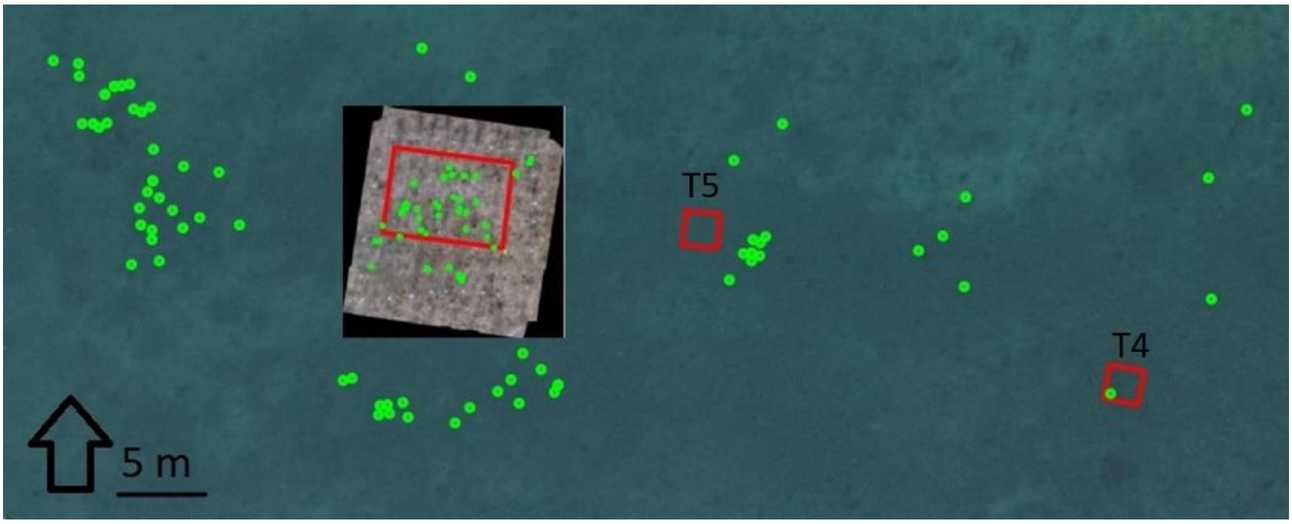


Figure 210 The investigation trench from 2017 in relation to the excavation units 4 and 5 as well as a large number of surrounding piles.

One of the most evident cultural features of prehistory are settlement patterns (Buršić-Matijašić 2012). The Neolithic and Copper Age sites in Istria are represented by caves and open-air sites (Čuka 2009; Jerbić Percan 2011; Komšo 2004, 2007, 2008), and the Bronze Age is represented with fortified megalithic structures on high positions overlooking the surrounding landscapes, known as hillforts (Buršić-Matijašić 1998, 2007; Hänsel et al. 2005). Although with some possible exceptions presented in Chapter 2, pile-dwellings were not found in the Adriatic coast. In the Alps however, lakeside pile-dwellings represented a building solution used throughout a 3000-year-old period, starting from the Late Neolithic. Three major occupational hiatuses occurred during the Alpine pile-dwelling tradition, in some cases confirmed to have been closely related to climate change (Magny 2004, 2015; Magny et al. 2009; Menotti 2004a:211).

Indirect cultural connections between Zambratija and the southern Alpine settlements are visible in the pile-dwelling building tradition unusual for the Northern Adriatic. Although with 100 marked piles, there were no official attempts for finding architectural patterns in Zambratija so far. This will be done here, by focusing mostly on the piles marked in and around the 2017 investigation trench (**Figure 211**).

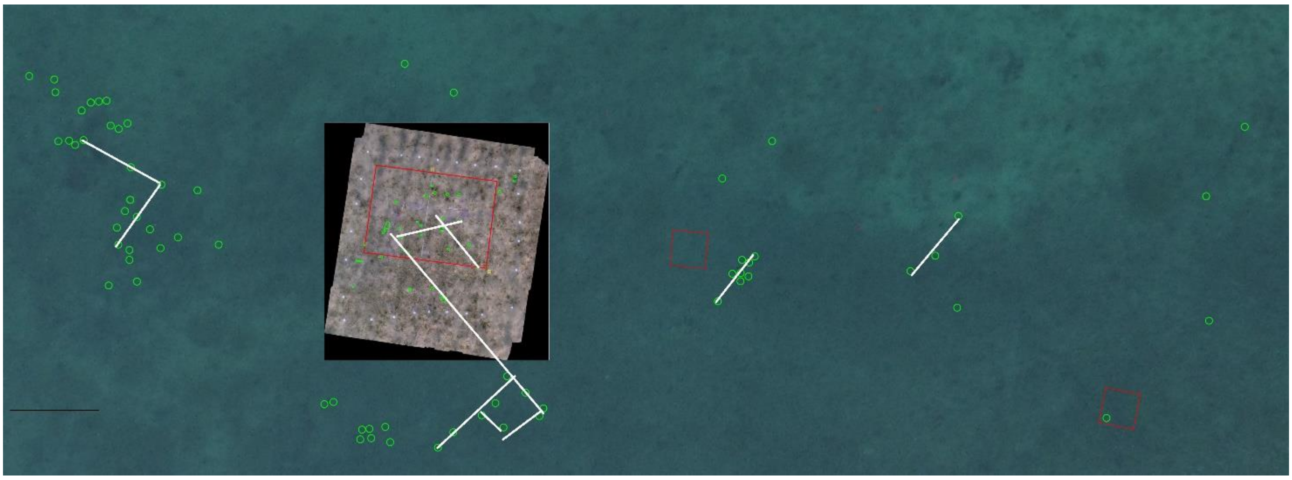


Figure 211 Possible patterns visible in the previously marked piles and the photogrammetry, marked with white lines.

The spatial analysis of the sediment leads answering the third research question (*With consideration for the site's chronology, spanning the Late Neolithic to the Bronze Age, what socio-economic developments are observable at the Zambratija Bay site relative to the broader Alpine Adriatic archaeological record(s)?*). As seen in **Figure 211**, several lines were recognised as possible architectural features. Since the number of marked piles is still growing, the potential for further investigations towards determining the settlement patterns in Zambratija can be expanded. The 62-year-old dendrochronological sequence derived from only 11 piles, support the site's research potential and significance as a valuable contributor towards building a Southern Alpine Oak dendrochronology.

The results of the systematic dendrochronological research of the Alpine pile-dwellings revealed an incredibly accurate chronology of Central European Prehistory on a calendrical timescale with a six month resolution (Köninger 2015:37), and stemmed the longest undisturbed tree-ring sequence in the world of the Northern Alpine oak, today dated between 8480 BC and 2009 AD (Čufar et al. 2015:92). The Alpine mountain massive represents a physical barrier, naturally dividing the lakes and their surrounding environment and consequently the prehistoric pile-dwellings to the Northern and Southern variations. Dendrochronology showed that life on the Northern lakes lasted from the Late Neolithic, at around 4200 Cal BC to the Iron Age around 630 Cal BC (Köninger 2015:37), with three occupational hiatuses between 3540–3410 Cal BC, 2400–2000 Cal BC and 1500–1200 Cal BC (Menotti 2004a:211, 2015b:24). Due to different biological markers to those in the Northern Alpine oak tree-rings, the dendrochronology of the Southern pile-dwellings is still under construction. However, wiggle-matching dating methods (Billamboz 2004:125; Billamboz and Martinelli 2015:95) and teleconnection (Čufar et al. 2015:92), which use radiocarbon dated floating southern oak tree-ring sequences and align them with the northern master sequence, showed a shorter pile-dwelling tradition in the south, lasting from around the Late Neolithic to the Early Bronze Age (Marzatico 2004:93; Menotti 2015b:24; Velušček 2006a:63), with a hiatus found in Slovenian dendrochronology between around 3300 and 3160 Cal BC (Čufar et al. 2010) (**Figure 212**).

The date from Zambratija indicates that the settlement is one of the earliest examples of a prehistoric pile-dwelling south of the Alps, with an open possibility of it being a maritime outpost of a traditionally lacustrine settlement building practice. The nearest contemporary pile-dwellings are in IItaly (Marzatico 2004; Pini 2004; Visentini 2001) and Slovenia (Velušček 2006a, 2006b), showing evidence of flood risk and other climate variations which have had an impact on occupational discontinuity (Menotti 2009). The mentioned hiatus seen in Slovenian Oak dendrochronology coincides with the calculated marine transgression timeframe in Zambratija. The abandonment of the settlement in Zambratija is therefore supported with not only environmental evidence, but also comparative research. In regards to showing signs of interaction between the Alpine pile-dwellings and Zambratija on site, there is not enough reliable evidence at this stage. Indications of trade with the Adriatic do exist in the Ljubljansko Barje Hočevarica pile-dwelling, where a ray bone was found in the archaeological layers (Velušček 2004:78). There are also similarities in the ceramics with the occurrence of brushed surface ceramics with finger impressions, and spindle whorls at Restnikov Prekop (Velušček 2006b:169).

Since the wooden piles showed radiocarbon date ranges similar to Nakovana pottery, the occurrence of architecture from the same timeframe would be a reliable indicator of Alpine cultural influences. The stratified cultural layer in Unit 5 contained Nakovana pottery, brushed surface ceramic fragments, a perforated funnel and two spindle whorls. The typology of the finds indicates a wide timeframe between the Neolithic and the Bronze Age. The unit also contained knapped chert tools and was surrounded by wooden piles. The archaeological layer was placed immediately over a layer of peat and organic remains, similar to the stratigraphical situation in ZAM-7, and the piles were pushed into the clay sediments under the peat, described by the archaeologists as greenish clay. This clay is most likely the decayed peat found in the layers following the organic peat in the cores. As seen on **Figure 211**, layers containing material culture in units 1, 3 and 5 as well as in core ZAM-7 were positioned between the organic peat at the bottom, and marine sediments towards the seabed surface.

Site	Lab reference	Uncalibrated 14C age	Calibrated age	Context
Monkodonja hillfort	KIA-15283	5778±31 BP	4768–4539 Cal BC	Earliest occupation
Palù di Livenza pile-dwelling	GrN-22836	5560±80 BP	4490–4330 Cal BC	Earliest occupation
Jačmica cave	OxA-18183	5325±29 BP	4252–4044 Cal BC	Nakovana layer
Zambratija	SUERC-77772	5310±32 BP	4240–4044 Cal BC	Dendro sample #18
Zambratija	Beta-296187	5260±30 BP	4230–3980 Cal BC	Unit 1, Layer 2
Palù di Livenza pile-dwelling	GrN-25996	5240±110 BP	4230–3950 Cal BC	Pile-dwelling occupation
Novačka cave	OxA-18184	5252±29 BP	4229–3978 Cal BC	Nakovana layer
Zambratija	SUERC-81648	5157±28 BP	4041–3819 Cal BC	ZAM-7 core, 95–96 cm
Zambratija	SUERC-77773	5129±34 BP	4034–3801 Cal BC	Dendro sample #29
Ljubljansko barje pile-dwellings	Dendrochronology	/	3300–3160 Cal BC	Occupational hiatus
Zambratija	Beta-296186	2860±30	1120–930 Cal BC	Laced boat
Monkodonja hillfort	KIA-28974	2820±26 BP	1040–901 Cal BC	Peak occupation

Figure 212 New radiocarbon dates from cultural contexts in Zambratija and the published preliminary Zambratija date (Koncani Uhač and Čuka 2015) as well as the radiocarbon date of the Bronze Age laced boat (Koncani Uhač and Uhač 2013) (in red). The dates are displayed in a chronological comparative order, starting with the earliest occupation of the Monkodonja hillfort and the Palù di Livenza pile-dwelling in Italy (Visentini 2001). Nakovana ceramics contexts on the Istrian Peninsula (Forenbaher et al. 2013) are also included, as well as the start of the occupational hiatus in Ljubljansko Barje (Čufar et al. 2010). All mentioned sites presented on a map in Figure 215.

The settlement in Zambratija coincides with the timespans of Palù di Livenza/Bannia-Palazzine in Italy (Visentini 2001). The Square-mouthed pottery found on the sites (Visentini 2001:199) is a style that occurs in the Italian Liguria and Veneto Regions in Italy, where it appears in the Late Neolithic and at the beginning of the Copper Age. It is believed that the style was connected with the Adriatic-Balkans territory in the Late

Neolithic, in the last phase of the Danilo culture and the first phase of the Hvar culture. This link was observed not only based on pottery decorations, but also due to the appearance of female terracotta figurines and pintaderas (Aspes 1984:345). The only two fragments of the Square-mouthed pottery in Istria were found in the Jačmica cave (Jerbić Percan 2011:18), which is one of the rare sites in Istria with radiocarbon dated layers containing Nakovana style pottery (Forenbaher et al. 2013; Jerbić Percan 2011).

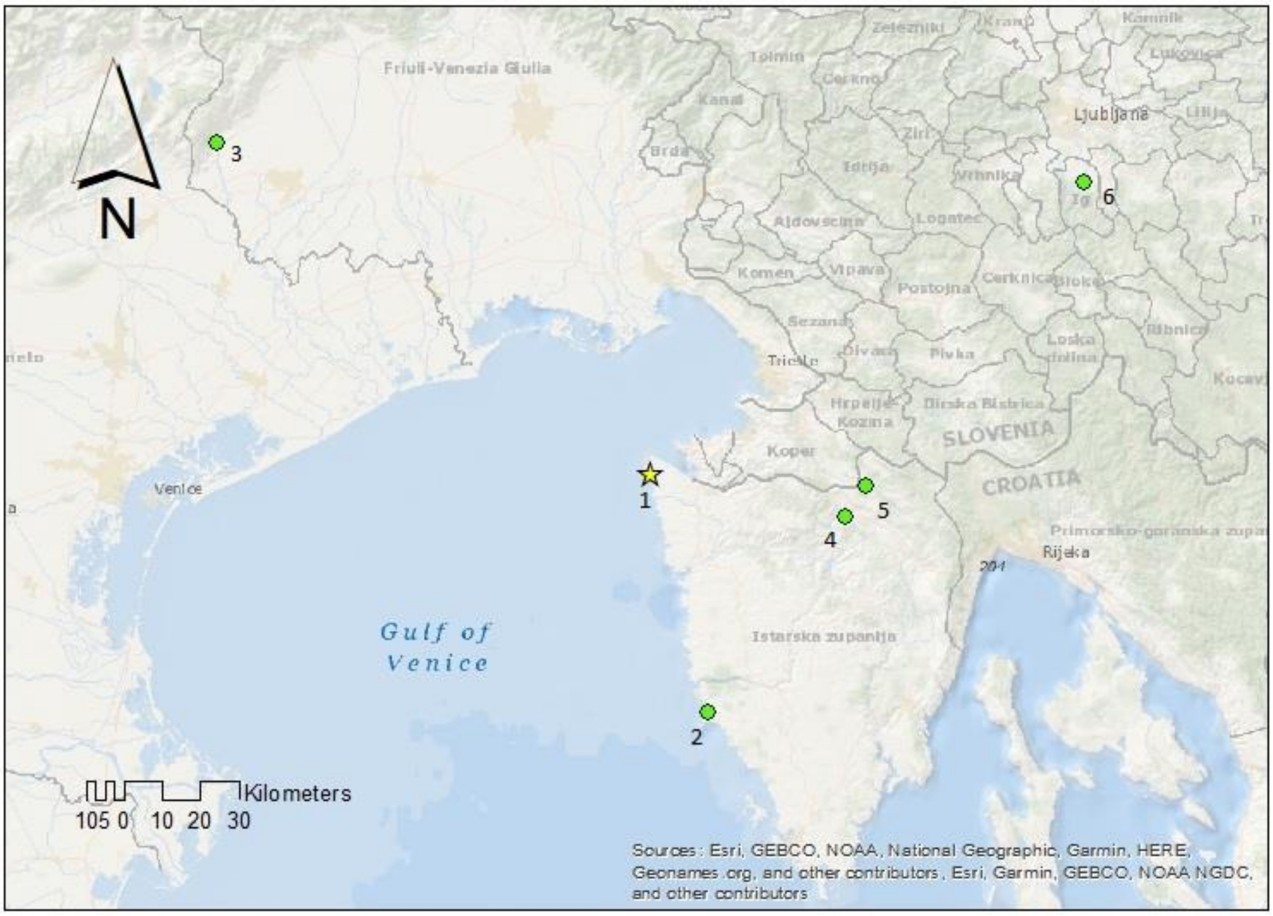


Figure 213 Sites mentioned on figure 214: Zambratija (1), Monkodonja hillfort (2), Palù di Livenza pile-dwelling (3), Jačmica cave (4), Novačka cave (5), Ljubljansko barje pile-dwellings (6).

Although scarce, but reliable, radiocarbon dates from Late Neolithic/Early Copper Age Nakovana contexts on the Eastern Adriatic all show a consistency of setting these pottery sherds into the timeframe between 4000–3500 BC (Forenbaher et al. 2013:592). Other than Nakovana style, the other found pottery shows a diverse collection of shapes and decorations attributed to wider timeframes, such as brushed surface ceramics (Čuka 2009; Jerbić Percan 2011; Vitasović 1999). The new radiocarbon dates align with the preliminary Zambratija date, as well as with known Nakovana-style from stratified contexts in the Eastern Adriatic, and some of the earliest dates from the prehistoric pile-dwellings south of the Alps (see **Figure 212**).

Archaeological evidence suggests that Zambratija might have been occupied during the Bronze Age. One date range derived from ZAM-2 2026–1781 Cal BC can be taken into consideration for connecting the site to Early Bronze Age radiocarbon dates from the Monkodonja hillfort, where the building of the earliest megalithic walls was set to between 1777 and 1745 Cal BC (Hänsel et al. 2005:16). The radiocarbon date derived from the Zambratija boat wood yielded a radiocarbon range between 1120–930 Cal BC (Boetto et al. 2015; Koncani Uhač et al. 2017a; Koncani Uhač and Uhač 2012:534), which fits well into the peak occupational timeframe in Monkodonja between 1040–901 Cal BC (Hänsel et al. 2005:22).

The remains of a laced boat and the one fragment of a Bronze Age handle are not from stratigraphic contexts, but they do at least indicate activity at the time. Also, the mentioned radiocarbon date from ZAM-2 derived from a stratigraphically unclear context, from shells and snail. The possibility of marine origin of these samples would indicate that the deposition in the sediment occurred after the settlement was already abandoned due to sea-level rise. Whether that activity was caused by erosion or by human intervention during the Bronze Age can only be revealed with more in-depth systematic investigation.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

The archaeological units, sediment cores and seabed finds in Zambratija Bay show that the Holocene climate change events had a significant impact to the environment and local population. The eroded sediments preserved in the submerged karstic sinkhole provide an ecological history of more than 6000 years, showing evidence of the existence of three different environments – freshwater, brackish and marine. The brackish environment was directly influenced by human populations, visible in the form of settlement remains. The settlement was in use for at least 62 years according to the dendrochronology, but ceramics from the core sediments suggests a much longer cultural continuity. The abandonment of the settlement is closely related to the marine transgression, indicating a human response to climate change, significant to current scientific debates. Although not yet analysed, the remaining cores ZAM-3, ZAM-5, ZAM-6 and ZAM-8 from Zambratija Bay represent repositories of these climatic events, which would not only help understand the adaptive pathways of past environments and human populations to climate change, but also to the modern Zambratija population.

The discussion in Chapter 8 addressed the research questions by performing a comparative analysis of all available data from the submerged prehistoric pile-dwelling in Zambratija Bay. As seen, sea-level and environmental change coincide with the site's occupation. Although the data from Zambratija is in line with the large sea-level change Northern Adriatic database (Vacchi et al. 2016), the current knowledge could be further expanded with valuable information and an in-depth statistical analysis of depositional sea-level markers, such as ostracods and foraminifera transfer functions. Other biological markers, such as marine shell and snail taxonomy would further support these studies, as well as environmental studies such as pollen analysis, microfauna and plant fossil analysis. With great potential for extensive dendrochronological investigation, the site could also contribute to the building of the Southern Alpine Oak database, and possibly changing the knowledge of the World Heritage listed prehistoric pile-dwellings around the Alps.

The Zambratija sea-level curve

Figure 214 represents a synthesis of all archaeological, environmental and radiocarbon data from Zambratija Bay. It is organised as a timeline starting at 6000 BC with information on the environmental changes and chronology depicted as two ribbons on the bottom of the image. The lower, colourful ribbon represents environmental change and the upper ribbon shows all radiocarbon date ranges from ZAM-1, ZAM-2 and ZAM-7, shown as black rectangles. The rectangles are represented in scale, meaning that the margins are positioned on their exact date range years on the timeline. The rectangles depicted above the radiocarbon ribbon represent the date ranges of wooden piles, also in scale.

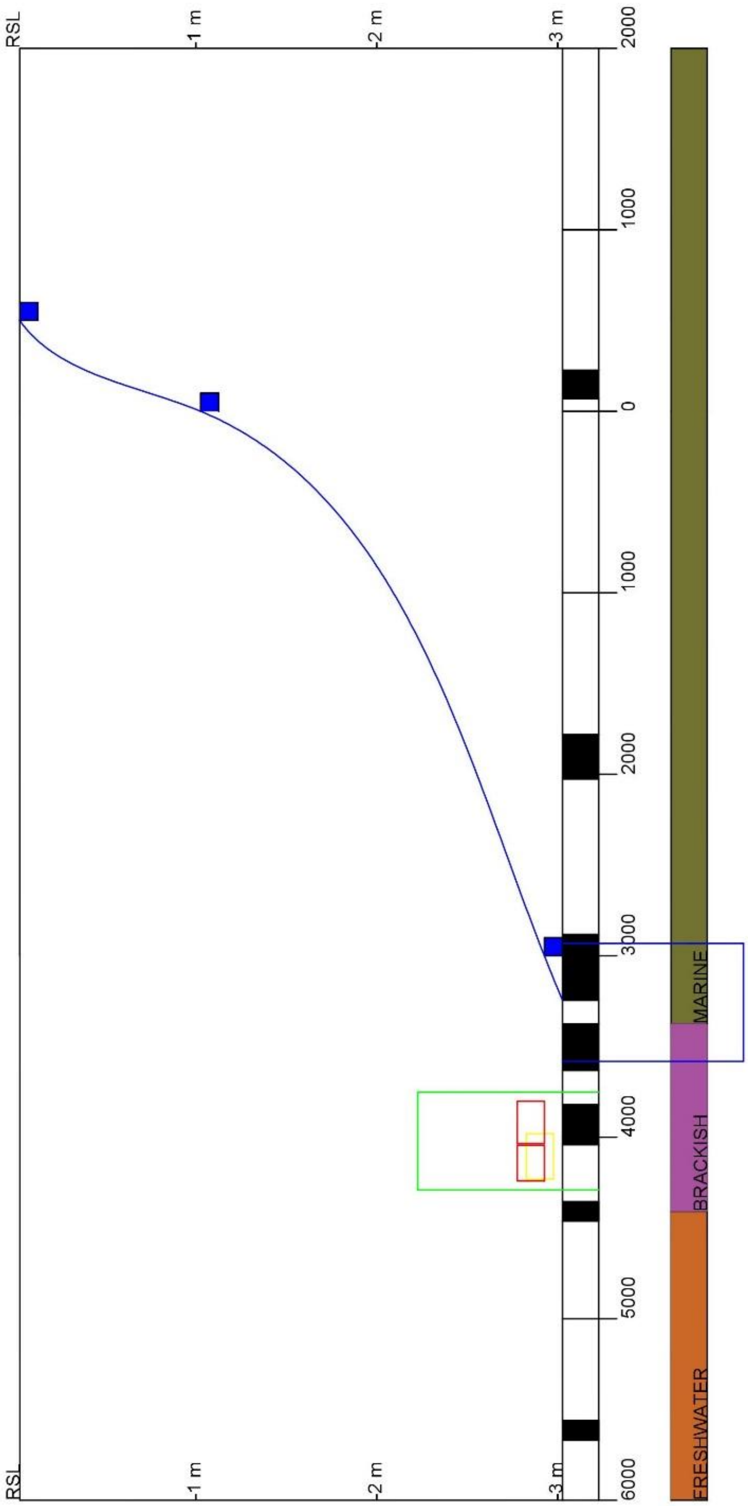


Figure 214 Environmental, cultural and sea-level changes in Zambratija Bay.

According to the data from this thesis, the environmental, sea-level and cultural reconstruction in Zambratija Bay goes as follows. Freshwater environments lay on top of the bedrock with the earliest radiocarbon date range between 5669–5560 Cal BC from ZAM-7. The reed leaf from the same core was radiocarbon dated to 4461–4354 Cal BC, indicating the change of environment to brackish further up in the core stratigraphy. Traces of Vivianite were found at the bottom of ZAM-1, where they most likely indicate anaerobic conditions, but also at the top of the freshwater layers of the same core, close to the laminations at the start of a brackish environment. Here, the Vivianite registered in ZAM-1 might be an indicator of human interventions in or around the environment.

The settlement, marked with a green rectangle facing upwards, was built soon after wetland formation, with the earliest date from a wooden pile at 4240–4044 Cal BC. The tree-rings from this pile correlated to 10 more wooden piles from Zambratija Bay, forming a 62-year-old dendrochronological sequence, and the piles show possible building patterns. One more of those 10 piles was also radiocarbon dated, yielding an age range between 4034–3801 Cal BC. The two piles which are a part of the dendrochronological sequence are marked with red rectangles. One more rectangle in yellow represents the radiocarbon age of the initial radiocarbon date from Zambratija Bay at 4230–3980 Cal BC. The presence of wooden piles in a brackish, wetland environment and the radiocarbon dates derived from the piles indicate that this is a prehistoric pile-dwelling similar to those found around the Alpine lakes.

The ashy layer from ZAM-7 containing ceramic fragments showed a similar date to the piles at 4041–3819 Cal BC. The physical characteristics of this layer correlate to the cultural layers with Nakovana ceramics from Unit 1 and 5. Nakovana ceramics are an Early Copper Age cultural phenomenon which is documented throughout the Eastern Adriatic Coast. The layers around the ash contain significant amounts of microceramics, indicating a cultural presence until the sediments start changing colour and consistency to greenish clay, and a strong magnetic signal indicates marine transgression.

Fibrous peat from core ZAM-1 shows that the environment was still brackish in Zambratija at 3632–3375 Cal BC. Marine transgression, marked with a blue rectangle facing downwards, occurred sometime after the peat. The micoceramic deposits around these positions are present, but not as prevalent as during peak occupation. The transgression was recognised as a strong magnetic signal accompanied by the occurrence of pyrrhotite. Foraminifera, marine shells and marine clay prevail in ZAM-1 at 3246–2882 Cal BC, which is a trend that continues in ZAM-2. Although ZAM-2 was not the most reliable core, the dates did show Holocene deposits at 2026–1781 Cal BC and 70–227 Cal AD. The sea-level curve was constructed based on data from the cores, the Vacchi et al. (2016) study of sea-level markers in Northeastern Adriatic, as well as the data from Savudrija Bay (Koncani Uhač and Auriemma 2015). These markers are depicted on the image as blue squares.

Recommendations

The results presented in this thesis opened a set of new research questions which imply that the investigations in Zambratija Bay should be focused on creating a database and preferably establishing an on-site interdisciplinary laboratory. At this stage there is no evidence to support that the earliest settlement in Zambratija that was built right after wetland formation was Late Neolithic or Copper Age. The earliest radiocarbon dates from wooden piles and sediment core layers as well as the typological characteristics of the stratified pottery fragments do imply Copper Age. This is not a statistically sufficient sample size, and these assumptions should be confirmed with a larger trench. A suitable position for this trench would preferably in the area where the large quantities of piles are close to the centre of the sinkhole, such as that presented in Figure 208 and 209. Furthermore, the interdisciplinary research should also focus on expanding the current 62-year-old dendrochronological sequence, a complete paleoenvironmental reconstruction with regards to pollen, and zooarchaeological study. The main archaeological focus should remain on the material culture, especially with regards to ceramics and lithics, and architectural patterns and their position within the paleolandscape.

The people that lived in the Zambratija Bay pile-dwelling were using Nakovana ceramics, which is a style originating from the Southern Adriatic. It is possible that life in the settlement continued after the most recent date, however there are no radiocarbon dates from stratigraphic contexts to confirm this assumption. The assumption was made based on the material culture found in archaeological units during the initial campaigns and due to the fact that a Bronze Age boat lies in the near vicinity of the settlement, with radiocarbon dates and with the new data obtained from microceramic deposits in shallower sediments. The microceramics can, however, be explained with possible erosion. Cultural continuity can be followed in the bay by looking at the submerged road assigned to the Roman Antiquity, which can be confirmed with the presence of a Roman Villa rustica in the Bay, which was the initiating reason for the discovery of all three underwater sites in Zambratija Bay. The original reason for the prospection of the bay was because the existing embankment was scheduled to be elongated due to not being efficient in protecting the Zambratija port from increasingly stronger climatic events in the few years prior. This makes Zambratija Bay a case study with a 6000-year-old climate change chronology.

Local involvement and future prospects

The archaeological investigations in Zambratija Bay have had a positive impact on the local population and opened a discussion about modern climate change and environmental and cultural protection. Driven by the 2008 archaeological discoveries in the bay, a group of local fishermen and enthusiasts that called themselves the Pinna Nobilis[22] initiative, named after the protected mollusc species that can be seen in the bay as well as in the photogrammetry, took action in 2017 and presented the Special Management Zone in Zambratija Bay project (Iveša et al. 2017). The project is focused around the protection and preservation of the environmental and archaeological features in the bay, which also includes the submerged pile-dwelling (**Figure 215**).

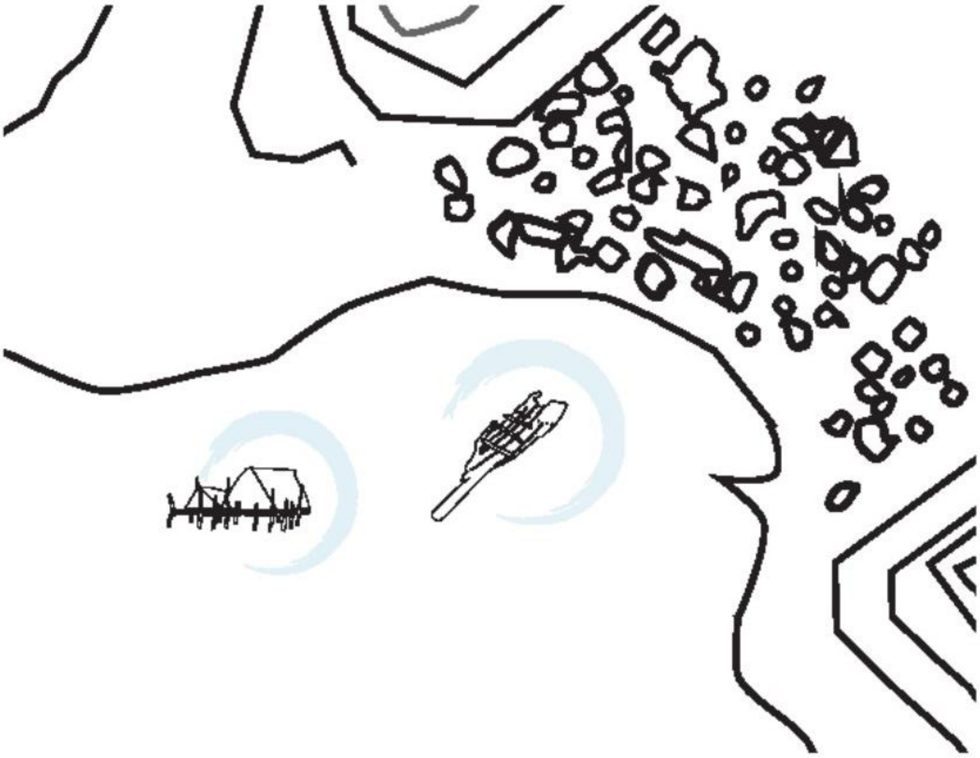


Figure 215 Image of the archaeological sites in Zambratija Bay presented in the Special Management Project brochure (Iveša et al. 2017).

With the IPCC report sea-level change models show that current climate and sea-level changes are affecting global coastal landscapes and populations at a record rate, similar to those recoded at the end of the LGM and the beginning of the Holocene (Van de Noort 2013:11-14). Zambratija Bay is unfortunately a part of the endangered modern shoreline, which includes the unique archaeological and environmental features in the

[22] https://flag-pinnanobilis.hr/

bay. The Pinna Nobilis initiative serves as a positive example how archaeological evidence served as a critical point for the local community to take action and raise awareness on current climate change issues.

The settlement in Zambratija is not only significant for being submerged 3 m under water, but also for being a prehistoric pile-dwelling. This settlement pattern has not been recognised in the Eastern Adriatic coast until recently, when the investigations in the Zadar archipelago show that the pile-dwelling tradition might have been present further south. With this prehistoric cultural influence from the Alps, where these archaeological sites are under world heritage protection, Zambratija shows potential for changing our knowledge on European and world prehistory. This knowledge was hidden so far due to environmental circumstances that preserved the paleolandscape and archaeology of the bay, where today they are placed 3 metres below RSL. The radiocarbon dates from the wooden piles imply one of the earliest known examples of the pile-dwelling phenomenon in the region. The origin of the Alpine pile-dwellings has been traced to the so-called 'pile-dwelling wheat', originating in the Western Mediterranean Early Neolithic sites in Spain and Italy. Therefore, in order to provide evidence of direct connections to those early sites, future research should be focused on a more in-depth analysis of plant micro and macrofossils. This thesis suggests a small-scale combination research strategy called archaeology of the core, where the laboratory analysis of discrete samples from a core can serve as a baseline for performing a small-scale archaeological excavation. The archaeology of the core would therefore be able to simultaniously connect the potential findings of the pile-dwelling wheat to cultural layers.

Putting in perspective that the original data presented in this thesis was extracted from three sediment cores, 11 samples of wood and a photogrammetry model produced with a GoPro camera, it becomes clear that the red areas on **Figure 216** should represent a global case study from which evidence of past life and adaptations to climate changes, can be obtained with minimal resources and maximum efficiency.

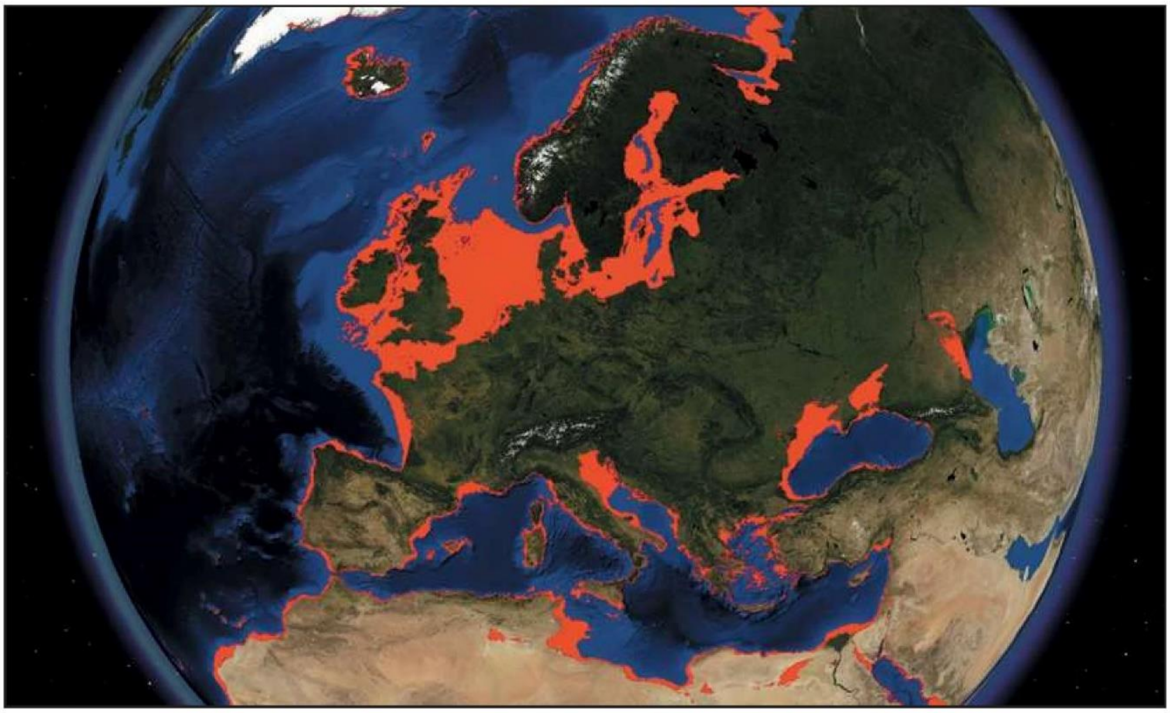
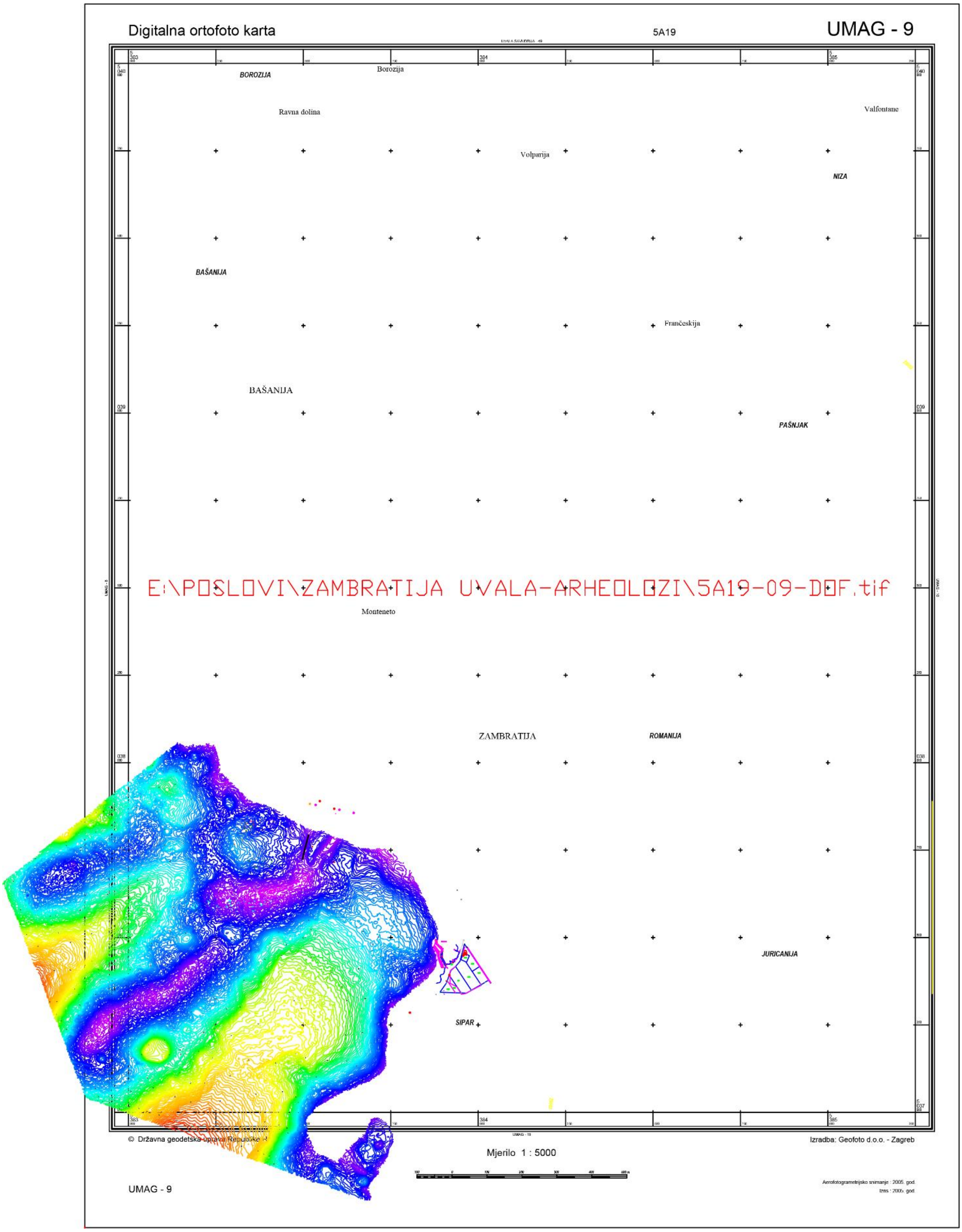


Figure 216 Europe at the LGM. The red shows land that would have been exposed at the time (Bailey 2011:315).

APPENDICES

Appendix I Georeferenced site survey map which includes the bathymetry and the positions of the environmental and archaeological features of the bay. Raw data used with permission by AMI.



Appendix II Permit to perform the investigations in Zambratija Bay.

REPUBLIKA HRVATSKA
MINISTARSTVO KULTURE
UPRAVA ZA ZAŠTITU KULTURNE BAŠTINE
KONZERVATORSKI ODJEL U PULI
Pula, Ul. Grada Graza 2
Tel: 385-52-375-660;
Poreč, Sv. Maura 16
Tel: 385-52-451-711;
Klasa: UP/I 612-08/17-08/0095
URBROJ: 532-04-02-10/12-17-06
Pula, 28. travnja 2017.

Ministarstvo kulture, Konzervatorski odjel u Puli, na temelju članka 47. i 49. u svezi s člankom 6. stavkom 1. točka 9. Zakona o zaštiti i očuvanju kulturnih dobara (NN 69/99, 151/03, 157/03, 87/09, 88/10, 61/11, 25/12, 136/12, 157/13, 152/14, 98/15), članka 5. Pravilnika o arheološkim istraživanjima (NN 102/10), te članka 13. stavka 2. i 4. i članka 31. stavka 3. i 5. Pomorskog zakonika (NN 181/04, 76/07, 146/08, 61/11, 56/13 i 26/15), rješavajući zahtjeva Arheološkog muzeja Istre iz Pule, radi dobivanja odobrenja za podvodno arheološko istraživanje u uvali Zambratija (Grad Umag), a po pribavljenoj suglasnosti Ministarstva pomorstva, prometa i infrastrukture i Ministarstva obrane, donosi sljedeće

RJEŠENJE

1. Arheološkom muzeju Istre iz Pule odobrava se podvodno arheološko istraživanje u uvali Zambratija (Grad Umag).
2. Istraživanja iz točke 1. ovog rješenja izvodit će se od 01. svibnja do 30. lipnja 2017.
3. Stručna voditeljica istraživanja bit će Ida Koncani Uhač (OIB:38838417281) iz Arheološkog muzeja Istre.
4. Stručnu i tehničku ekipu tijekom istraživanja čine: Katarina Jerbić (OIB: 34371442336), dr.sc. Slobodan Miko (OIB 97038631583), Maja Čuka (OIB: 43073545092), Enrique Aragon Nuňez (AAD476957), Kurt Thomas Bennet (LK190759), Alba Ferreira Dominguez (ANR185538). U istraživanju će se koristiti plovila gumenjak tipa *quicksilver* dužine 4,3 m s vanbrodskim motorom (639 RK) te aluminijska radna sklopiva platforma (4x3 m) na pontonima. Troškovi obuhvaćeni ovim istraživanjem će se snositi iz stipendije Katarine Jerbić kojom doktorandica raspolaže u svrhu svog doktorskog istraživanja na Sveučilištu Flinders u Južnoj Australiji, a s kojom Arheološki muzej Istre ima sporazum o suradnji.
5. Arheološko istraživanje iz točke 1. ovog rješenja može se obaviti pod uvjetima:
   - da se osigura zaštita i konzervacija izvađenih predmeta te zaštita podmorskog arheološkog lokaliteta nakon završetka istraživanja,
   - da se izvađeni predmeti privremeno pohrane u Arheološkom muzeju Istre, do konačne odluke o mjestu pohrane nalaza koju donosi Ministarstvo kulture na prijedlog Hrvatskog vijeća za kulturna dobra i Hrvatskog muzejskog vijeća,
   - da stručni voditelj osigura uvjete sukladno člancima 12. i 13. citiranog Pravilnika,
   - da su osigurana potrebna materijalna sredstva i tehnički uvjeti za izvođenje radova,
   - da stručni voditelj o početku, prekidu, nastavljanju ili napuštanju radova obavijesti nadležnu lučku kapetaniju sukladno čl. 14. citiranog Pravilnika,

- da se zaštita na radu obavi sukladno sa zakonskim propisima i pravilima struke.

6. O danju početka i završetka istraživanja, kao i o svakoj promjeni vezanoj uz istraživanje iz točke 1. ovog Rješenja voditelj istraživanja dužan je obavijestiti Konzervatorski odjel u Puli.
7. Stručni voditelj istraživanja dužan je u roku od tri mjeseca od dana završetka radova podnijeti stručno izvješće o rezultatima istraživanja i to:
   - Konzervatorskom odjelu u Puli,
   - Upravi sigurnosti plovidbe Ministarstva pomorstva, prometa i infrastrukture,
   - Ministarstvu obrane.

   Skraćeno stručno izvješće o rezultatima istraživanja stručni je voditelj dužan dostaviti Odjelu za arheologiju Uprave za zaštitu kulturne baštine Ministarstva kulture u Zagrebu.

O b r a z l o ž e nj e

Arheološki muzej Istre iz Pule podnio je ovom tijelu zahtjev za dobivanje odobrenja za podvodno arheološko istraživanje u uvali Zambratija (Grad Umag).

Predmetno područje upisano je u Registar kulturnih dobara RH pod br. RRI 107 od 22.12. 1966.

Ovogodišnji ciljevi istraživanja će obuhvatiti uzimanje uzoraka za geoarheološke, sedimentološke i dendrokronološke analize na području potopljenog prapovijesnog naselja u svrhu rekonstrukcije paleookoliša. Istraživanja će se izvodit od 01. svibnja do 30. lipnja 2017. Stručna voditeljica istraživanja bit će Ida Koncani Uhač iz Arheološkog muzeju Istre. Sve osobe koje će sudjelovati u podvodnom istraživanju imaju odgovarajuće ronilačke kvalifikacije. Pokretni nalazi bit će privremeno pohranjeni u Arheološkom muzeju Istre, do konačne odluke o mjestu pohrane nalaza koju donosi Ministarstvo kulture na prijedlog Hrvatskog vijeća za kulturna dobra i Hrvatskog muzejskog vijeća..

Odobrenje ovog tijela izdano je uz prethodnu suglasnost Uprave za sigurnost plovidbe Ministarstva pomorstva, prometa i infrastrukture (Klasa: 342-04/17-02/06, Urbroj: 530-04-2-1-17-2 od 29. 03. 2017.) vezano uz sigurnost plovidbe, te Ministarstva obrane (Klasa: 342-08/17-01/1, Urbroj:512-01-17-52 od 27. 04. 2017.), vezano uz interese obrane, a sve u skladu s člankom 13. Pomorskog zakonika.

U provedenom postupku utvrđeno je da su za predmetno arheološko istraživanje ispunjeni svi uvjeti propisani člankom 47. stavkom 2. Zakona o zaštiti i očuvanju kulturnih dobara te je slijedom iznijetog valjalo riješiti kao u izrijeci ovog rješenja.

<u>Uputa o pravnom lijeku:</u>

Protiv ovog rješenja može se izjaviti žalba Povjerenstvu za žalbe pri Ministarstvu kulture u roku od 15 dana od dana primitka ovoga rješenja. Žalba se predaje ovom tijelu neposredno ili šalje poštom preporučeno, a može se izjaviti i u zapisnik. Na žalbu se sukladno članku 9. stavku 2. točka 29. Zakona o upravnim pristojbama („Narodne novine" broj 115/16), ne plaća upravna pristojba.

PROČELNICA:
Lorella Limoncin Toth
dipl. povjesničar umjetnosti

Dostaviti:

1. Arheološki muzej Istre, Arheološki muzej Istre, Carrarina 3, 52100 Pula
2. Ida Koncani Uhač, Arheološki muzej Istre, Carrarina 3, 52100 Pula
3. Ministarstvo pomorstva, prometa i infrastrukture, Uprava sigurnosti plovidbe, Prisavlje 14, 10000 Zagreb
4. Lučka kapetanija Pula, Riva 18, 52100 Pula
5. Lučka kapetanija Pula, Ispostava Umag, Josipa Broza Tita 3, 52470 Umag

6. Ministarstvo obrane, Trg kralja Petra Krešimira IV 1, 10000 Zagreb
7. Ministarstvo unutarnjih poslova, Pomorska policija Pula, Tršćanska 36, 52100 Pula
8. Ministarstvo kulture, Uprava za zaštitu kulturne baštine, Odjel za arheologiju, Runjaninova 2, Zagreb
9. Ministarstvo kulture, Uprava za zaštitu kulturne baštine, Služba za inspekcijske poslove zaštite kulturne baštine, Runjaninova 2, Zagreb
10. Pismohrana

Uputa za otpremu:
Dostaviti s povratnicom pod rednim br. 1-2
Dostaviti običnom poštom pod rednim br. 3-9

Appendix III Agreement between the author and the Archaeological Museum of Istria in Pula.

AGREEMENT

1. Introduction

This Agreement relates to the participation of the Ph.D. candidate Katarina Jerbić (the Student) from Flinders University of South Australia of Sturt Road, Bedford Park, South Australia 5042 (Flinders), on the research of the Zambratija site, which is managed by Ida Koncani Uhač, a senior curator at the Archaeological Museum of Istria in Pula, Croatia.

2. Background

The Archaeological Museum of Istria, based in Pula, Carrarina street 3, 52100, Republic of Croatia, represented by the director Darko Komšo, is undertaking a fieldwork project of the submerged prehistoric settlement on the underwater archaeological fieldwork in the Zambratija bay.

The scientific representative of the project is archaeologist (with a degree equivalent to MA) Ida Koncani Uhač, a senior curator in the Archaeological Museum of Istria, and the head of the Underwater archaeology department at the Museum.

The Student , a Ph.D. candidate of archaeology at Flinders under the supervision of Professors Dr Jonathan Benjamin and Dr Wendy van Duivenvoorde, is investigating the subject of "Zambratija – A Submerged Prehistoric Pile-Dwelling Settlement" as part of her scientific research (Ph.D research).

The Student was an employee of the Archaeological Museum of Istria from January 2012 until December 2014, and was actively participating in the underwater archaeological excavations in the Zambratija bay in 2014 and 2015.

3. Site Access Approval

With this Agreement the Archaeological Museum of Istria express their approval of and agrees to the Student for the purpose of her Ph.D research participating in the specific investigations of the paleo-environment, sea-level change and the analyses of the geoarchaeological research, which will all be a part of the future investigations on the site, and also to participate on the underwater archaeological excavations in Zambratija, as well as to use the documentation that is reffering to the mentioned scientific issues, and all of the above will be done in cooperation and supervision of the leading project manager, senior curator of the Archaeological Museum of Istria, Ida Koncani Uhač.

4. Thesis Preparation and Submission

The Student will provide the Archaeological Museum of Istria with the opportunity to review and provide comments on her thesis prior to submission.

This should be at least 30 days before the proposed submission date for the thesis. The Archaeological Museum of Istria will complete their review and provide comments in no later than 14 days after receipt of the thesis. This review process will in no way prevent the Student from submitting her thesis in accordance with the University's standard course requirements.

5. Intellectual Property

Each party grants to the other party a non-exclusive, irrevocable, non-transferable royalty-free licence to their Background Intellectual Property solely for the purpose of the Student undertaking the Ph.D. research.

Nothing in this Agreement assigns any Intellectual Property Rights in either party's Background Intellectual Property to the other party.

For the avoidance of doubt the Student will own the copyright in her thesis.

6. Rights to Publish

The Student retains the right to publish works arising from her Ph.D. research.

The Student must give notice of any proposed publication to the Archaeological Museum of Istria at least 30 days before the proposed submission date for the publication.

6. Acknowledgement

The Student will adequately acknowledge the assistance of the Archaeological Museum of Istria in all publications and presentations arising from her PhD project.

In undertaking her P.hD research the Student will be subject to all procedures and regulations of Flinders, including all academic and disciplinary policies.

Signed for and on behalf of the Archaeological Museum of Istria by:

Darko Komšo
Director

Signature

muzej istre
PULA

Date: 14.11.2016.
URBROJ: 988

Signed by the Student, Katarina Jerbić

Signature

Date: 05.12.2016

Appendix IV Flinders University fieldwork approvals and forms.

Flinders UNIVERSITY

Boating Safety Plan

No boating is permitted unless approval is given by the University Boating and Diving Officer (UBDO). All Field Trip Forms, the Risk Assessment and a Boating Safety Plan must be submitted to the UBDO no later than **72 hours** prior to departure. All participants must abide by Flinders University policy and procedures: The Field Trip Leader or Skipper must induct/brief all crew of the Safety Management System i.e. safety gear and emergency protocols in place. A scheduled calling system must be implemented with nominated contacts. A minimum of two people must be present on-board at all times. PFD's are to be worn on-board vessels at all times. SPOT device is recommended for remote or commercial work. Vessels not to operate in winds exceeding 25 knots and seas greater than 2 metres. Note, accuracy of details recorded in this form may greatly improve emergency or search and rescue efforts so care should be taken to provide accurate details where possible.

Boat owner: Name: Christian Petretich Mobile: +385989178043 (Katarina Jerbić) Address or main Port of Landing: Zambratija, Croatia	**Skipper (Person in Command):** Name: Ida Koncani Uhač Mobile: +385989826242 Training/ Licence no. (i.e. Coxswains): B1168664

Boat Name: ---	**Boat Registration No: 148 UM**	**Survey type & date** (*i.e. 2D, 2C*): Dendrochronology samples

Boat Type: Elan 433	**Boat Length: 4.33 m**	**Boat Colour: Blue**	**Engine (HP): Johnson B4803, 4.42 kW**

Description of boating work: Boat will be used for collecting dendrochronological samples from the Prehistoric site in Zambratija. It will also be used to transport divers from shore to the site. See diving plan.

Departure location/s: **Zambratija Bay, Croatia**	**Destination:** **Zambratija Bay, Croatia**	**GPS Points:** **45°28'28.2"N 13°30'16.0"E**	**GPS Route:** **45°28'28.2"N 13°30'16.0"E**

Field Trip Leader: Name: Katarina Jerbić Mobile: +385989178043 (CRO), +61452158808 (AU)	**Nominated University Contact:** Name: Blake Lenthall Mobile: +61423381999

Departure date: Date: 29/05/2017 Time: 07:00 (GMT+1)	**Expected Return:** Date: 03/06/2017 Time: 19:00 (GMT+1)	**Date/Time to call search:** Date: ____/____/____ Time: :

Local emergency contact (i.e. Sea Rescue): Name: Emergency number Number: 112 (Emergency number in Croatia) Scheduled calling: ☐ **Y** ☐ **N**	**Nearest Hospital:** Name: Pula General Hospital Number: +385 52 376 000 Address: Aldo Negri 6, 52100 Pula, Croatia

Communications for remote boating operations (i.e. outside of metropolitan waters) mobile phone coverage will likely to be intermittent. In this situation a supplementary means of communication must be established with the nominated University contact. Please identify below:

Satellite phone no: N/A	**SPOT device: N/A**

Boating Plan & Emergency Contacts January 2017

VHF Channel: N/A	27 MHz Channel: N/A	UHF Channel: N/A	GRN Channel: N/A

Safety Equipment, First Aid and PPE taken (beyond what is supplied on-board a surveyed vessel): Note, A SPOT device is recommended to be taken for observer roles on commercial boats or remote operations. It can assist as an alternate form of communication and should be carried in the pocket so in an event the crew member falls over board or the vessel sinks, the emergency button can be activated triggering a rescue from emergency services anywhere in the world.

University Personnel on-board (*Name & contact number, staff, student or volunteer*):

1.Katarina Jerbić, +385989178043 (CRO), +61452158808 (AU), Student ....
2. ....
3. ....
4. ....
5. ....
6. ....

Special Medical Concerns:

NO

Personnel with current Provide First Aid or higher:

YES

If trailering: Vehicle;

Make: N/A........ Model: .... Colour: .... Rego: ....

Trailer Rego: .... Boat Ramp Name: ....

Field Trip Leader:

Name: Katarina Jerbić Signature: ______________________________ Date: ____/____/______

***FIELD TRIP LEADERS MUST RETAIN A COPY OF THIS FORM ONBOARD AND A COPY OF THIS FORM MUST BE FORWARDED TO THE NOMINATED CONTACT SO THAT THEY ARE BOTH AWARE OF EMERGENCY PROTOCOL**

University Boating and Diving Officer Only

Boating plan checked: ☐ **Y** ☐ **N**	Risk assessment complete: ☐ **Y** ☐ **N**
Boating plan recommended for approval: ☐ **Y** ☐ **N**	Special conditions approved: ☐ **Y** ☐ **N**
Comments or recommendations:	
Signed:	Date: ___/___/______

EMERGENCY CONTACTS LIST

Police/ Fire/ Ambulance (Australia)	**000**
Coast Guard Assist (South Australia)	**(08) 8248 6100**
Marine Radio (Distress, safety and calling)	**VHF Channel 16** (International) **27 MHz Channel 88** (Australia) **UHF Channel 5** (Australia)
Divers Emergency Services (International)	**1800 088 200**
Flinders University Security (24hrs)	**(08) 8201 2880**
University Boating and Diving Officer (UBDO)	**Matt Lloyd – 0414 190 051 or (08) 8201 2534**
Associate Director, WHS Flinders University	**Helen Webb – 0414 190 024 or (08) 8201 3703**

FLINDERS UNIVERSITY DIVE PLAN

Flinders UNIVERSITY

Multidisciplinary Investigations of the Submerged Prehistoric Settlement in Zambratija Bay, Croatia

This form must be submitted for approval to the Dean of the School no later than 72 hours before the first dive listed below is scheduled to occur. Dive Coordinators – please retain a COPY of this form to submit with all Post Dive forms.
All divers must be listed on the University Diver Register, and must hold a current Commercial Dive medical. Divers must maintain a logbook of all dives, which may be inspected by the UDO at any time. Note: 'Diving' includes Snorkelling. All divers must abide by the procedures outlined in the most recent version of the Flinders University Diving Procedures Manual.
No dive shall exceed the standard short form DCIEM air decompression tables, or the limits given at Table 3.1 in the Flinders University Diving Procedures Manual (to be used for ALL dives of shallower than 12 metres) – whichever is applicable. No diving is permitted unless a copy of this form has been completed for the dive, and been approved by the School Dean.

Project Title: Multidisciplinary Investigations of the Submerged Prehistoric Settlement in Zambratija Bay, Croatia	
Principal Investigator (Flinders University): Katarina Jerbić	☎: AU mobile +61 45 2158 808 ☎: CRO mobile +385 98 9178 043
Principal Investigator (Archaeological Museum of Istria): Ida Koncani Uhač	☎: CRO work +385 52 351 300 ☎: CRO mobile +385 98 9826 242
Faculty Dive Administrator: John Naumann	☎: wk; 82015533, mbl; 0427427179, priv;0419851975,Sat ph; 0420107179
University Boating & Diving Officer: Matt Lloyd	☎: wk; 82012534, mbl; 0414190051, priv;0439875442,

Diving Dates:	**Location/s (GPS):**
from 29/05/2017	Zambratija Bay; 45°28'28.2"N 13°30'16.0"E
until 03/06/2017	Stay in: Dives: Submerged Prehistoric Settlement in Zambratija Bay, Croatia.

Brief Description of project, and intended principal work methods:

Multidisciplinary investigations of the submerged prehistoric settlement at Zambratija Bay, Croatia. Two distinctive operations will be performed:

1. Coring of the seabed – with the cooperation of the Croatian Geological Survey (http://www.hgi-cgs.hr). No diving will be performed for this part of the project. All necessary equipment will be provided by the Croatian Geological Survey.
2. 3D photogrammetry, total station survey and collecting of wooden samples for dendrochronology. SCUBA diving and snorkelling will be performed for this part of the project. Other participants will also be joining, all employees and affiliates of the Archaeological Museum of Istria in Pula, the institution holding the permit for performing archaeological investigations on the site.

Dive Coordinators for operation:	Kurt Bennett, Ida Koncani Uhač
Other participants (Flinders University students/volunteers):	Enrique Aragon Nunez, Kurt Bennett
Other participants (Archaeological Museum of Istria employees and affiliates):	Ida Koncani Uhač, Maja Čuka, Andrea Sardoz, Alba Ferreira Dominguez
Diver/s:	Katarina Jerbić, Ida Koncani Uhač, Maja Čuka, Andrea Sardoz, Enrique Aragon Nunez, Kurt Bennett, Alba Ferreira Dominguez
Diver attendant/s (surface) & Standby Diver:	Rotation system (see above listed)

Gas mix to be used:	☑ AIR	☐EAN32	☐ EAN36	☐Other (note mix)

Dive plan for each dive. Include diving method, proposed depth/duration for each dive, and expected repetitive group/s at end of dive/s (using DCIEM tables). Attach a separate sheet if necessary.

Generally 1-2 dives per day, teams of 2, max depth 4.5m. Planned dives: 70 min. max bottom time; Surface Interval ≥ 60 min.
DCIEM calculation for each dive:

1. Dive 1; 70 min @ 4.5m ⇒ "C", SI = 1:00 ⇒ RF = 1.3, No Dec limit = 250 min
2. Dive 2; 70 min @ 4.5m x 1.3 ≡ 91 min ⇒ "D", SI = 1:00, RF = 1.4, No Deco Limit = 214 min

No more than 4 divers in the water at any given time. Two topside attendants at all times. Divers to obtain site plan with tape measures, slates and cameras. Divers to undertake underwater photography, collecting of wooden samples from the site and handling with a pogo stick for the total station survey.
Consecutive days diving: 5 days diving, 1 day off.

Tides and weather are expected to be good, and site is not influenced by them. Expected visibility >15m.
Entry and exit points are over a pebbled beach and concrete jetty to a boat (2 and 3 on the image below). The boat drives divers to the site (approximately 100m). Vantage points on the shore give good visibility of the site. Dive flags and floats are displayed. Oxygen sets at each site. Boat will be stationed on site. Communication with shore over radio connection.

See below images of the site for clarification:

1. Car park
2. Pebbled beach (~ 20m)
3. Concrete jetty (~ 25m)
4. The site

Equipment required (Attach a separate sheet if necessary): Camera with underwater housing

Estimated return date/time: 09/07/2017

Nominated Contact: Blake Lenthall ☎:0423 381 999, office: 8201 3034,

Has your nominated contact been notified of procedures to follow in the event you are late reporting back? ☒Y ☐N

Special permit/s required? Specify permit # and issuing agency if applicable:
Letter of agreement between the Archaeological Museum of Istria in Pula (holder of rights to perform investigations on site) and Katarina Jerbić. Signed by the Museum's director Darko Komšo and Katarina Jerbić.

Have the proper authorities been notified? ☒Y ☐N

Emergency Response Plan
The Emergency Response Plan details requested here must be completed for all Flinders University Diving Projects. This should be done in conjunction with the Risk Assessment for each project. The intention is to require the Field Leader for a project to think about the 'worst case scenario' they could be faced with in the event of a serious incident occurring during work on their project, and detail the actions that will be taken to either get assistance to the site, or get an injured person to a location where outside help can be obtained.

Location of nearest medical assistance (provide at least two options):

Nearest Ambulance: Umag Medical Centre ☎ +385 52 702 222 or 112
Nearest Hospital: Pula General Hospital ☎ +385 52 376 000 or 112
Nearest Hyperbaric Unit: Pula Oxy Clinic ☎ +385 52 217 877
Ambulance, Police, Fire services Station ☎ 112
Most professional people speak good English.

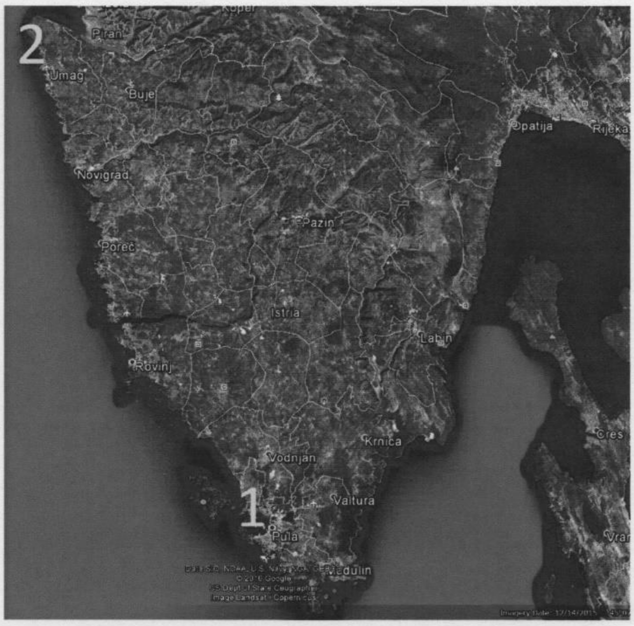
Time it will take to get assistance to the site – under worst-case conditions: 1 hour

Time it will take to walk out from site: 5 min

Extra medical supplies that may be necessary for your field trips:
Diving First Aid kit, field first aid kits
1 x Oxygen Kit & cylinder
(All provided by the Archaeological Museum of Istria in Pula)

Other supplies that may be necessary for your field trips (eg. water, food): Boat, survey gear, cameras, shelters	
Means of contact while in the field (specify phone no's): Katarina Jerbić AU +61452158808; CRO +385989178043 Ida Koncani Uhač CRO +385989826242	
Diving Operations	
Proposed No. dives per day: 2	**Main working depth (m):** 3.5 m
Level of exertion (high/medium/low): low	**Intended maximum depth (m):** 4.5 m
** NB: ENOUGH OXYGEN (O_2) MUST BE CARRIED IN THE BOAT AND THE VEHICLE TO ENSURE THAT AT LEAST TWO PATIENTS CAN BE GIVEN 100% O_2 DURING THE ENTIRE EVACUATION PROCEDURE, FROM DIVE LOCATION TO MEDICAL FACILITY.	

Transport to dive site (incl. tow vehicle & boat):
Katarina Jerbić will pick up Flinders students from the airport with the rented car and will drive them to the site. Rented vehicle will also be used for transport from the accommodation to the site (max. 10 minutes driving distance). No towing required as the owner of the boat lives in Zambratija and his boat is anchored in the bay.



Pula (1) to Zambratija (2) road (highway) distance is 94.84 km. Pula is the economic capital and the biggest city in the peninsula. It has a reputable hospital, hyperbaric unit and an airport.

Travel After Diving. Will altitude restrictions delay return travel after this dive (see Section 3.6 of the Flinders University Diving Manual)? Please indicate altitude and delay period if appropriate.
NO.

Do any special conditions need to be adopted above and beyond normal safe diving practice? (NB: written approval must be obtained from the Dean prior to conducting any dive that falls into this category):
YES; exemption from the use of Shark Shields. Adriatic and Mediterranean Seas do not have large sharks.

Have you done a Risk Assessment for this project, and submitted it to the Executive Dean? ☒Y ☐N
Have all necessary Flinders University field trip forms been registered? ☒Y ☐N
Has University Security been notified of date/location of this Dive Operation? ☒Y ☐N
I certify that I have notified all personnel involved in the operation of potential hazards that exist within the area of the dive location and discussed the Risk Assessment for the trip. Once on site I will reassess diving conditions, and diving will not be attempted unless I deem the area safe for the type of diving and work intended to be carried out. The Vessel has been checked, and deficiencies noted & rectified.

Dive Coordinator's Signature:	**Date: 12.04.2017.**

University Diving Officer Only	
Dive plan checked: ☐Y ☐N	Risk assessment complete: ☐Y ☐N
Dive plan recommended for approval: ☐Y ☐N	
Comments:	
Signed:	Date:

School Dean Only

Approved: ☐Y ☐N	Risk Assessment complete: ☐Y ☐ N	Permission granted for 2 person dive team? ☐Y ☐N
Comments:		
Signed:		Date: __/__/____

Flinders UNIVERSITY

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL FIELD TRIP FORM

EHL FIELD TRIP FORMS TO BE COMPLETED IN ACCORDANCE WITH
EHL FIELD TRIP GUIDELINES & PROCEDURES

SUMMARY

School or local Work Area to record details on the Field Trip database

FIELD TRIP TITLE:	Multidiscplinary Investigations of the Submerged Prehistoric Settlement in Zambratija Bay
FIELD TRIP PURPOSE: (eg. Film Shoot, Diving, Bushwalking):	Coring Total station survey Underwater 3D photogrammetry Underwater collection of wooden samples for dendrochronology
DATE:	FROM: 02 May 2017 TO: 09 July 2017
FIELD TRIP DESTINATION: (eg. Darwin, Canada, Victor Harbour)	Zambratija Bay, Zambratija, Croatia
DESTINATION TYPE: (eg. Metro, Regional, Remote, Interstate, Interstate remote etc.)	Regional
BRIEF DESCRIPTION OF FIELD TRIP:	The investigations will take place in the Zambratija Bay, next to the village of Zambratija, Croatia. The purpose is to perform geological coring of the seabed, 3D photogrammetry of the site and taking samples of wood for dendrochronological analyses. The piston corer is used on soft, unconsolidated sediments. Zambratija Bay is located at 45°28'28.2"N 13°30'16.0"E.
NAME OF FIELD TRIP LEADER:	Katarina Jerbić
MOBILE NUMBER:	(AUS) +61452158808 (CRO) +385989178043
EMAIL ADDRESS:	katarina.jerbic@flinders.edu.au
NAME OF FIELD TRIP LEADER'S SUPERVISOR:	Dr Jonathan Benjamin
TOTAL NUMBER OF PARTICIPANTS:	FLINDERS STAFF: 0
	FLINDERS STUDENTS: 3
	VOLUNTEERS: 2

Signed: (Nominated University Contact person)	Date:
Signed: (Field Trip Leader)	Date: 12.04.2017.
Signed: (Field Trip Leader's Supervisor)	Date:
Signed: (School Dean or Nominee)	Date:

Flinders UNIVERSITY

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL Field Trip Vehicles

Booking a University Vehicle

Contact the Transport Office on 8201 2015.

A booking form (available from School Offices) must be completed at the time of booking a vehicle.

Where possible, University or hired vehicles must be used for the transportation of staff and students on Field Trips.

Use of Private Vehicle

Private vehicles used on University business **must** be covered by comprehensive insurance, **Use of Vehicles on University Business (Field Trips)**. Private vehicles must be roadworthy, registered, driven by a licensed driver and only used when there is no reasonable alternative.

Please Note:

- **Vehicle Insurance Cover**
  In most cases personal/private comprehensive vehicle insurance is valid on work related travel. However, it may be wise to confirm that this is included in your comprehensive cover, with your insurance provider.

- **Private vehicles are not covered by University insurance.**
  Workers' Compensation insurance for staff covers personal injury but not vehicle damage.

- **Security in Car Parks**
  Vehicles should be locked and made secure when left in the University car parks. Do not leave any valuables in open view in vehicles. Advise the security office of the field trip and and length of time the vehicle will be left in carpark.

- **Alcohol and Drugs**
  In accordance with the University's **Use of Vehicles on University Business** policy, vehicles are not to be driven by any person whose blood alcohol level is 0.05% or more, or who has consumed other drugs which affect their ability to drive safely.

If you are using a private vehicle please provide the following details:

Name:	**N/A**
Contact Number:	
Registration Number:	
Make of vehicle:	
Model of vehicle:	
Colour of vehicle:	
I agree and understand private vehicle use.	
Signature :	

Flinders University

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL Participant Safety Acknowledgment

To be completed by all participants and returned to Field Trip Leader.
A copy to be retained by participant.

For repeated field trips to the same or similar locations, this form can be completed on a semester basis unless the participant's personal circumstances change

As a participant on a field trip you are asked to **READ, UNDERSTAND, SIGN and RETURN** this form (*in accordance with requirements of the OHS&W Act, 1986*). Whilst participating in the field trip you must carry your **personal ID** and **medications**, together with **food** and **drink** provisions as required.

The following guidelines are for your personal safety. Failure to comply with reasonable instructions may result in you not being permitted to participate in the remainder of the field trip.

1. **Obey all reasonable directions** from Field Trip Leader. All boating operations require that you heed instruction and direction of the boat operator, and all diving instructions from the dive leader.
2. **Wear appropriate clothing** for prevailing weather conditions (sturdy, enclosed footwear and hat are required).
3. **Stay clear of hazardous areas** or dangerous locations (eg cliff edges, mine shafts, quarry faces and open slopes).
4. **Behave** in an orderly manner at all times.
5. **Respect** the property of others at all times – such as that of landowners and places where you are accommodated.
6. **Do not leave your group without notifying the Field Trip Leader** of your intended movements in time and place.
7. **Limit the consumption of alcohol or other drugs** to ensure that you do not endanger your own safety or the safety of any other person on the field trip.
8. Firearms, spring or gas powered spears, unauthorised explosives and other weapons **are not permitted** on any field trip.
9. All participants are expected to **assist in housekeeping duties** as directed by the Field Trip Leader.
10. University **insurance**, see <u>EHL Field Trip Guidelines & Procedures</u>.

I have **read, understood and agree** to the conditions of this field trip. I agree that I will not intentionally cause any concern regarding my own health and safety or that of others on the field trip.
I hereby give permission for medical treatment to be administered to me in the event of an emergency.

Name: (BLOCK CAPITALS):

Sign: **Date:** **Mobile ☎**

In the event of any emergency please contact the following person:
(Next of Kin, who is not on the Field Trip)

Name: **Contact No:**

Medical condition: Please advise if you suffer from any known medical conditions, including allergies which may affect your health or safety on any field exercise, and if you will be taking any medications during any trips, as follows:

Medication:

This is a confidential form.

For the duration of the field trip/s this document will be held by the Field Trip Leader and the University Nominated Contact Person.

Valid from: **Valid to:**

If you are under 18 years old, your parent/guardian/care-giver also needs to sign the form, below.

Sign: **Date:**

PLEASE ENSURE ALL PARTICIPANTS SIGN FORMS AND RETURN TO FIELD TRIP LEADER BEFORE FIELD TRIP COMMENCES.

Flinders University

Field Trip Name or Booking Ref. Number(s) (if applicable):

Submerged Prehistoric Settlement, Zambratija, Croatia

EHL Field Trip Itinerary and Planning

1.	**Field Trip Leader:** (Name)	**Katarina Jerbić**	**Topic No.**	**Zambratija fieldwork**
	Contact Phone:	Work: +385 98 9178 043		Mobile: +385 98 9178 043
2.	**Departure:**	Date: 28/04/2017	Time: 21:50	Location: Adelaide, SA
3.	**Return:**	Date: 09/07/2017	Time: 15:30	Location: Vienna, AUT
4.	**Destination**	**Contact Details** (if applicable)		**Contact No.**
	Zambratija, Croatia	Katarina Jerbić		+385 98 917 8043

5. **Transport arrangements:** International flights, one (1) rented vehicle, boat

6. **Emergency contacts:**

6.1 Nominated Contact Person at the University
Name: Mr Blake Lenthall Contact No. +61 4 2338 1999

6.2 Security after hours (to initiate late return procedures * below) Contact +61 8 8201 5840

6.3 Emergency Services locations and contacts nearest to destination:

Nearest Medical Facility:	Umag Medical Centre	Contact No. +385 52 702 222 or 112
Nearest Hospital:	Pula General Hospital	Contact No. +385 52 376 000 or 112
Nearest Hyperbaric Unit:	Pula Oxy Clinic	Contact No. +385 52 217 877
Fire Services:		Contact No. 112
Ambulance:		Contact No. 112
Police:		Contact No. 112

If it is anticipated that the return time will be after hours or on a weekend, a copy of the completed documentation must be provided to Flinders University Security

7. **Late return procedures:**

*Procedure to be followed by Nominated Contact Person OR Security at the University if field trip group is not back on time:

- Phone Field Trip Leader.
- Phone other participants if the leader is not contactable.
- Phone Security on 8201 2880 (24 hours). Check for returned gear if other participants not contactable.
- Check for return of University vehicle.
- Call Emergency Services in field trip area (Police, Coastguard, Park Ranger, landowner etc).
- Advise School Dean.
- School Dean to advise Executive Dean.

Signed: (Nominated University Contact person)	**Date:**
Signed: (Field Trip Leader) [signature]	**Date: 12.04.2017.**

Flinders UNIVERSITY

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL FIELD TRIP HEALTH AND SAFETY CHECKLIST

Refer **EHL GUIDE TO ASSESSING RISKS AND IDENTIFYING HAZARDS**

Item	Checked		
Transport/Equipment/Itineraries/Maps			
Transport arrangement identified?	☑Yes	☐ No	☐N/A
Vehicles & trailers are registered, roadworthy and covered by insurance?	☑Yes	☐ No	☐N/A
Vehicles, trailers, tow bars compatible and Road Traffic Act compliant?	☑Yes	☐ No	☐N/A
Motor vehicles spare parts (hoses, belts, tools) etc. identified/obtained?	☐Yes	☐ No	☑N/A
Motor vehicle safety & recovery equipment ie. Bull bar, winch, tow rope, jumper leads, shackles etc.	☐Yes	☐ No	☑N/A
Relevant licenses and permits obtained?	☑Yes	☐ No	☐ N/A
Written itineraries have been prepared?	☑Yes	☐ No	☐N/A
Relevant maps obtained?	☑Yes	☐ No	☐N/A
Equipment has been inspected to ensure its integrity and is of an approved design and meets minimal legal requirements?	☑Yes	☐ No	☐ N/A
Briefings/Consultation/Accommodation/Catering			
Participant briefing sessions held in advance of the field trip?	☑Yes	☐ No	☐N/A
The participants have been consulted regarding arrangements, potential hazards etc?	☑Yes	☐ No	☐N/A
A personal needs list has been developed, implemented and communicated?	☑Yes	☐ No	☐N/A
Catering arrangements organised?	☑Yes	☐ No	☐N/A
Accommodation arrangements have been organised?	☑Yes	☐ No	☐ N/A
If working alone, participant is advised that regular contact must be made with Nominated Contact Person?	☑Yes	☐ No	☐N/A
Occupational Health and Safety			
The hazards associated with the field trip have been identified/controls developed?	☑Yes	☐ No	☐N/A
Relevant University OHS&W Procedures brought to the attention of participants?	☑Yes	☐ No	☐N/A
Student or volunteer responsibilities communicated to participants?	☑Yes	☐ No	☐N/A
Policy on drugs and alcohol explained to participants?	☑Yes	☐ No	☐N/A
Fire fighting equipment required for the trip identified/obtained?	☑Yes	☐ No	☐N/A
First aid kits have been checked for contents and refilled?	☑Yes	☐ No	☐N/A
Qualified First Aid Officer(s) identified/communicated to participants? Please note: A qualified First Aid Officer must be present on all field trips to remote locations or where the risk assessment identifies the need.	☑Yes	☐ No	☐N/A
Emergency procedures relevant to the field trip identified and developed. Eg. Medical, fire, evacuation)	☑Yes	☐ No	☐N/A
Effective communication system identified/obtained? eg. Mobile phone coverage, satellite phone for remote areas.	☑Yes	☐ No	☐N/A
Clothing relevant to conditions identified?	☑Yes	☐ No	☐N/A
Personal Protective Equipment required identified?	☑Yes	☐ No	☐N/A
Weather forecasts and field site conditions obtained?	☑Yes	☐ No	☐N/A

Flinders University

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

Advising Authorities (where relevant)			
Local Park Ranger advised of proximity of field party?	☐ Yes	☐ No	☑ N/A
Department of Environment and Natural Resources (DENR) and/or Department of Aboriginal Affairs and Reconciliation (ARD) (where relevant) advised of the dates for planned field trip and associated trips?	☐ Yes	☐ No	☑ N/A
Local Council advised of trip (where relevant)?	☑ Yes	☐ No	☐ N/A
Have permits and special permissions been obtained.	☑ Yes	☐ No	☐ N/A
Special Safety Precautions are required. **NB. If you tick Yes to any of the following, your Field Trip is considered High Risk. All possible hazards must be identified on the Risk Assessment form.**			
Does your Field Trip include any of the following: • Boating trips? • Scuba diving? • Snorkeling? If yes, you must contact the Maritime Archeology Diving Officer on ext. 15533.	☑ Yes	☐ No	☐ N/A
Cliff walking, climbing, clambering over rocks?	☐ Yes	☑ No	☐ N/A
Bush walking?	☐ Yes	☑ No	☐ N/A
Tractor driving or other plant and equipment?	☐ Yes	☐ No	☑ N/A
The use of high voltage equipment?	☐ Yes	☐ No	☑ N/A
Firearms, spring or gas powered spears, explosives and other weapons will be taken on Field Trip.	☐ Yes	☐ No	☑ N/A
Involving geological and mining trips?	☐ Yes	☐ No	☑ N/A
Other trips that may expose people to medium to high risk? Eg. Mountain bike riding, canoeing, kayaking, swimming.	☐ Yes	☑ No	☐ N/A
Flying in any form, ie. Planes. Air balloon, Helicopter	☑ Yes	☐ No	☐ N/A
Are you going Overseas? Relevant vaccinations identified/field party advised? Visas, Passports, Embassies, Government travel warnings have been considered.	☑ Yes	☐ No	☐ N/A
Dangerous/Hazardous substances (eg. Petrol, LP Gas) • Containers and labeling is compliant • Storage and use, hazards identified/controlled • Containers must be bunded whilst in transit	☐ Yes	☐ No	☑ N/A

IMPORTANT:

I have **READ** and **UNDERSTOOD** the **EHL Field Trip Guidelines & Procedures**	☑ Yes	☐ No

The following Field Trip Forms have been completed: (*Please tick*)

- ☐ **Participant Health & Safety Acknowledgment** forms – one for each participant
- ☐ **Field Trip Itinerary & Planning** form
- ☐ **Field Trip Health & Safety Checklist** form
- ☐ **Private Vehicle** form (if applicable) – one for each vehicle
- ☐ **Field Trip Summary**
- ☐ **Risk Assessment**

The Field Trip Leader to ensure: (*Please tick*)

- ☐ A signed and full copy of the **Field Trip documentation** is provided to the University Nominated Contact Person or Security if it is anticipated that the return time will be after hours or on a weekend.
- ☐ All participants are provided with a copy of the completed **Field Trip Itinerary & Planning** form
- ☐ Field Trip Leader retains a **full copy of signed documentation**
- ☐ School/Local Work Area Office retains **full copy of signed documentation for archiving for 7 years**

Signed: (Field Trip Leader) [signature] **Signed: (Field Trip Leader's Supervisor)**	**Date: 12.04.2017.** **Date:**

Flinders University

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL FIELD TRIP RISK ASSESSMENT FORM

Cost Centre: EHL Faculty	**Department: Archaeology**	**Location: Zambratija Bay, Zambratija, Croatia (45°28'28.2"N 13°30'16.0"E)**	**Area Supervisor:**
	Assessed by: Katarina Jerbić and John Naumann	**Date: 12.04.2017.**	**Review Date: +30 Days**

Refer **EHL GUIDE TO ASSESSING RISKS AND IDENTIFYING HAZARDS**

The following table includes most hazards that would be associated with a medium-low risk trip.
List identified hazards for your field trip and detail measures taken to address the hazards. The **Field Trip Health & Safety Checklist** and the **Hazard Identification Guidelines** can provide indicators for possible hazards.
If necessary, this generic risk assessment must be modified to meet individual requirements of each Field Trip. The Action by and Date columns will need to be completed.

Item	Hazard	P	C	RA	Control	Action by	Date of Trip
Field Trip: General	**International Travel**	hU	F	M	Reputable international airline, International safety standards, Follow local instructions	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Motor vehicle accident	U	M	M	Drivers licences & training, appropriate vehicle. Driver has rest break every 2 hours, own car	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Exposure to elements	U	m	M	Monitor local weather conditions, sunscreen, appropriate shelter from winter wind	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Heat Stress/ Dehydration	U	M	M	Sufficient water, at least 2.5 litres per person per day, appropriate clothing. Extra water will be carried by boat.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Medical emergency	U	M	M	No medication is needed, mobile communication, dive medicals current. Known allergies. All persons trained for first aid.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Bites and Stings	U	M	M	Mobile communication, first aid kit	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Slippery surface, footing	U	M	M	Appropriate footwear, team lifting, limit size of loads	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Manual handling	U	m	M	Appropriate footwear, team lifting, limit size of loads	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Natural disaster (e.g. bushfire)	U	M	M	Emergency planning, communication, street directory	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Alcohol/recreational drug use	U	M	M	No alcohol/recreational drugs on field trips	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Emergency Evacuation	U	M	M	On arrival emergency evacuation points to be	Katarina Jerbić & all	28.04.-

Item	Hazard	P	C	RA	Control	Action by	Date of Trip
					identified and local procedures followed. To be communicated to participants	participants	09.07.2017.
	Lack of communication	**P**	**M**	**M**	Mobile coverage to be checked and phones charged and can be re-charged. Consider satellite phone	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Tripping	**U**	**m**	**M**	Taping down or covering over trip hazards or cables, use of safety cones to designate hazard	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Working in public places	**U**	**m**	**M**	Have Flinders ID readily available. Work in safe areas only, considering the public and traffic. Use of safety vests and cones to identify hazards and working area	Katarina Jerbić & all participants	28.04.-09.07.2017.

Can you identify any further hazards?	**NO ☐**	Adequately controlled. No further action required, proceed to Summary of Risk and Signature block.
	YES ☒	Further hazards identified. Proceed further with Risk Assessment

ADDITIONAL HAZARDS

To evaluate other identified hazards associated with this trip; type each identified hazard on the form, complete the Probability (P) and Consequence (C), using the Risk Matrix enter the Risk Assessment rating (RA) refer page 10. Complete a detailed list of controls you will put in place to ultimately eliminate or significantly reduce the associated risk.

Item	Hazard	P	C	RA	Control	Action by	Date
Task-Specific Items	Allergies	U	F	M	Assess all participants' dietary requirements allergies and other food-related concerns. Address any concerns at commencement of project. Collect contact information in case of emergency from Participants.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Food safety	U	M	M	Keep all meat and dairy products in the refrigerator until ready for use. If any food smells 'off' discard immediately. All special needs food to be kept separate from the general food supply. Students to be briefed on food safety at commencement of field trip as they may be preparing their own meals.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Food safety (Bacteria)	P	M	M	There are off-site toilet and shower blocks for both women and men on the island. Wash hands after using the toilets and before and after touching food. Use clean towels or clothes to dry hands.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Personal Hygiene (skin infection, cuts, small bites)	P	m	M	Report to first aid officers and immediately apply antiseptic and cover. Seek medical advice if required of any injury and will implement the appropriate emergency strategies	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Unforeseen hazards & allow participant feedback	L	L	L	At the end of each day all students will attend a debriefing on the days' activities. They will then be briefed on the following days tasks.	Katarina Jerbić & all participants	28.04.-09.07.2017.
Boating	Person overboard	U	M	M	Personal Floatation Devices to be worn at all times. Boat and safety briefing	Katarina Jerbić & all boating	28.04.-09.07.2017.

Item	Hazard	P	C	RA	Control	Action by	Date
						participants	
	Exposure to elements	L	m	M	Monitor local conditions, apply sunscreen, appropriate protection and shelter, safety briefings and instruction. Boat enclosed cabin.	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Weather	U	M	M	Monitor weather, only go out in safe conditions, check weather night before and morning of departure. Boat skipper to make decision about weather conditions and travel.	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Tides	L	m	M	Water safety training, check weather and tide reports prior to departure. Boat can access shore incase of emergency rescue.	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Boat capsize	hU	F	M	Carry Flares, Radio, safety plan, Personal flotation devices	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Motor malfunction	hU	m	M	Carry basic tool kit, inboard motor and auxiliary engine	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Radio Malfunction	L	m	M	Instructions, back up radios and mobile phones	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Anchor irretrievable	U	m	M	Carry mobile phone, cut anchor line, spare anchor and rope	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Vessel stress/damage	L	F	H	Routine maintenance & repair of boat & motor. Vessel checklist complete	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
	Entries & Exits from the boat; difficulties	U	M	M	Safety briefing, following instructions	Katarina Jerbić & all boating participants	28.04.-09.07.2017.
Snorkelling	Check equipment for mould (prevent sickness)	hU	M	M	Check equipment before snorkelling. Clean gear and check daily.	Katarina Jerbić & all snorkel participants	28.04.-09.07.2017.
	Dangerous animals	U	M	M	Dive safety briefing. Brief about jellyfish.	Katarina Jerbić & all snorkel participants	28.04.-09.07.2017.
	Recording equipment, measuring tapes, etc (entanglement)	U	M	M	Dive safety briefing. Team leader appointed before dive. Buddy work. All participants to carry knives.	Katarina Jerbić & all snorkel participants	28.04.-09.07.2017.
	Tides	hU	N	L	Tide times consult dive plan. Snorkelling not limited by high or low tides.	Katarina Jerbić & all snorkel participants	28.04.-09.07.2017.
	Warmth	P	FA	M	Construct shelter on shore to protect from wind. Participants to bring dry clothes to change into immediately after snorkelling. Boat has an enclosed	Katarina Jerbić & all snorkel participants	28.04.-09.07.2017.

Field Trip Name or Booking Ref. Number(s) (if applicable): Submerged Prehistoric Settlement, Zambratija, Croatia

Item	Hazard	P	C	RA	Control	Action by	Date
					cabin with heater.		
Diving	Repetitive diving	L	m	M	Dive coordinator to follow DCIEM tables, conservative dive planning	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Decompression Illness	hU	F	M	Experienced dive tea. Diver medical current. Dive coordinator to monitor health pre and post dive. Diver briefing, controls ensure to follow correct dive profiles, conservative surface intervals, maximum repetitive group H. Oxygen on board.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Pulmonary and ear Barotrauma	hU	F	M	Experienced dive team. Diver medical current. Dive coordinator to monitor health pre and post dive. Diver briefing, controls conservative ascent rate.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Contaminated air	hU	M	M	Ensure air cyllinders are tested annually, and refills are from an authorised dive shop.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Equipment malfunction i.e. regulator failure	H	F	M	Ensure dive equipment is serviced annually. Dive coordinator to brief emergency response in event of failure, equipment checked prior to diving. Follow diving manual.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Out of air/drowning	hU	F	M	Experienced dive team. Dive coordinator and divers to check cylinder pressure before dive, ensure sufficient reserves, back to boat with minimum 50 bars.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Entanglement/drowning	hU	F	M	Wear dive knife. Standby diver.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Cold and hypothermia	U	M	M	Appropriate wet or dry suits worn, conservative dive profiles.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Physical exertion before, during and after dive	U	M	M	Relevant diving medical & appropriate level of fitness.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Low visibility	hU	N	L	Experienced dive team, attached buoy line and standby diver.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Strong current	hU	N	L	Check tide times and monitor current. Diver to be attached to buoy line at all times. Standby diver.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Boat traffic/propellers	U	M	M	Skipper to monitor boat traffic. Dive flag deployed. Motors off on diver deployment and retrieval.	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Manual handling	L	m	M	Manual handling training, team lifting.	Katarina Jerbić & all participants	28.04.-09.07.2017.
Survey work	Heat/Fatigue/Sun	L	m	M	Briefing, PPE, hat, water, work in teams	Katarina Jerbić & all participants	28.04.-09.07.2017.
Coring	The piston corer is a general purpose tool that relies on its weight for penetration into the seafloor. It has a trigger device that hits the seafloor before the core barrel and releases the corer allowing it to freefall. As the barrel enters the sediment a special	U	m	M	Safety briefing. PPE. Protective clothing. Following instructions. The corer is handled by experts (geologists from the Croatian Geological Survey), and Katarina Jerbić will be on the shore taking pictures while the geologists collect the coring sediments.	Katarina Jerbić & all participants	28.04.-09.07.2017.

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

Item	Hazard	P	C	RA	Control	Action by	Date
	internal piston creates a vacuum and helps to draw the core into the barrel. This suction reduces compaction of the sample in the inner sleeve.						
Recording/measuring	Slips, trips, falls, cuts	hU	m	M	Briefing, PPE, work in teams	Katarina Jerbić & all participants	28.04.-09.07.2017.
Photography	Sun/heat	P	m	M	Briefing, PPE, water, hat, work in teams	Katarina Jerbić & all participants	28.04.-09.07.2017.
	Rain/wind	P	FA	M	Briefing, PPE, Protective clothing (dry gear)	Katarina Jerbić & all participants	28.04.-09.07.2017.
Public transport	Commercial Ferry	U	F	M	Commercial ferry (over 20 years of experience), full survey maritime safety standards	Katarina Jerbić & all participants	28.04.-09.07.2017.

SUMMARY OF RISK **Review the risk measured, and the controls, then please select the relevant risk summary statement:**

- **A** The assessment reveals that the potential risk to health from the use of the plant/equipment/procedure is not currently significant ☐
- **B** The assessment reveals that the potential risk to health from the use of the plant/equipment/procedure is significant, however controls are in place that reduce risk to acceptable levels ☑
- **C** The assessment reveals that the potential risk to health from the use of the plant/equipment/procedure is significant. Interim controls are in place to reduce risk to acceptable levels. ☐

Signed: (Field Trip Leader) [signature] **Date: 12.04.2017.**

Signed: (Field Trip Leader's Supervisor) **Date:**

Flinders University

Field Trip Name or Booking Ref. Number(s) (if applicable):
Submerged Prehistoric Settlement, Zambratija, Croatia

EHL GUIDE TO ASSESSING RISKS AND IDENTIFYING HAZARDS

Probability - Risk Factors →		Consequence - Risk Factors →	
Very Likely VL	Probably occur immediately or within a short period of time	**Fatality F**	May cause death or loss of facility
Likely L	Probably occur in time	**Major M**	Severe injury or illness or major property damage
Possible P	Could happen occasionally	**Minor m**	Minor (usually reversible) injury or illness resulting in days off work or minor property damage
Unlikely U	Could eventually happen	**First Aid FA**	First aid level treatment
Highly Unlikely hU	Has potential to occur, but probably never will	**Negligible N**	No medical treatment

Forms of Hazard	
Physical	Mechanical action, impact, electrical exposure, heat/cold, noise, vibration, explosion etc.
Chemical	Corrosive liquid, toxic gases, noxious fumes etc.
Ergonomic	Height of workbench, design of chair, set-up of a work station etc.
Radiation	x-ray machine, infrared beams etc.
Psychological	Stress from using equipment without proper training or instruction, interpersonal conflict
Biological	Sharps, specimen containers carrying infected material, viruses from A/C system
Sources	Environment Substances Equipment/plant Work systems

Risk Matrix

Consequence	Probability					Control Hierarchy	
	Very likely	**Likely**	**Possible**	**Unlikely**	**Highly unlikely**	Elimination	*Is it necessary*
Fatality F	Extreme	High	High	High	Medium	Substitution	*Is there a less hazardous alternative*
Major injury M	High	High	High	Medium	Medium	Isolation	*Eg Restrict access, use in a closed container, fume cabinet*
Minor injury m	High	Medium	Medium	Medium	Medium	Engineering	*Eg Trolleys to move loads, guards on machinery, Fume cupboard*
First aid FA	Medium	Medium	Medium	Low	Low	Administration	*Eg: Training, Safe Work Procedure, signage*
Negligible N	Medium	Medium	Low	Low	Low	PPE - Personal Protective Equipment	*Eg: Gloves, respirator, safety glasses*

Appendix V Harpha Sea d.o.o. Sub-bottom profiling report.

HARPHA SEA

Sub-bottom profiler survey in Zambratija Bay (Croatia)

(version 1.0)

Offer no. 290616-1

Client: **ARHEOLOŠKI MUZEJ ISTRE**
Carrarina ulica 3
52100 Pula

Representative: **Ida Koncani Uhač**

Contractor: **Harpha sea, d.o.o. Koper**
Čevljarska 8
6000 Koper

Contractor representative: **Aljoša Žerjal**, CEO

Koper, March 2017

The company was entered in the Companies Register kept by the Regional Court in Koper under ref. no. 1-4550-00. Company reg. no.: 5815541, VAT ID: SI43893252, Initial capital: 8,763.00 EUR, Transaction account: 05100-8010459017

Content

The company was entered in the Companies Register kept by the Regional Court in Koper under ref. no. 1-4550-00. Company reg. no.: 5815541, VAT ID: SI43893252, Initial capital: 8,763.00 EUR, Transaction account: 05100-8010459017

1. Introduction

Report delivers methodology and results of sub-bottom profiler survey in the part of Zambratija bay.

2. Survey equipment

2.1 Vessel

The survey was carried out with inflatable boat NM450 (KP-4194), measuring 4.5 m in length and with 0.5 m of draught (Fig. 1). The boat is permanently equipped with the following sensors: MBES, GNSS receiver, GPS compass, inertial measuring unit (IMU), sound velocity sensor. In addition, the boat was mobilized with SBP. All the sensors are integrated with laptop PC with software for operation and navigation.

Figure 1: Survey vessel NM450.

2.2 *Sub-bottom profiler (SBP)*

The survey was done with parametric sub-bottom profiler (SBP) Innomar SES-2000 compact (Fig. 2, Tab. 1). The sonar enables the logging of sub-bottom acoustic profile under the sailing path which shows the layers of different sediments or buried objects.

Figure 2: Sub-bottom profiler Innomar SES-2000 compact.

Range	1 m - 400 m
Penetration	up to 40 m
Vertical resolution	up to 5 cm
Primary freq.	cca. 100 kHz
Secundary freq.	5 kHz - 15 kHz
Ping rate	up to 50 Hz
Puls width	± 2°

Table 1: Technical specification of SBP Innomar SES2000_Compact.

2.3 *Positioning sensors*

GNSS correction

Real-time GNSS correction was assured with Croatian Positioning System (CROPOS) which is a GNSS reference station network that is transmitting correction for GPS and GLONASS systems.

Mobile GNSS receivers

For vessel real-time positioning two GNSS receivers were used, primary receiver: JAVAD, Triumph-1 and secondary receiver: JAVAD, TRG3T.

Characteristics: Carrier phase GNSS receivers, that work with GPS, GLONASS and Galileo systems. Horizontal accuracy in RTK mode is ± 2 cm. The survey was carried out in RTK mode. With the two receivers we obtained position as well as orientation/heading of the boat in real-time.

2.4 Inertial measuring unit (IMU)

Teledyne TSS, model DMS-05.

The IMU is used to monitor attitude of the boat (roll, pitch and heave). The data is used for compensation of the sonar data in real-time.

TSS DMS05 is a survey-grade IMO-certified Motion Reference Unit for marine applications. DMS05 provides roll, pitch, and heave even in highly volatile environments.

2.5 Software for navigation and data logging

Navigation was done with professional software package Reson PDS2000. The software enables the integration of the sensors, monitoring the survey and plotting the vessel path in real time at the helmsman post. It gives the operator view of data from the integrated sensors and navigation control according to survey lines and cartographic background. Parametric sub-bottom profiler (SBP) operation and logging was done in Innomar SesWin software.

3. Survey execution

Survey was carried out on Wednesday, March 15th. Since the current tidal prediction was not favourable due to neap tide and high pressure the boat was launched in Savudrija. The final preparations were done at pier in Zambratija where the survey was started.

The survey was concentrated within the round depression where lines were spaced with a grid of about 25 m. The second area of interest was to the NW where the lines were surveyed with a grid of about 50 m. Additionally there were some lines surveyed outside of the primary area of interest on approach or during manoeuvring. All together we surveyed 21 section with combined length of 9 kilometres (Map 1).

4. Results

4.1 Spatial data (geodesy)

Real time horizontal GNSS positions of the boat (WGS84) were online projected into ETRS_HTRS96-TM coordinate system. GNSS heights were transformed in orthometric heights with the use of geoidal separation of -44.05 m.

4.2 SBP sections

The results of the SBP survey were surprisingly good and provide insight into the stratigraphy of the upper sediment layer. There was no penetration through the limestone rock reefs but within the depressions with soft sediment the penetration of the signal was up to 5 m (Fig. 3).

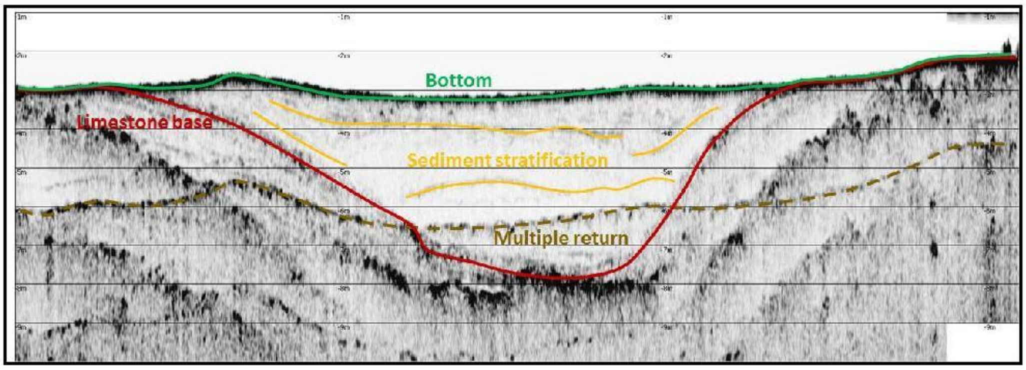


Figure 3: SBP section 1503207123947 with rough interpretation.

5. Conclusion

We were able to finish the survey as expected and obtained usable results.

6. Project team

Aljoša Žerjal, hydrographer, project manager

Dr. Sašo Poglajen, survey execution, data processing and interpretation

Iztok Rant, survey execution and data processing

Rok Soczka Mandac, survey execution

7. Supplements

Map 1: Plan of surveyed SBP sections.

8. Deliverables

Report and supplement in PDF format.

Each SBP section in SES, SGY and JPG format.

SBP lines in Shape file format (SHP).

Harpha sea, d.o.o. Koper

Čevljarska 8

6000 Koper

VAT ID: SI43893252

www.harphasea.com

cale@harphasea.si

Appendix VI The coring fieldwork team. Left to right: Hrvoje Burić (CGS), Dr Ida Koncani Uhač (AMI), the author, Dr Ozren Hasan (CGS), Dr Ivan Razum (CGS).

Appendix VII Underwater archaeological investigation and survey team. Left to right, up: Dr Ida Koncani Uhač (AMI), Alba Ferreira Dominguez (Aix-Marseille), Maja Čuka (AMI), Kurt Bennett (Flinders), Enrique Aragon Nuñez (Flinders). Down: the author and Zambratija local Mr Christian Petretich (Photo: M. Uhač).

Appendix VIII Pre-diving checklists.

Flinders University

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zambratija Bay   Project Prehistoric settlement investigation   Date 30.5.17

Dive Coordinator Kurt Bennett   Surface Attendant Maja Čuka   Coxswains Christian Petretich   Vessel Elan 483

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☑ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☑ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply?	(11) Appropriate weight belt or integrated weights with release?
(2) Air supply turned on and contents of tank read?	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges?	(13) Depth gauge reads zero with maximum depth indicator zeroed?
(4) Breathe to test function of primary and secondary regulator?	(14) Mask, snorkel and fins in good condition?
(5) Purge regulator, check for free flow?	(15) Dive knife sharp and accessible?
(6) Inflator hose connected and operating ok?	(16) Safety sausage with cord?
(7) All dumps functioning?	(17) ~~Safety line~~, Float line, Buddy line or Voice coms? (circle) Anchor line
(8) Tank tightly secured to BCD harness?	(18) Communication protocol understood? Buddy
(9) Suitable exposure protection, gloves, booties, hood and wetsuit?	(19) Shark Shield functioning and turned on prior to entering the water? NA
(10) If dry suit, seals, inflator and dump connected and checked? NA	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	Kurt Bennett (dive coord.)	☑	/	200	120	-3.6	12:02	12:55	53	53	–	[illegible] B	NONE
1	Katarina Jerbic (dive leader)	☑	/	200	115	~3.6	12:02	12:55	53	53	–	[illegible] B	NONE
1	Ida Koncani Uhač	☑	/	200	120	~3.6	12:02	12:55	53	53	–	[illegible] B	NONE
1	Enrique Aragon Nunez	☑	/	200	150	-3.6	12:02	12:55	53	53	–	B	NONE.
~~1~~		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑ Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett. Diver 1 [signature] Diver 2 [signature] Diver 3 [signature] Diver 4 [signature] Diver 5 ____ Diver 6 ____

PRE-DIVE EQUIPMENT CHECKLIST & PRE-DIVE EQUIPMENT CHECK & SAFETY LOG COMBINED_2017_ v1.0.docx

Flinders University   GROUP 1

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zambratija Bay Project Prehistoric settlement investigation Date 31.05.2017.

Dive Coordinator KURT BENNETT Surface Attendant MAJA ČUKA Coxswains Christian Pepercich Vessel Elan 483

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☑ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☑ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply? ✓	(11) Appropriate weight belt or integrated weights with release? ✓
(2) Air supply turned on and contents of tank read? ✓	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges? ✓	(13) Depth gauge reads zero with maximum depth indicator zeroed? ✓
(4) Breathe to test function of primary and secondary regulator? ✓	(14) Mask, snorkel and fins in good condition? ✓
(5) Purge regulator, check for free flow? ✓	(15) Dive knife sharp and accessible? ✓
(6) Inflator hose connected and operating ok? ✓	(16) Safety sausage with cord? ✓
(7) All dumps functioning? ✓	(17) Safety line, Float line, Buddy line or Voice coms? (circle) Anchor line
(8) Tank tightly secured to BCD harness? ✓	(18) Communication protocol understood? Buddy
(9) Suitable exposure protection, gloves, booties, hood and wetsuit? ✓	(19) Shark Shield functioning and turned on prior to entering the water? N/A
(10) If dry suit, seals, inflator and dump connected and checked? N/A	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	Kurt Bennett (Coordinator)	☑	/	210	100	-3.6	10:51	11:59	68	68	–	C	NONE
1	Enrique Aragon	☑	/	200	120	-3.6	10:51	11:59	68	68	–	C	NONE
		☐											
		☐											
		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑ Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett Diver 1 [signature] Diver 2 [signature] Diver 3 ____ Diver 4 ____ Diver 5 ____ Diver 6 ____

PRE-DIVE EQUIPMENT CHECKLIST & PRE-DIVE EQUIPMENT CHECK & SAFETY LOG COMBINED_2017_ v1.0.docx

Flinders University GROUP 2

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zambratija Bay Project Prehistoric settlement investigation Date 31.05.2017.

Dive Coordinator KURT BENNETT Surface Attendant ENRIQUE ARAGON Coxswains Christian Ketchum Vessel ELAN 483

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☐ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☐ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply?	(11) Appropriate weight belt or integrated weights with release?
(2) Air supply turned on and contents of tank read?	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges?	(13) Depth gauge reads zero with maximum depth indicator zeroed?
(4) Breathe to test function of primary and secondary regulator?	(14) Mask, snorkel and fins in good condition?
(5) Purge regulator, check for free flow?	(15) Dive knife sharp and accessible?
(6) Inflator hose connected and operating ok?	(16) Safety sausage with cord?
(7) All dumps functioning?	(17) Safety line, Float line, Buddy line or Voice coms? (circle)
(8) Tank tightly secured to BCD harness?	(18) Communication protocol understood?
(9) Suitable exposure protection, gloves, booties, hood and wetsuit?	(19) Shark Shield functioning and turned on prior to entering the water? N/A
(10) If dry suit, seals, inflator and dump connected and checked? N/A	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	Ida Koncani Uhač (leader)	☑	/	210	120	-3.6	12:40	13:35	55	55	–	C	NONE
1	Katarina Jelić	☑	/	220	140	-3.6	-11-	-11-	55	55	–	C	NONE
1	Maja Čuka	☑	/	220	120	-3.6	-11-	-11-	55	55	–	C	NONE
		☐											
		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑ Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett Diver 1 I. Koncani U. Diver 2 Katarina Jelić Diver 3 Maja Čuka Diver 4 ______ Diver 5 ______ Diver 6 ______

Flinders University GROUP 1

✓ = we have
/ = don't have

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zambratija Bay Project Prehistoric settlement investigation Date 01.06.2017.

Dive Coordinator KURT BENNETT Surface Attendant MAJA ČUKA Coxswains Christian Petrović Vessel Elan 403

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☑ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☑ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply?	(11) Appropriate weight belt or integrated weights with release?
(2) Air supply turned on and contents of tank read?	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges?	(13) Depth gauge reads zero with maximum depth indicator zeroed?
(4) Breathe to test function of primary and secondary regulator?	(14) Mask, snorkel and fins in good condition?
(5) Purge regulator, check for free flow?	(15) Dive knife sharp and accessible? /
(6) Inflator hose connected and operating ok?	(16) Safety sausage with cord? /
(7) All dumps functioning?	(17) Safety line, Float line, Buddy line or Voice coms? (circle)
(8) Tank tightly secured to BCD harness?	(18) Communication protocol understood?
(9) Suitable exposure protection, gloves, booties, hood and wetsuit?	(19) Shark Shield functioning and turned on prior to entering the water?
~~(10) If dry suit, seals, inflator and dump connected and checked?~~ NA	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	KURT BENNETT	☑	/	210	100	3.5	09:03	10:13	70	70	70	C	NONE
1	ENRIQUE ARAGON	☑	/	210	100	3.5	09:03	10:13	70	70	70	C	NONE
		☐											
		☐											
		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑ Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett Diver 1 [signature] Diver 2 [signature]
Diver 3 ______ Diver 4 ______ Diver 5 ______ Diver 6 ______

PRE-DIVE EQUIPMENT CHECKLIST & PRE-DIVE EQUIPMENT CHECK & SAFETY LOG COMBINED_2017_ v1.0.docx

Flinders University

Group 2

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zaumbratja Bay Project Prehistoric Settlement investigation Date 02.06.2017

Dive Coordinator KURT BENNETT Surface Attendant ENRIQUE ARAZ Coxswains Christian Petoerich Vessel Elan 483

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☑ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☑ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply?	(11) Appropriate weight belt or integrated weights with release?
(2) Air supply turned on and contents of tank read? ✓	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges?	(13) Depth gauge reads zero with maximum depth indicator zeroed?
(4) Breathe to test function of primary and secondary regulator?	(14) Mask, snorkel and fins in good condition?
(5) Purge regulator, check for free flow?	(15) Dive knife sharp and accessible?
(6) Inflator hose connected and operating ok?	(16) Safety sausage with cord?
(7) All dumps functioning?	(17) Safety line, Float line, Buddy line or Voice coms? (circle)
(8) Tank tightly secured to BCD harness?	(18) Communication protocol understood?
(9) Suitable exposure protection, gloves, booties, hood and wetsuit?	(19) Shark Shield functioning and turned on prior to entering the water?
(10) If dry suit, seals, inflator and dump connected and checked?	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Time in (Air Out (B^{ar}/P^{SI}))	Depth (m)	Time out (Time In (24H:00))	Air out (Time Out (24H:00))	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	IDA KANCAN UHAČ	☑	/	195	11:05	-3.6	12:20	110	75	75	75	C	NONE
1	ALBA FERREIRA DOMINGUES	☑	/	220	12:10	-3.6	13:20	70	70	70	70	C	NONE
1	MAJA ČUKA	☑	/	210	11:05	-3.6	12:20	110	75	75	75	C	NONE
1	KATARINA JERBIĆ	☑	/	210	12:05	-3.6	13:20	50	70	70	70	C	NONE
		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑ Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett Diver 1 I. Kancan Diver 2 [signature] Diver 3 Maja Čuka Diver 4 [signature] Diver 5 ______ Diver 6 ______

PRE-DIVE EQUIPMENT CHECKLIST & PRE-DIVE EQUIPMENT CHECK & SAFETY LOG COMBINED_2017_ v1.0.docx

Flinders University

PRE-DIVE EQUIPMENT CHECKLIST & DIVE SAFETY LOG (cd)

Dive Location Zambratija Bay Project Prehistoric settlement Date 2.6.2017.
Dive Coordinator Kurt Bennett Surface Attendant Maja Coxswains Christian Peledrih Vessel Elan 483

Pre-dive daily checks: First Aid Kit ☑ Oxygen Cylinder ☑ Shark sighting logs ☑ **Prior to each dive:** Dive Flag ☑ Boat shark shield ☑ Dive ladder ☑

Pre-dive equipment checks: Must be performed under the supervision of the Dive Coordinator for all dives. Only dive equipment which has been serviced annually and is in good condition is permitted.

(1) Contents gauge at zero before turning on air supply?	(11) Appropriate weight belt or integrated weights with release?
(2) Air supply turned on and contents of tank read?	(12) Watch, timing device or dive computer?
(3) Any leaking hoses and or faulty gauges?	(13) Depth gauge reads zero with maximum depth indicator zeroed?
(4) Breathe to test function of primary and secondary regulator?	(14) Mask, snorkel and fins in good condition?
(5) Purge regulator, check for free flow?	(15) Dive knife sharp and accessible?
(6) Inflator hose connected and operating ok?	(16) Safety sausage with cord?
(7) All dumps functioning?	(17) Safety line, Float line, Buddy line or Voice coms? (circle)
(8) Tank tightly secured to BCD harness?	(18) Communication protocol understood?
(9) Suitable exposure protection, gloves, booties, hood and wetsuit?	(19) Shark Shield functioning and turned on prior to entering the water?
(10) If dry suit, seals, inflator and dump connected and checked?	(20) Diver fit, healthy and able to perform the dive?

Dive No.	Diver's Name & Classification	Equipment checked	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Equipment faults or Comments
1	Kurt Bennett	☑	/	210	150	3.5	0900	1000	60	60	60	B	NONE
1	Ida Koncani Uhač	☑	/	210	120	3.5	0900	1000	60	60	60	B	NONE
		☐											
		☐											
		☐											
		☐											

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**
3. * RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

Validated: Daily on-site risk assessment done ☑ All safe ☑
Pre-dive briefing given ☑ Post dive diver health ok ☑

Signed: Dive Coordinator Kurt Bennett Diver 1 [signature] Diver 2 ____
Diver 3 ____ Diver 4 ____ Diver 5 ____ Diver 6 ____

PRE-DIVE EQUIPMENT CHECKLIST & PRE-DIVE EQUIPMENT CHECK & SAFETY LOG COMBINED_2017_ v1.0.docx

Flinders University

DAILY DIVE SAFETY LOG (d)

Dive Location Zambratija Bay Project Prehistoric settlement investigation Date 02.06.2017

Dive Coordinator Kurt Bennett Surface Attendant Maja Čuka Coxswains Christian Petrović Vessel Elan 483

Dive No.	Diver's Name & Classification	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Comments
1	ALBA FERREIRA DOMINGUEZ	/	210	150	3.5	10:28	11:05	37	37	37	B	NONE
1	KATARINA JERBIĆ	/	220	150	3.5	-"-	-"-	37	37	37	B	NONE

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**

VALIDATED:

Daily on-site risk assessment ☑ Pre-dive briefing ☑

All safe ☑ Post dive diver health ok ☑

Dive Coordinator **SIGNED ;**

SIGNED ; Diver 1 Diver 2 Diver 3 Diver 4 Diver 5 Diver 6 Diver 7 Diver 8

* RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

DAILY DIVE SAFETY LOG_2017_v1.0.docx

Flinders University

DAILY DIVE SAFETY LOG

(d)

Dive Location Zambratija Bay Project Prehistoric settlement investigation Date 03/06/2017

Dive Coordinator Kurt Benett Surface Attendant Ida Koncani Uhač Coxswains Christian Petretich Vessel Elan 483

Dive No.	Diver's Name & Classification	RF In	Air In (B^{ar}/P^{SI})	Air Out (B^{ar}/P^{SI})	Depth (m)	Time In (24H:00)	Time Out (24H:00)	Total Time (min)	Bottom Time (min)	Effective Bottom Time (min)	RG Out	Comments
1	KATARINA JERBIĆ	/	200	150	-3,6	11:40	12:22	42	42	42	B	NONE
1	KURT BENETT	/	~~150~~ 200	150	-3,6	11:40	12:22	42	42	42	B	NONE
1	MAJA ČUKA	—	—	—	—	-11-	12:10	30	30	30	—	APNEA/snorkling only.

1. **IN CASE OF EMERGENCY;** in Australia call Emergency Services (Police, Fire & Ambulance) **000**, Divers Emergency Service **1 800 088 200**, Flinders University Security **82012 2880**, UBDO (Matt Lloyd) **0414 190 051**
2. This log sheet must be submitted to the UBDO at the completion of the diving trip. 3. **All accidents, incidents, near misses or equipment failure must be logged and reported to the UBDO immediately.**

VALIDATED:

Daily on-site risk assessment ☑ Pre-dive briefing ☑

All safe ☑ Post dive diver health ok ☑

Dive Coordinator **SIGNED ;**

SIGNED ; Diver 1 [illegible] Diver 5

Diver 2 [illegible] Diver 6

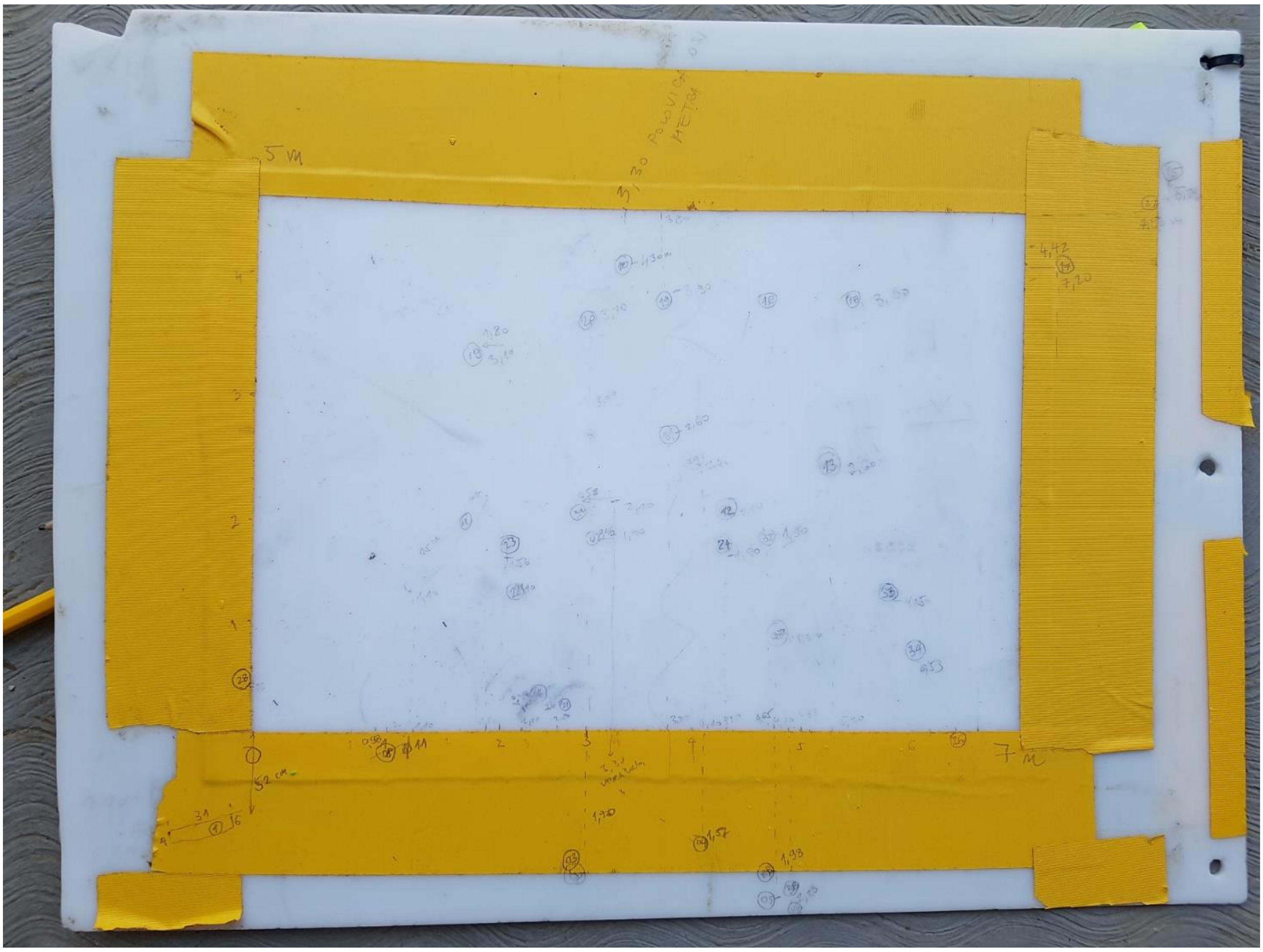
Diver 3 [illegible] Diver 7

Diver 4 Diver 8

* RG = Repetitive Dive Group, RF = Repetitive Factor (after Surface Interval) from DCIEM Tables. ** Effective Bottom Time = RF x Bottom Time. *** m = metres

DAILY DIVE SAFETY LOG_2017_v1.0.docx

Appendix IX Original underwater drawing.



Appendix X Troels-Smith procedure.

Description of coastal sediments

The standard system for describing unconsolidated sediments is that of Troels-Smith (1955). While somewhat daunting in its use of Latin terms, it does provide an international system for comparison and serves a checklist for the characteristics to record. However, it is still dependent to some extent on the expertise and experience of the operator. Although some guidelines are given below, description of sediments is not easy and it is recommended that someone with experience be consulted if at all possible.

Sediment description of Troels-Smith (1955)

This a simplified guide to this system of sediment description, adapted to coastal sediments. Full Latin names for the characteristics and components are given but the abbreviations (in bold type) are more commonly used. For a more detailed description see Long et al. (1999), Troels-Smith (1955), Birks and Birks (1980) or the slightly modified version in Aaby and Berglund (1986).

Apart from using the Troels-Smith scheme, it is also useful to give a generic description in uncoded language, e.g. 'slightly organic, laminated, sandy dark-grey clay', or 'woody darkbrown peat with *Phragmites* remains'. It is best to record the colour as accurately as possible with reference to a Munsell soil colour chart. This should be done as soon as possible after collection of the sediments as colours can fade or change very quickly on exposure to air due to oxidation.

Characteristics

Darkness	*nigror* (***nig.***)	where 0 = white, 4 = black.
Stratification	*stratificatis* (***strf.***)	where 0 = homogenous, 4 = very thin minor layers.
Elasticity	*elasticas* (***elas.***)	where 0 = plastic clay, 4 = fresh *Sphagnum* moss.
Dryness	*siccitas* (***sicc.***)	where 0 = water, 4 = air dry.
Nature of upper contact	*limes* (***lim.***)	where 0 = diffuse (> 1 cm) 1 = very gradual (between 2 mm and 1 cm) 2 = gradual (between 1 and 2 mm) 3 = sharp (between 0.5 and 1 mm) 4 = very sharp (< 0.5 mm)

Components

Estimated on a four point scale where 1 = 0-25%, 2 = 25-50%, 3 = 50-75%, 4 = 75-100%. When needed, a + can be used to indicate a 5% component (++ = 10%). A good hand lens (x8 - x20) helps greatly in identifying components.

Peats:

Th *Turfa herbacea* Herbaceous peat. Usually composed of grass and sedge roots.

Long pale brown roots can often be clearly seen, sometimes with thick rhizomes of species such as *Phragmites*, *Typha* and *Scirpus*. Fine herbaceous roots appear as a mass of pale translucent wormlike fragments, each with a central bundle of more opaque appearance, when examined under a dissecting microscope.

Tl *Turfa lignosa* Wood peat. Composed of short fibres. Sometimes recognisable twigs, branches and bark present.

Sh *Substantia humosa* Highly decayed, unrecognisable organic remains. Amorphous, black with very fine matrix.

Fragments:

Dh *Detritus herbosus* Fragments of herbaceous plants over 2mm (stems, leaves etc.)

Dl *Detritus lignosus* Woody fragments over 2mm

Dg *Detritus granosus* Animal and plant fragments 0.1-2mm.

Minerogenic sediments:

As	*Argilla steatodes*	<0.002mm, clay
Ag	*Argilla granosa*	0.002-0.06mm, silt
Ga	*Grana arenosa*	0.06-0.6 mm, fine and medium sand.
Gs	*Grana suburralia*	0.6-2 mm, coarse sand.
Gg	*Grana glareosa*	2-20mm, gravel.

Other remains should also be noted - for example snails, shells, archaeological remains, individual seeds, larger plant remains such as tree stumps etc. Some of these have official Troels-Smith terms. The important thing is to obtain as much information as possible from the descriptions of the sediments, especially bearing in mind the purpose of the individual study. Troels-Smith (1955) also provides a standard set of symbols for representing different sediment types. This should be used whenever stratigraphic profiles are drawn.

(Text adapted from: Kent, M., Gilbertson, D., Charman, D., and Pyatt, B., in preparation, Practical Ecology, Chapman & Hall).

References

Aaby. B. and Berglund, B.E., 1986, Characterization of peat and lake deposits, in: Berglund, B.E., ed., Handbook of Holocene Palaeoecology and Palaeohydrology, John Wiley, p. 231-246.

Birks, H.J.B. and Birks, H.H., 1980, Quaternary Palaeoecology, Edward Arnold.

Long, A.J., Innes, J.B., Shennan, I. and Tooley, M.J., 1999, Coastal stratigraphy: a case study from Johns River, Washington. In: Jones, A.P., Tucker, M.E. & Hart, J.K. (eds) The description and analysis of Quaternary stratigraphic field sections. Quaternary Research Association Technical Guide 7, Quaternary Research Association, London, pp. 267-286.

Troels-Smith, J., 1955, Karakterisering af lose jordater (Characterization of unconsolidated sediments): Danmarks Geologiske Undersøgelse, IV Series, v. 3, no. 10, p. 1-73.

EXAMPLE

Site	:	Holbeton Wood	Authors	: Group 1	
Core	:	HBW-1	Corer type	: Eijkelkamp gouge	
Date	:	18/10/97	Ground altitude	: 2.10 m OD	
Time	:	14:15	Grid reference	: 624499	

Depth (cm)	description and components	Nig	Strf	Sicc	Elas	Lim
0-22	grey sandy silt Ag3 Ga1	2	0	2	0	-
22-53	brown sandy silt with (*Juncus*?) plant rhizomes Ag2 Ga1 Th1	3	0	2	0	1
53-78	darkbrown silty *Phragmites* peat, with a trace of sand Th3 Ag1 Ga+	4	0	1	1	2
78-102	blue clayey silt, laminated, some shells with woody fragments As2 Ag2 Dl+ Dg+	2	2	2	0	2
102-104	brown piece of wood Dl4	3	0	1	1	4
104-160	grey-brown organic-rich silt with detrital plant material Ag4 Sh++ Dh+	2+	0	1	0	4
160	end of core					

Appendix XI Dendrochronology report.

Dendrochronological study of 20 timbers Zambratija site (Croatia)

K. Zerbic (Flinder University, Australia)

Report

L. Shindo
Aix-en-Provence, November 2017

Document attached:
File of dendrochronological measurements (“ZAMB_measurements.xlsx”)

Recipient
Katarina Jerbic, phD Candidate, Department of Archaeology, School of Humanities and creative Arts, Flinders University

Dendrochronological study
Lisa Shindo, doctor, dendrochronologist, Centre Camille Jullian associated researcher
CCJ, UMR CNRS 7299, Aix-en-Provence
0033 6 33 08 31 16, shindo@mmsh.univ-aix.fr
French Auto-enterprise : SIRET : 817 931 207 000 10 / APE : 7490B

Centre Camille Jullian
Histoire et archéologie de la Méditerranée et de l'Afrique du Nord de la Protohistoire à la fin de l'Antiquité

Table of contents

All pictures and figures are from the author.

1- Presentation

During spring 2017, Alba Ferreira (Centre Camille Jullian, France) and Katarina Zerbic (Flinders University, Australia) sampled some poles in Zambratija site, in Croatia. Poles' top ends were sawed, labelled and wraped into cellophane to keep them wet. The samples were bring to France for their study, in the Centre Camille Jullian (CNRS laboratory in Aix-en-Provence).

Zambratija site is studed by K. Zerbic for her Ph. D. thesis, in order to reconstruct the paleoenvironment in Zambratija bay and to observe its influences on the human settlement.

2- Methodology

Samples preparation

Firstly, we took pictures of the samples. Then, we cut a section with a cutter blade in order to have a comfortable access to the transversal section, where tree ring thickness is measured.

Then, some rays (between one and four) were cleaned up with a razor blade on each sample (Figure 1).

Finally, after the study, the samples will be wraped again and store in the Dendrothèque (archaeological woods warehouse) in Aix-en-Provence.

Wood anatomy

Thin sections are taken off in the three wood sections (transversal, tangential and radial). Then, they are examinated with a microscope in order to determine wood variety.

Tree rings measurment

Ring widths were measured using the incremental measuring table LINTAB with 0.01mm accuracy and TSAP-Win software (Rinntech Company, Heidelberg, Deutschland). Then, the tree-ring series were cross-dated. Cross-dating was carried out by means of DENDRON IV software (developed with RunRev LiveCode, Edinburgh, Scotland, by G.-N. Lambert CNRS, University of Franche-Comté, Besançon, France and Univesity of Liege, Belgium. Version: 20150221).

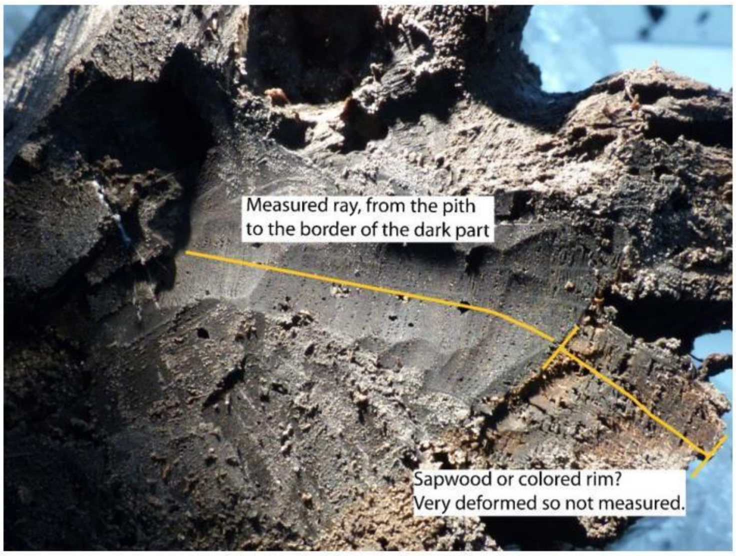


Figure 1 : Exemple of a tree ring measurment, on a ray cleaned up with a razor blade. Perpendicular to the first yellow line, we can see the pores in the beginning of each tree ring (sample ZAMB_04).

Tree ring synchronisation

The first objective is to date wood pieces. In reality, the dendrochronologist is dating the tree's death, wich is the tree's felling date.

The tree's felling date is given by the last tree ring, the one just under the cambium (between sapwood and phloem), when it is preserved (Figure 2). If cambium is missing and a part of sapwood is preseved, larch and oak felling dates is estimated and defined by an interval between the last measured ring's date, and the maximal probable sapwood's date. Finally, when sapwood is totally missing, we propose a *post quem* felling date, after the last hardwood measured ring.

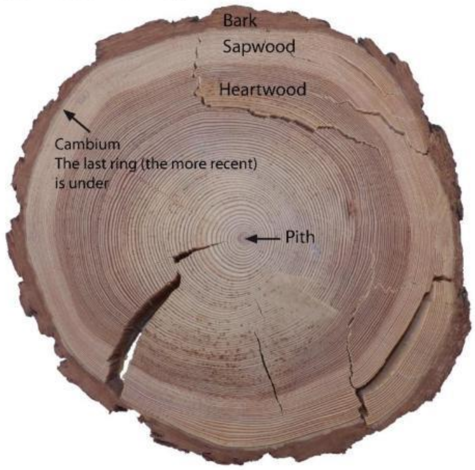


Figure 2 : Transversal section of a larch tree, with distinctive heartwood and sapwood. Location of the wood main parts (pith, heartwood, sapwood, cambium and bark).

3- Results and interpretations

Wood observation

The 20 samples have the same anatomy (macroscopic identification). To confirm this observation, A. Ferreira determined the wood varety of four samples: they are all oaks (Quercus sp.) (Table 1).

Due to a long stay in the seawater, all the samples have shipworm galleries so the wood structure is weaked and very breakable.

Several samples present irregular growth rhythms, with sets of narrow rings. Climatic, ecological and/or anthropic difficulties are the cause of these rings.

Cross-dating

Eleven of the 19 measured samples are synchronised. The average chronology has 62 years (Figure 3 and Figure 4). This average is not dated for the moment because we do not have master chronology (reference chronology) for Croatian prehistoric oaks.

In the square matrix (Figure 5), there are three different groups:

1) ZAMB_17, 18, 13, 33 and 23
2) ZAMB_23, 04 and 29
3) ZAMB_29, 19, 20, 24 and 05

The correlation in each of these groups are particularly strong.

Nine samples are not synchronised, neither with the average chronology, nor between them. They have between seven tree rings (ZAMB_07_1) and 40 tree rings (ZAMB_10).

4- Conclusions and prospects

Twenty poles from Zambratija sites were studied. They are all in oak (*Quercus* sp.).

Nineteen, with good dendrochronological series were measured, and 11 of them are synchronized. Their average chronology (62 rings) is not dated for the moment.

We send this average to F. Langenegger (Service de l'Archéologie de l'Office du Patrimoine du Canton de Neuchâtel (OPAN), Switzerland) and N. Martinelli (Dendrodata s.a.s., Verona, Italy) because they may have master chronologies for this period.

Then, Radiocarbon laboratory at Glasgow University (GB) will do two radiocarbon analysis (AMS). It will be a precious information to situate the average chronology in the time.

Later, if other poles are sampled, it will be very interesting to study them with dendrochronology to develop the average chronology and/or to build another one.

5- Further reading: bibliographic reference

BILLAMBOZ A., 2008, Dealing with heteroconnections and short tree-ring series at different levels of dating in the dendrochronology of the Southwest German pile-dwellings, *Dendrochronologia*, 26, p. 145-155

BILLAMBOZ A., MARTINELLI O., 2015, Dendrochronology and Bronze Age pile-dwellings on both sides of the Alps: from chronology to dendrotypology, highlighting settlement developments and structural woodland changes, MENOTTI F. (dir), The end of the lake-dwellongs in the cirum-alpine region, Oxbow books, p. 68-84

DUROST S., LAMBERT G.-N., 2006, Révision dendrochronologique du Nord de la France à l'âge du Fer et au début de l'époque romaine, BARRAL P., DAUBIGNEY A., DUNNING C., KAENEL G., ROULIERE-LAMBERT M.-J. (eds.), L'âge du Fer dans l'arc jurassien et ses marges. Dépôts, lieux sacrés et territorialité à l'âge du Fer. Actes du XXIXe colloque international de l'AFEAF, Bienne, 5-8 mai 2005, Besançon, Presses Universitaires de Franche-Comté.

KAENNEL M., SCHWEIGRUBER F. H., 1995, Multilingual Glossary of Dendrochronology. Terms and Definitions in English, German, French, Spanish, Italian and Russian, Paul Haupt, 467 p.

LAMBERT G.-N., 2006, Dendrochronologie, histoire et archéologie, modélisation du temps. Le logiciel Dendron II et le projet Historik Oaks, V1 et V2, Habilitation à diriger les recherches, Besançon, 152 p. et 206 p.

LAMBERT G.-N, BERNARD V., DUPOUEY J.-P., FRAITURE P., GASSMANN P., GIRARDCLOS O., LEBOURGEOIS F., LEDIGOL Y., PERRAULT C., TEGEL W., 2010, dendrochronologie et dendroclimatologie du chêne en France : questions posées par le transfer de données de bois historiques vers la dendroclimatologie, ASTRADE L. et MIRAMONT C. (dir.), Actes du colloque « Panorama de la dendrochronologie en France, 8,9 et 10 octobre 2009, Digne-les-Bains, Alpes de Haute Provence », collection Edytem, 11, p. 205-216

MARTINELLI N., 2013, Dendro-typology in Italy : the case studies of the pile-dwelling villages Lucone D (Brescia) and Sabione (Varese), BLEICHER N., SCHLICHTHERLE H., GASSMANN P., MARTINELLI O. (dir), Dendro -chronologie -typologie -ökologie. Festschrift für André Billamboz zum 65. Geburtstag, Hemmenhofener Skripte, Band 10. Janus-Verlag, p. 117-124

SCHWEINGRUBER F. H., 1978, Mikroskopische holzanatomie: Anatomie microscopique du bois, Birsmensdorf : Institut Fédéral de Recherches Forestières, Zürcher AG, Zug, 226 p.

SCHWEINGRUBER F. H., 1988, Tree rings. Basics and Applications of dendrochronology, De Reidel Publishing Company, 276 p.

SHINDO L., 2016, Bois de construction et ressources forestières dans les Alpes du sud au IIe millénaire. Dendrochrono-écologie et archéologie, thèse de doctorat, Aix-Marseille Université, 935 p. (https://hal-sde.archives-ouvertes.fr/tel-01325760/)

WINIGER A., 2008, La station lacustre de Concise 1, Statigraphie, datations et contexte environnemental. Avec les contributions de E. Burri, M. Magny, J.-P. Hurni, C. Orcel et J. Tercier, Cahiers d'archéologie romande, Lausanne, 111, 211 p.

Appendix 1: Dendrochronological analysis documents

Code	Specie	number of tree rings	pith	Rim precision
ZAMB_04	*Quercus* sp.	28	yes	+ aprox. 20 (crushed rings)
ZAMB_05	*Quercus* sp.	26	yes	+1
ZAMB_07_1	*Quercus* sp.	7	no	+ ?? Illegible
ZAMB_08	*Quercus* sp.	39	yes	+4-5
ZAMB_10	*Quercus* sp.	40	almost	+10 crushed
ZAMB_12	*Quercus* sp.	13	yes	+ many
ZAMB_13	*Quercus* sp.	28	yes	+10 + all the colored part (sapwood ?)
ZAMB_14	*Quercus* sp.	11	no	+1
ZAMB_15	*Quercus* sp.	33	no	+1
ZAMB_17	*Quercus* sp.	16	no	+ aprox 10 crushed
ZAMB_18	*Quercus* sp.	24	no	+ many
ZAMB_19	*Quercus* sp.	15	no	+1
ZAMB_20	*Quercus* sp.	29	yes	+1
ZAMB_23	*Quercus* sp.	56	yes	+1
ZAMB_24	*Quercus* sp.	20	yes	+1
ZAMB_25	*Quercus* sp.	28	yes	+ many crushed rings
ZAMB_28	*Quercus* sp.	/	/	/
ZAMB_29	*Quercus* sp.	43	yes	+12
ZAMB_33	*Quercus* sp.	27	yes	+ all the colored part (sapwood ?)
ZAMB_35_1	*Quercus* sp.	8	no	+2

/ = too deformed, not measured.

Table 1: Description and results of the 20 samples dendrochronological analysis.

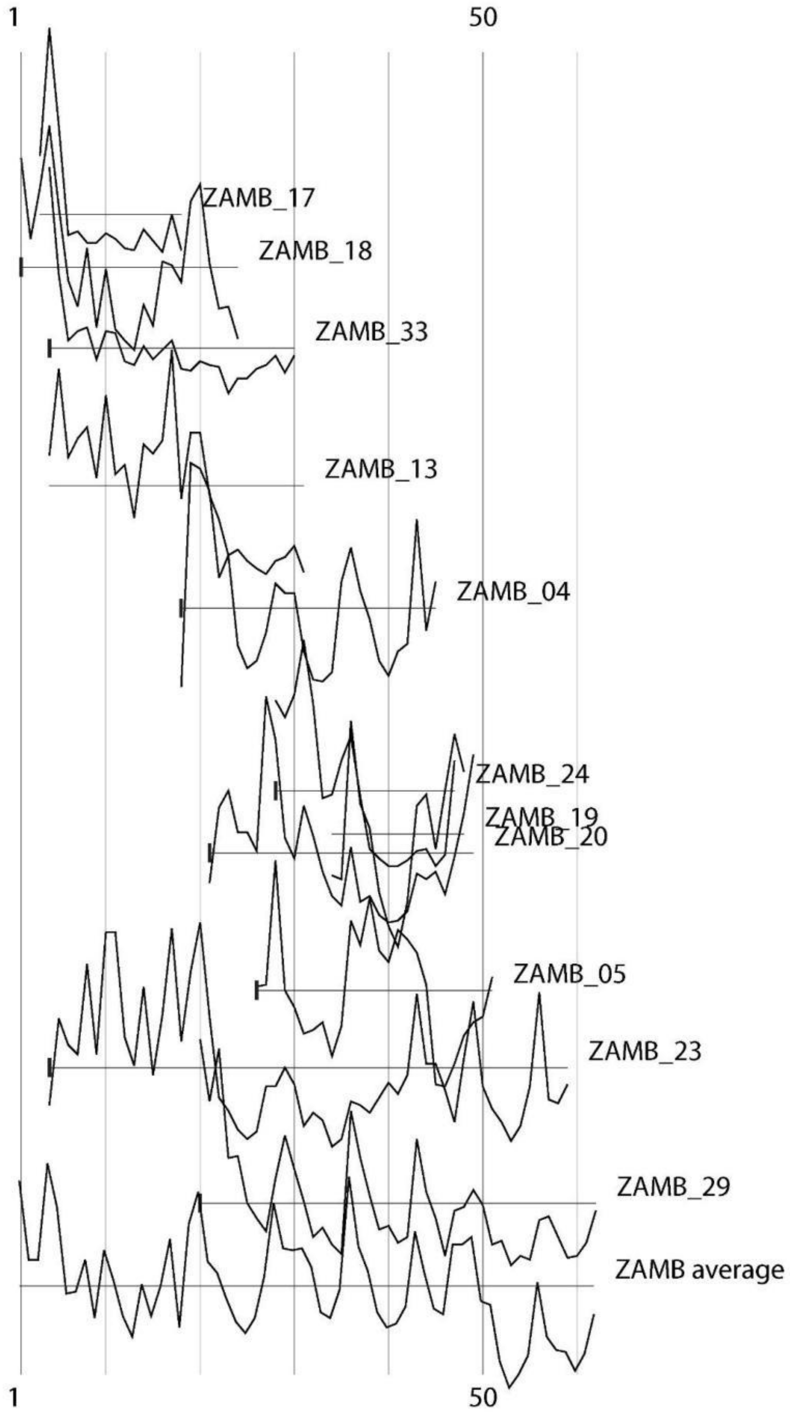


Figure 3 : Synchronisation position of the 11 correlated growth chronologies (**raw data**). In the graph lower part, the average chronology is represented.

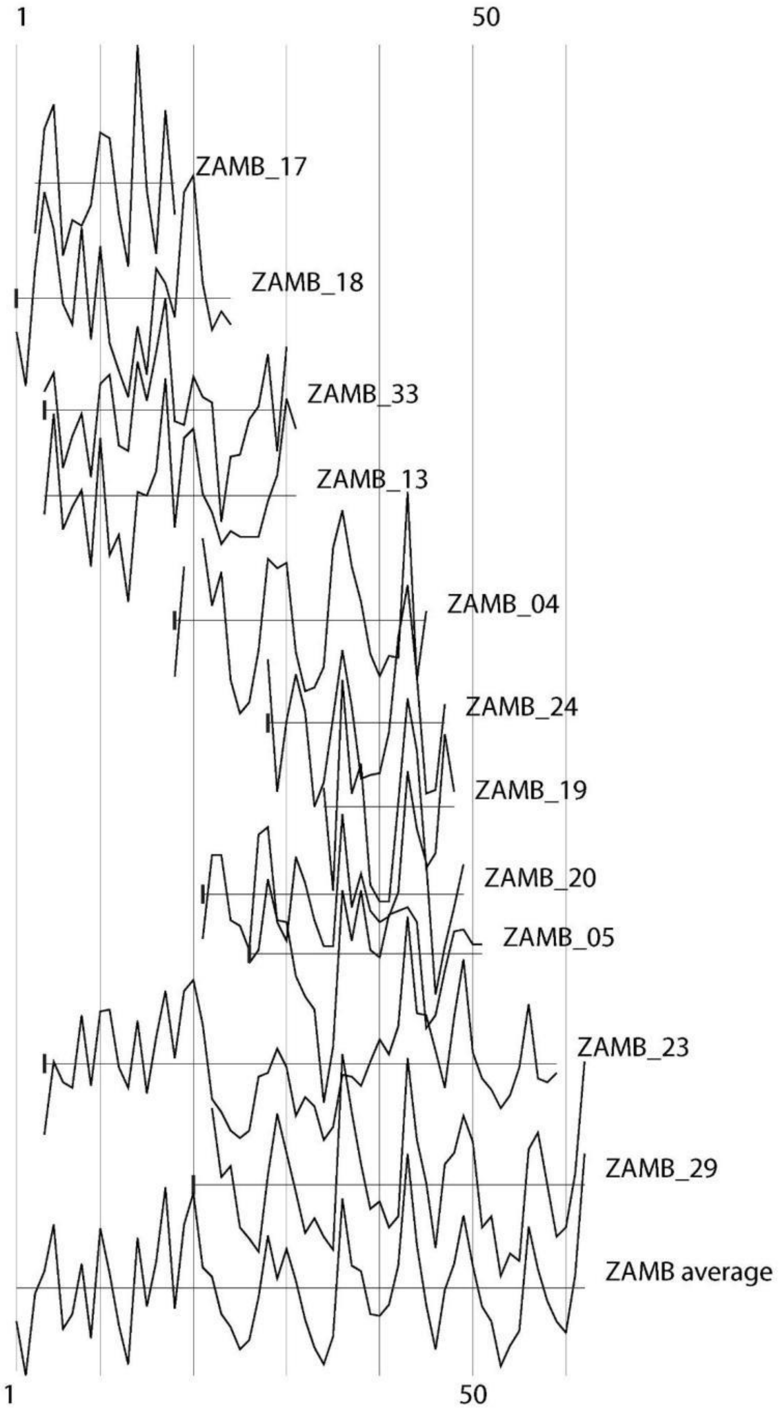


Figure 4 : Synchronisation position of the 11 correlated growth chronologies (**Corridor indexing**). In the graph lower part, the average chronology is represented.

12

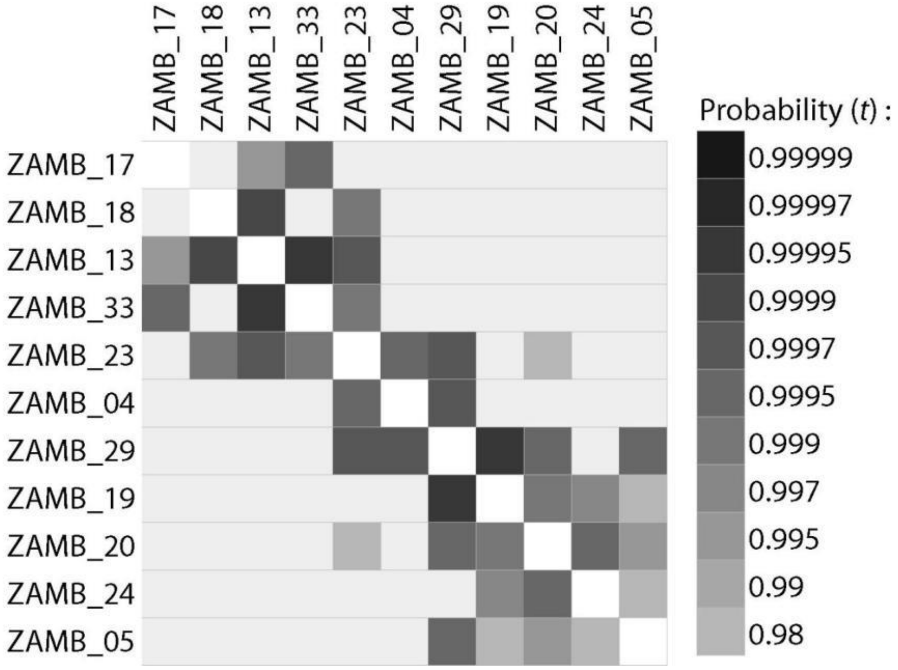


Figure 5 : Square matrix of Student test probability for the 11 correlated growth chronologies (indexing with the Corridor method (Lambert 2006)). The darker is the box, the higher is the correlation between the site series (matrix automatically drawn by Dendron IV software Lambert 2014).

Appendix 2: Ring width values

Ring width values of the 20 samples, 1/100 mm, TSAP format (Heidelberg) :

```
HEADER:
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DateEnd=3028
KeyCode=ZAMB_04
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Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
  52  273  267  245  159  182   93   70   77
106
 153  144  145   88   60   57   67  156  188
146
 119   78   64   87   95  217  107  155    0    0
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DateEnd=3026
KeyCode=ZAMB_05
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
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 209  212  397  203  180  139  146  157  106
150
 309  271  343  264  245  295  279  260  213
63
  61   96  136  156  166  224    0    0    0    0
HEADER:
DataFormat=Tree
Length=7
DateBegin=3001
DateEnd=3007
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Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Single curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
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 439  546  571  254  285  556  332    0    0
0
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Length=39
DateBegin=3001
DateEnd=3039
KeyCode=ZAMB_08
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
 247  259  198  195  160   75   71   85  120
131
 174  209  188  146  156  108   88  137  165
165
 188  219  216  150  124  142  186  197  181
142
 126  248  165  126  105   93   88   97  142
0
HEADER:
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Length=40
DateBegin=3001
```

DateEnd=3040
KeyCode=ZAMB_10
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
SapWoodRings=21
DATA:Single
145 77 127 82 150 116 74 64 65
69
53 65 83 63 56 103 257 227 191
152
137 95 92 74 80 97 102 154 117
67
55 36 48 55 69 55 50 42 49 34
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Length=13
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DateEnd=3013
KeyCode=ZAMB_12
Location=Zambratija_Croatia_KatarinaZerbic
Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
SapWoodRings=2
Unit=1/100 mm
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SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
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BibliographyCount=0
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116
199 215 85 0 0 0 0 0 0 0
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DateBegin=3001
DateEnd=3028
KeyCode=ZAMB_13
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
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108
178 170 182 270 125 190 190 129 105
72
76 65 58 53 66 69 80 54 0 0
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Length=11
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DateEnd=3011
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Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
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SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
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244
430 0 0 0 0 0 0 0 0 0
HEADER:
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DateEnd=3033
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Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
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54 63 67 93 85 75 60 59 87 53
64 43 54 0 0 0 0 0 0 0
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Species=QUSP
Dated=Undated
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WaldKante=---
Unit=1/100 mm
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SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
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40 57 48 39 70 40 0 0 0 0
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DateEnd=3024
KeyCode=ZAMB_18
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Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
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136
82 71 63 104 85 143 140 125 198
214
142 100 102 74 0 0 0 0 0 0
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Length=15
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DateEnd=3015
KeyCode=ZAMB_19
Location=Zambratija_Croatia_KatarinaZerbic
Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
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SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
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279
293 216 299 380 326 0 0 0 0 0
HEADER:
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Length=29
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DateEnd=3029
KeyCode=ZAMB_20
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
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CommentCount=0
BibliographyCount=0
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129
202 161 113 79 67 145 71 79 52
43
45 58 110 103 111 81 132 191 270
0
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KeyCode=ZAMB_23
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Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
SeriesStart=Ringwidth

SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
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112
190 102 163 248 136 204 254 160 81
67
48 40 46 91 92 110 93 53 65 58
32 40 76 73 65 81 95 84 103 182
113 113 87 57 119 176 92 69 57
37
52 91 184 79 75 94 0 0 0 0
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Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
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SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
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DATA:Single
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218
99 78 60 60 74 95 97 60 87 295
HEADER:
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DateEnd=3028
KeyCode=ZAMB_25
Location=Zambratija_Croatia_KatarinaJerbic
Species=QUSP
Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Mean curve
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ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
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294
272 184 208 69 70 68 63 73 94
212
119 99 63 48 102 134 112 124 0 0
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DateEnd=3043
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Location=Zambratija_Croatia_KatarinaJerbic
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Dated=Undated
Pith=P
WaldKante=---
Unit=1/100 mm
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SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
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195
158 121 82 92 74 62 223 171 127
90
94 75 82 192 133 102 61 111 116
135
118 73 78 50 60 56 100 104 81 59
60 76 112 0 0 0 0 0 0 0
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DateEnd=3027
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Species=QUSP
Dated=Undated
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WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
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SeriesStart=Ringwidth
SeriesEnd=Ringwidth
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ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
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130
172 145 163 184 123 119 140 130 127
72

103 105 123 130 152 116 152 0 0
0
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DateEnd=3008
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Species=QUSP
Dated=Undated
Pith=-
WaldKante=---
Unit=1/100 mm
DataType=Ringwidth
SeriesType=Single curve
SeriesStart=Ringwidth
SeriesEnd=Ringwidth
GlobalMathCommentCount=0
ImageCount=0
CommentCount=0
BibliographyCount=0
DATA:Single
328 420 308 179 76 65 279 177 0
0

Appendix XII All sampled wooden piles from Zambratija Bay (All photos: K. Jerbić).

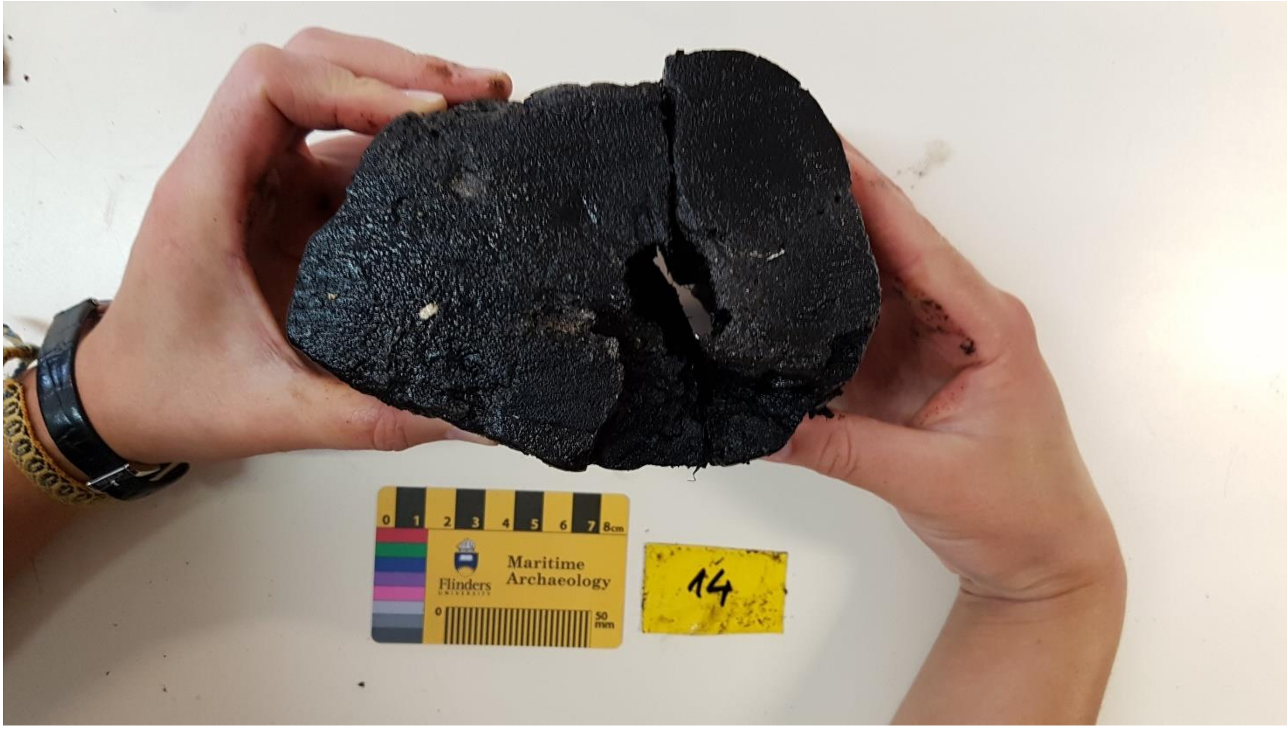
Pile 07


ZAMBRATIJA 17
ZAMB 17 / PRL 12
N · 12
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
12

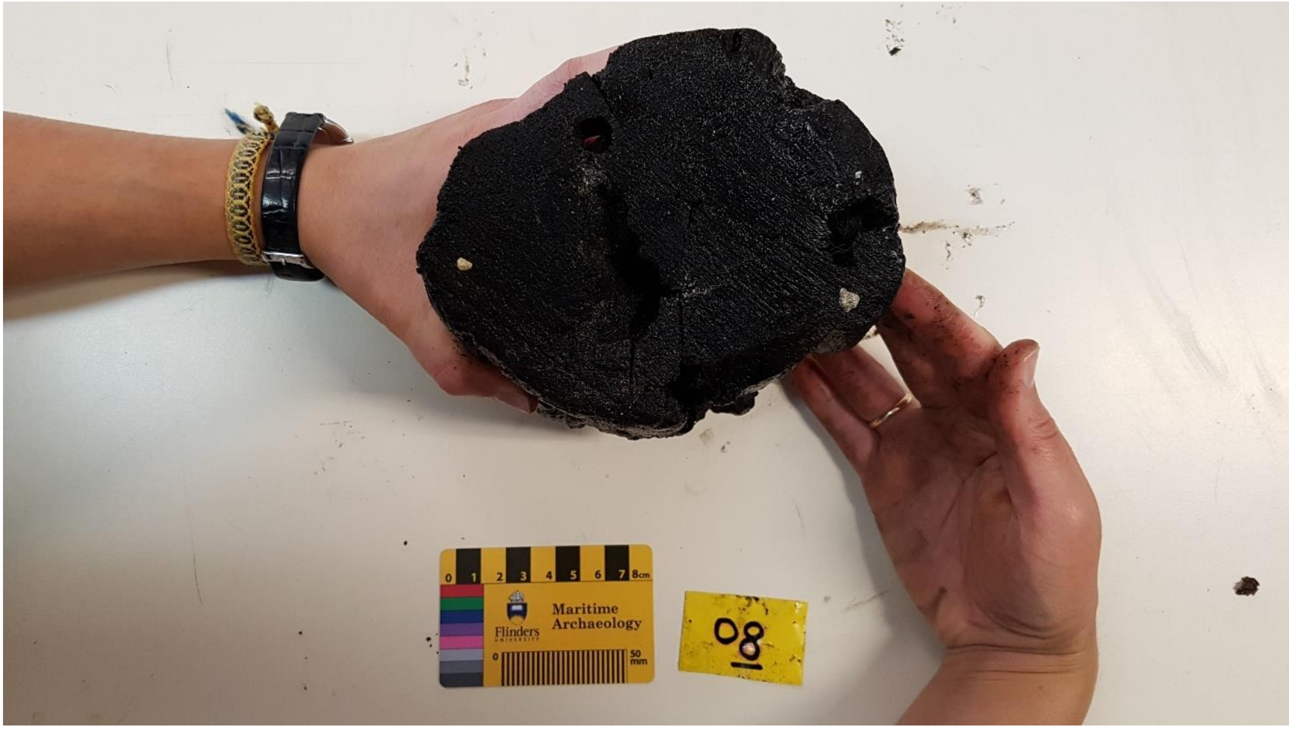
Pile 12


ZAMBRATIJA'17
ZAMB17 / PRI 14
N°14
Maritime
Archaeology
Flinders


Maritime
Archaeology
Flinders
14

Pile 14


ZAMBRATIJA 17
N°08
ZAMB17 / PRL08
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
08

Pile 08


ZAMB17 / PRL 20
N·20
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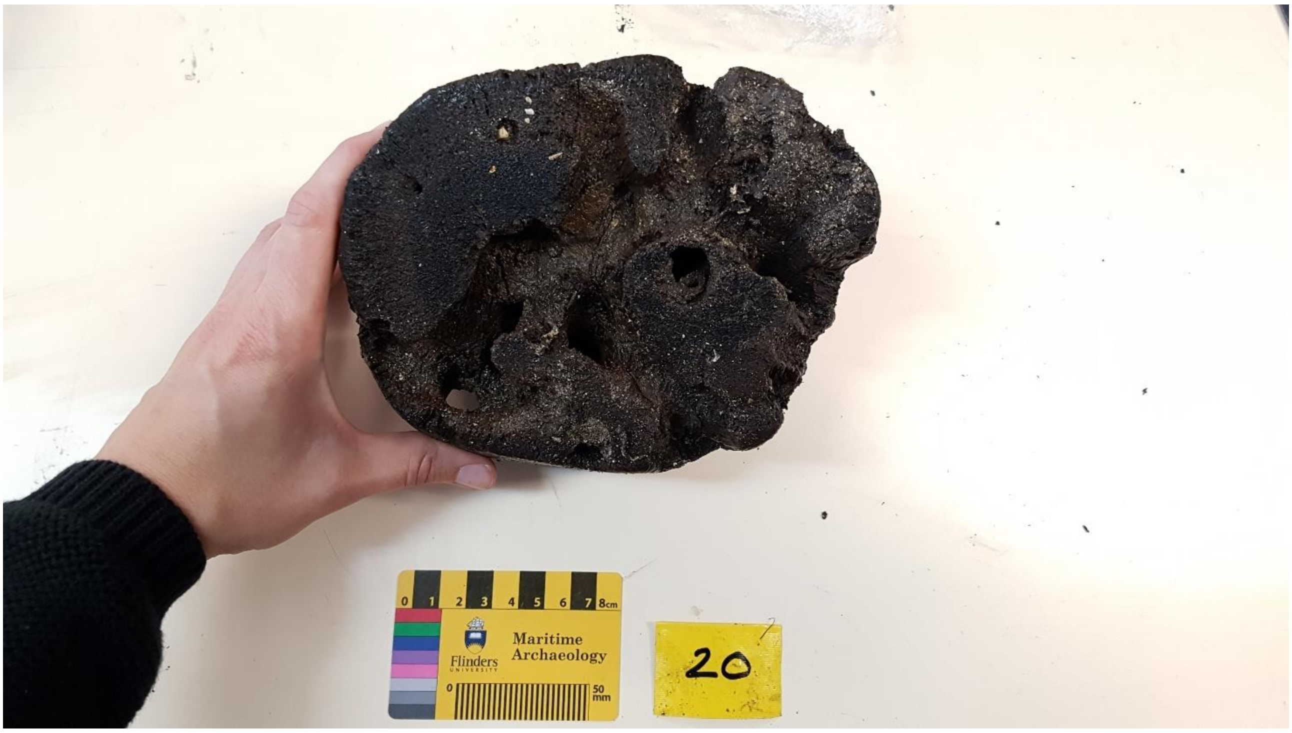
Maritime
Archaeology
Flinders
50
mm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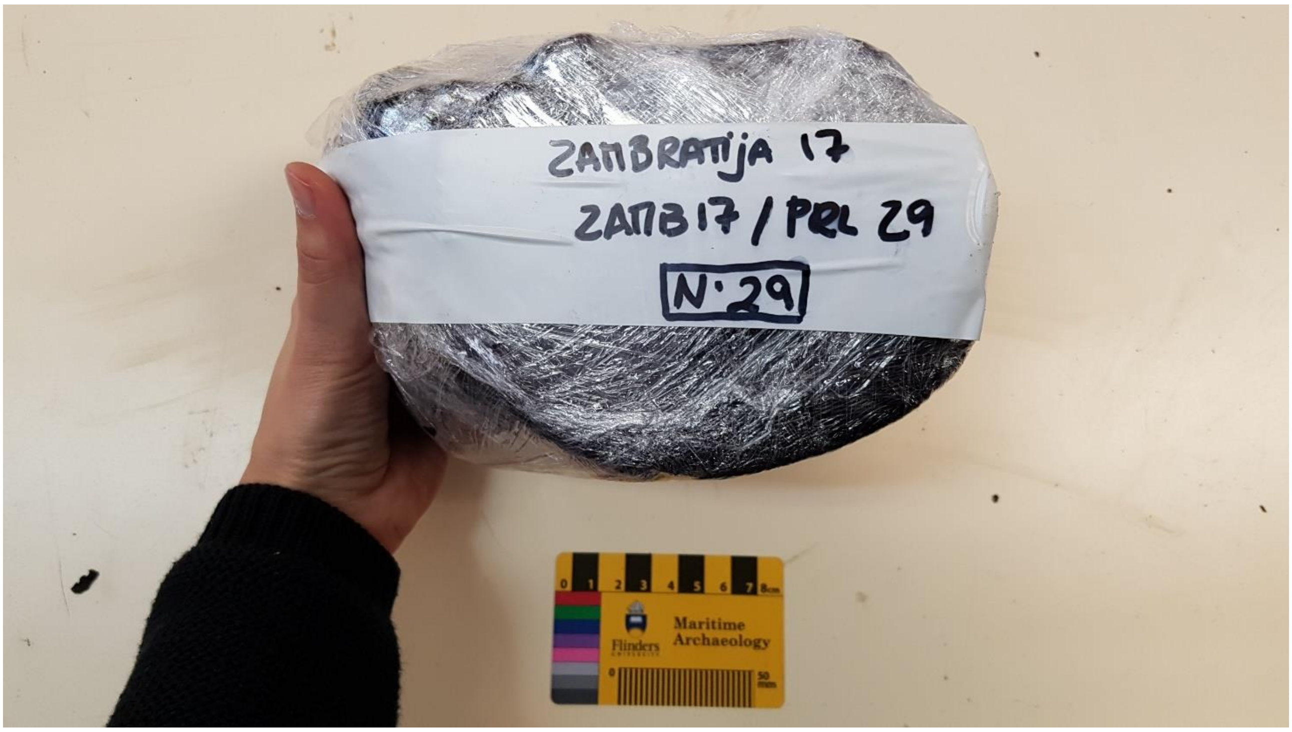
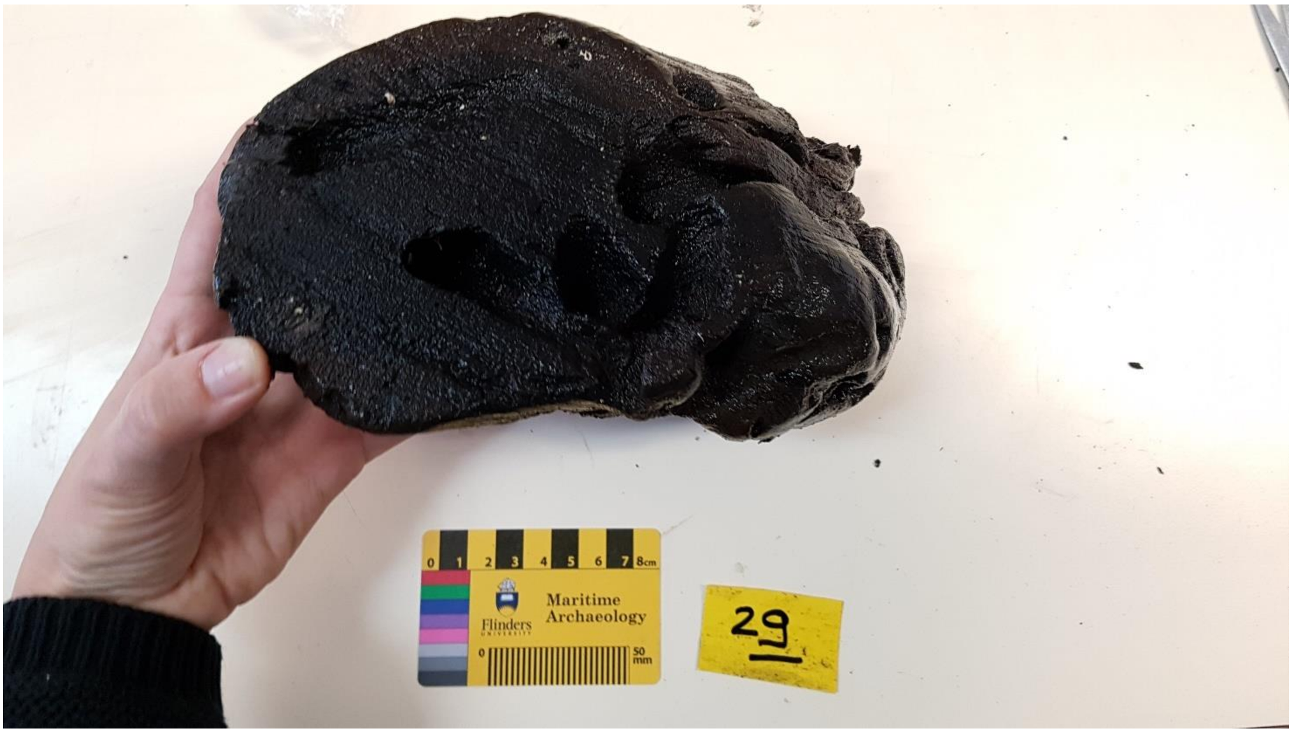
Maritime
Archaeology
Flinders
50
mm
20

Pile 20


ZAMBRATIJA 17
ZAMB17 / PRL 29
N·29
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
29

Pile 29


ZAMBRATIJA 17
ZAMB17 / PRL 23
N·23
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
23

Pile 23


ZAMBRATIJA 17
ZAMB 17 / PRL 17
N·17
Maritime Archaeology
Flinders
8cm
50 mm


Maritime Archaeology
Flinders
8cm
50 mm
17

Pile 17

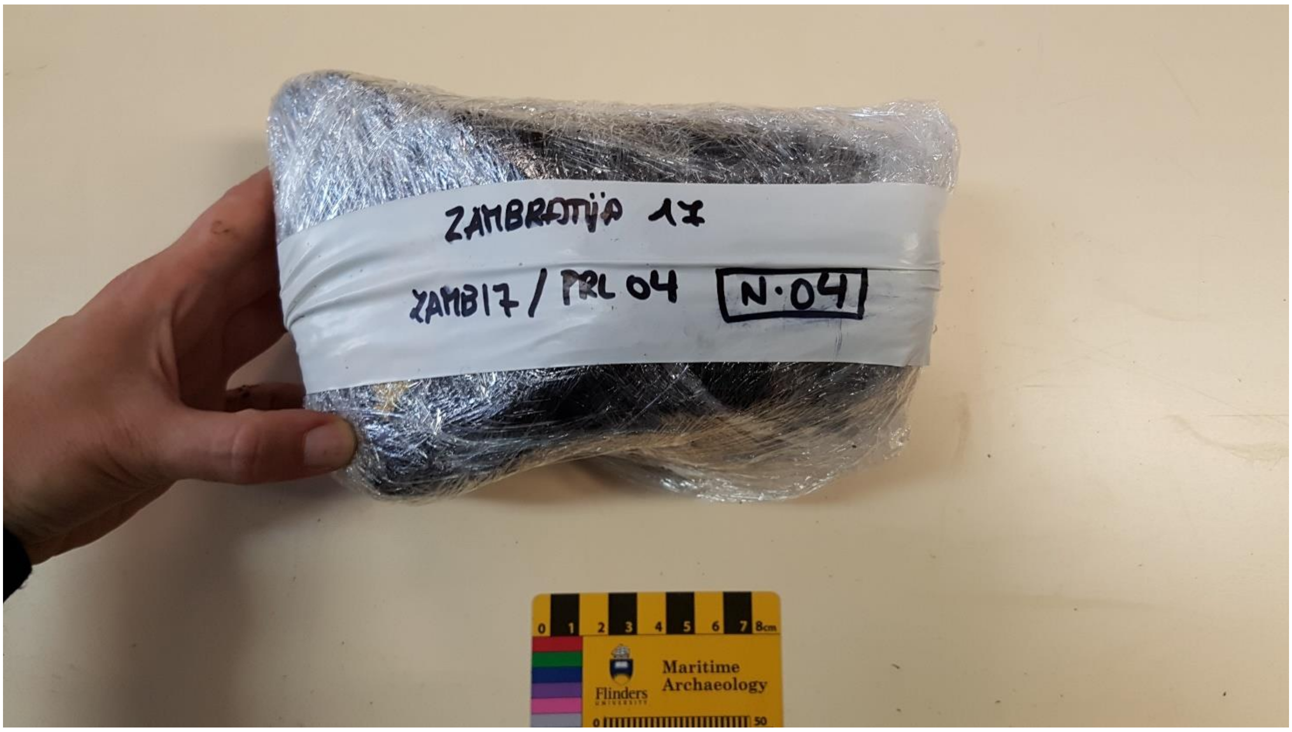
Pile 35

Pile 35


ZAMBRATija 17
ZAMB17 / PRL 19
N·19
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
19

Pile 19


ZAMBRATIJA 17
ZAMB17 / PRL 04
N·04
Maritime
Archaeology
Flinders


Maritime
Archaeology
Flinders
04

Pile 04

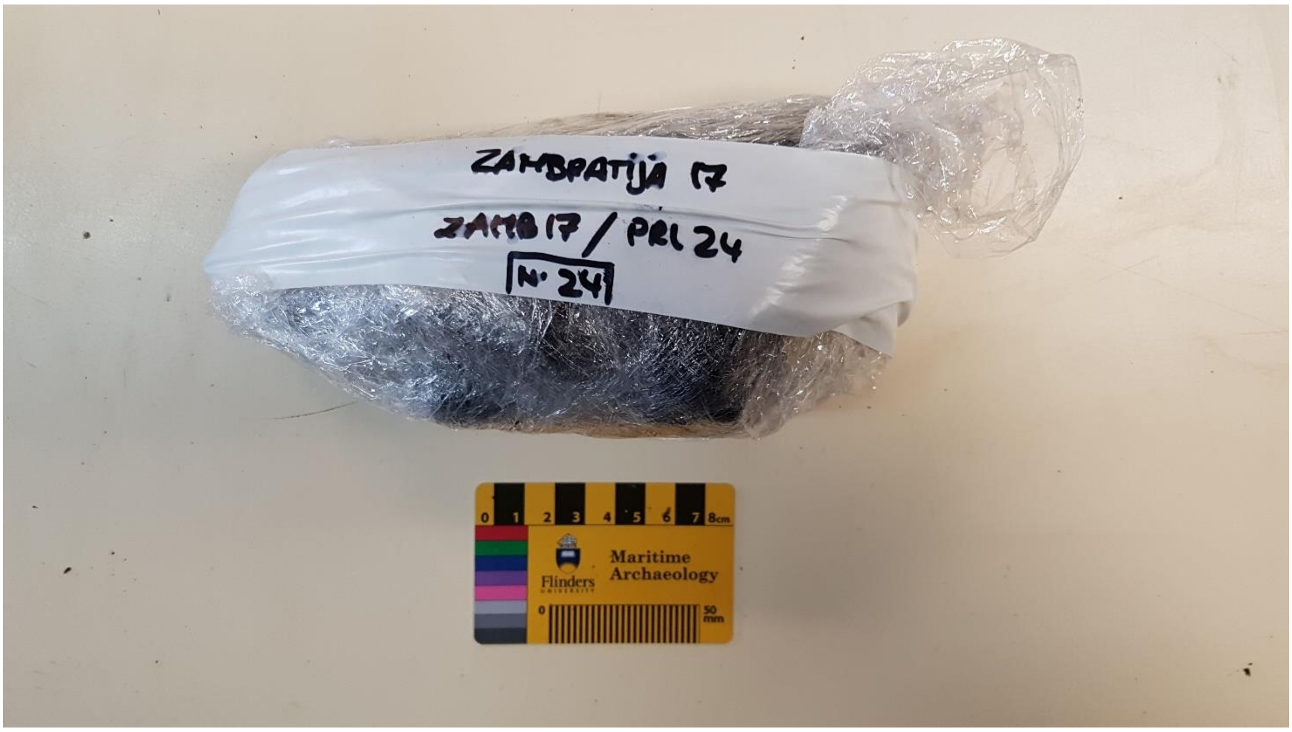
Pile 28

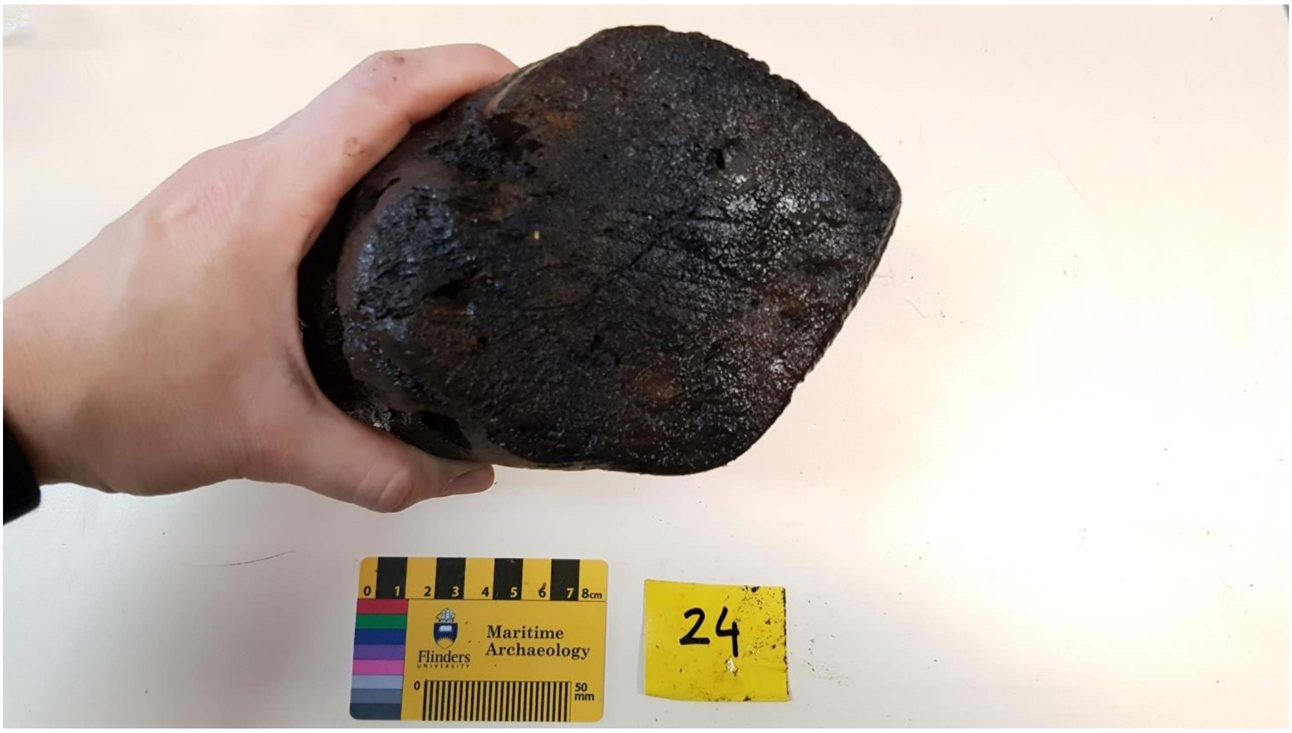
Pile 28


ZAHBRATIJA '17
N·15 ZAH17 / PRL15
0 1 2 3 4 5 6 7 8cm
Maritime
Archaeology
Flinders
UNIVERSITY
0
50
mm


0 1 2 3 4 5 6 7 8cm
Maritime
Archaeology
Flinders
UNIVERSITY
0
50
mm
15

Pile 15


ZAMBRATIJA 17
ZAMB17 / PRL 24
N° 24
0 1 2 3 4 5 6 7 8cm
Maritime
Archaeology
Flinders
0
50
mm


0 1 2 3 4 5 6 7 8cm
Maritime
Archaeology
Flinders
0
50
mm
24

Pile 24


ZAMBRATIJA 17
ZAMB17 / FRL33
N-33
Maritime
Archaeology
Flinders

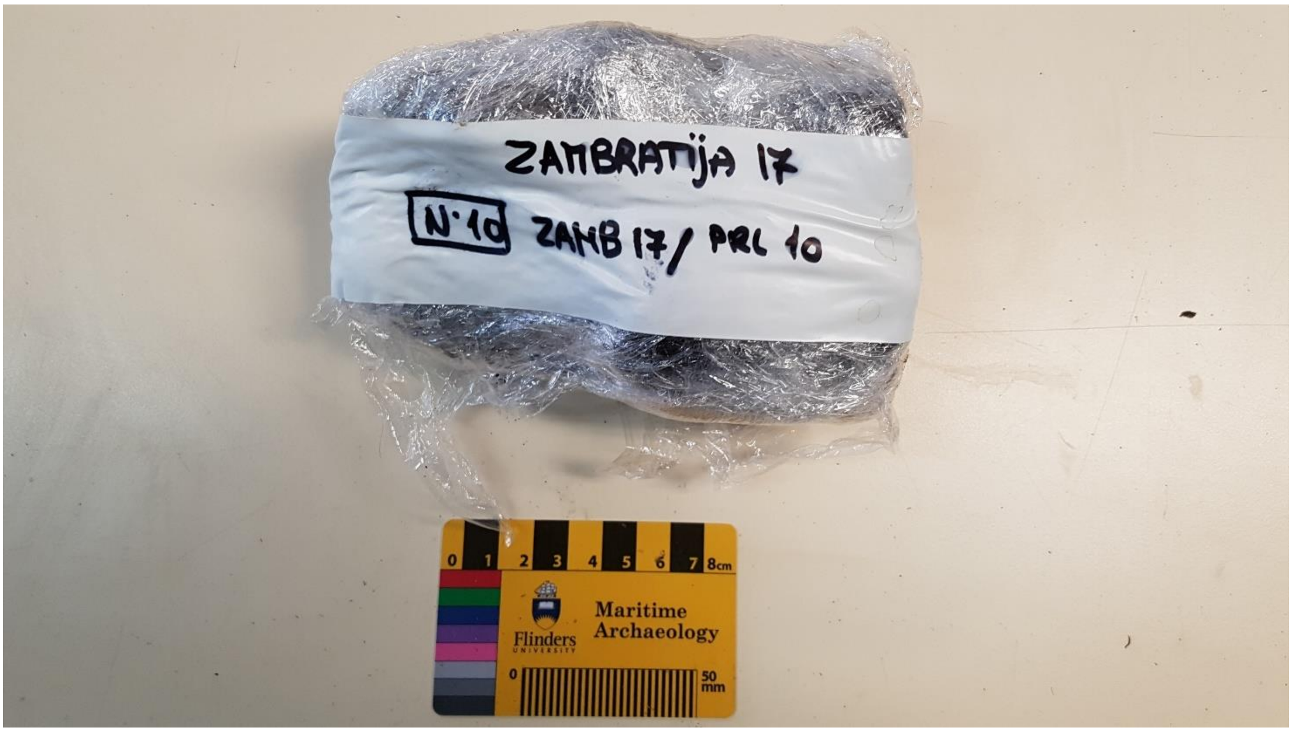

Maritime
Archaeology
Flinders
33

Pile 33


ZAMBRATIJA 17
ZAMB 17 / PAL 18
N·18
Maritime Archaeology
Flinders

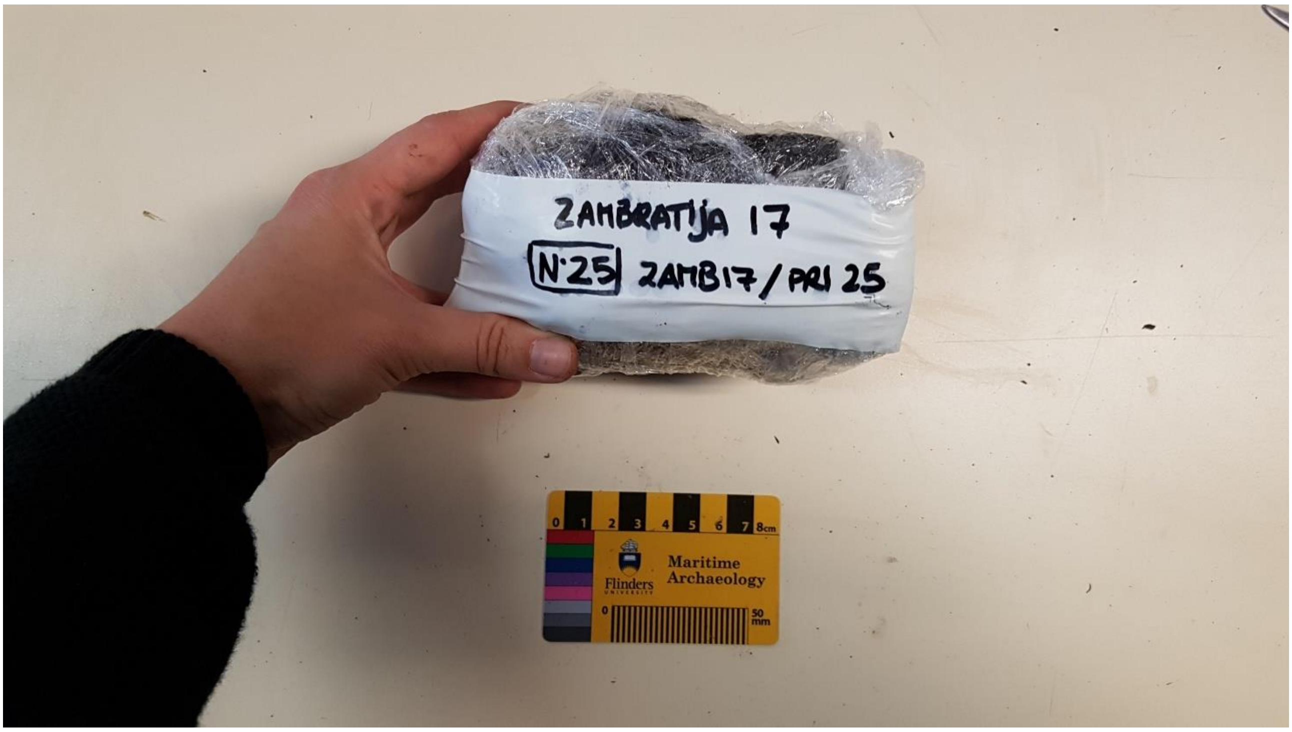

Maritime Archaeology
Flinders
18

Pile 18


ZAMBRATIJA 17
N·10 ZAMB 17 / PRL 10
Maritime Archaeology
Flinders
50 mm

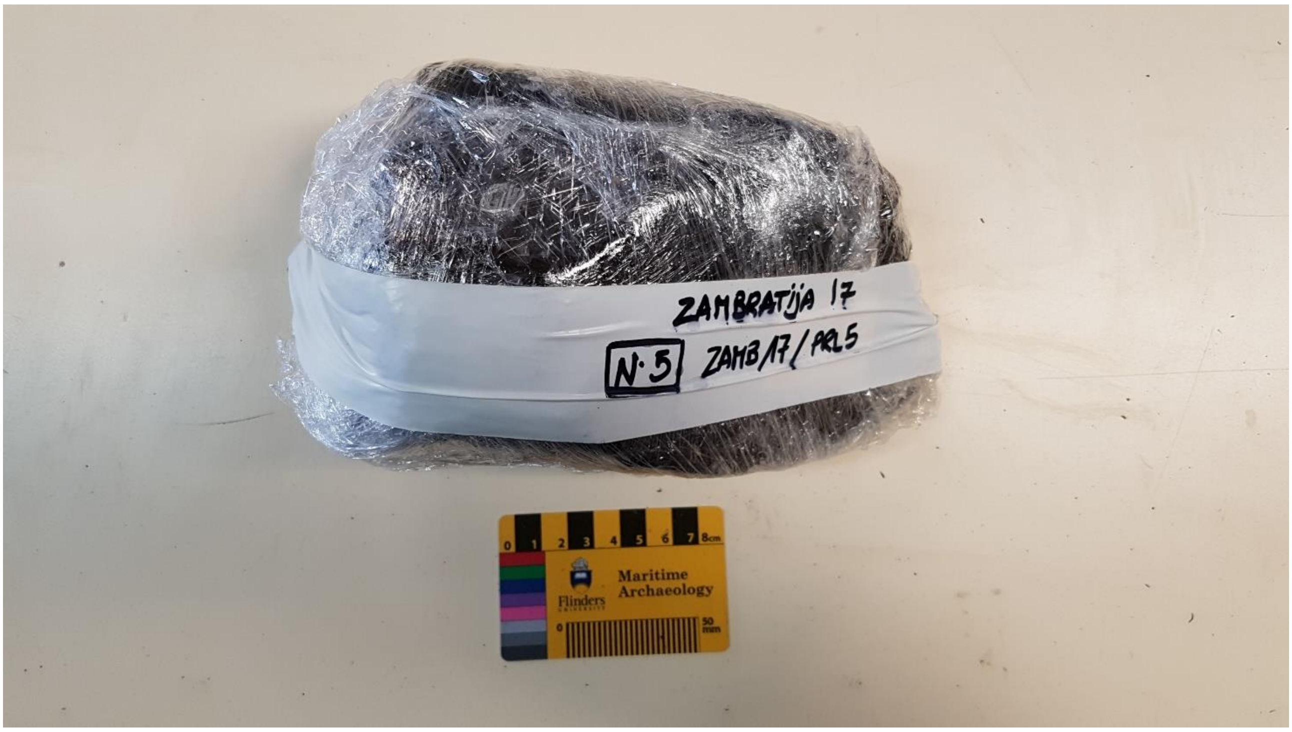

Maritime Archaeology
Flinders
10

Pile 10


ZAMBRATIJA 17
N°25 ZAMB17/PRI 25
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
25

Pile 25


ZAMBRATIJA 17
N·5 ZAMB/17/PAL5
Maritime
Archaeology
Flinders


Maritime
Archaeology
05

Pile 05


ZAMBRATIJA '17
N·13
Maritime Archaeology
Flinders


Maritime Archaeology
Flinders
13

Pile 13

Appendix XIII SUERC Radiorcarbon dating reports.

Scottish Universities Environmental Research Centre
Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, Glasgow G75 0QF, Scotland, UK
Director: Professor F M Stuart Tel: +44 (0)1355 223332 Fax: +44 (0)1355 229898 www.glasgow.ac.uk/suerc

RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	SUERC-76718 (GU46016)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-1, sample 01, 151-154 cm
Sample Reference	ZAM-1, 1
Material	Shell
$\delta^{13}C$ relative to VPDB	-1.4 ‰
Radiocarbon Age BP	4836 ± 32

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by :

University of Glasgow

The University of Glasgow, charity number SC004401

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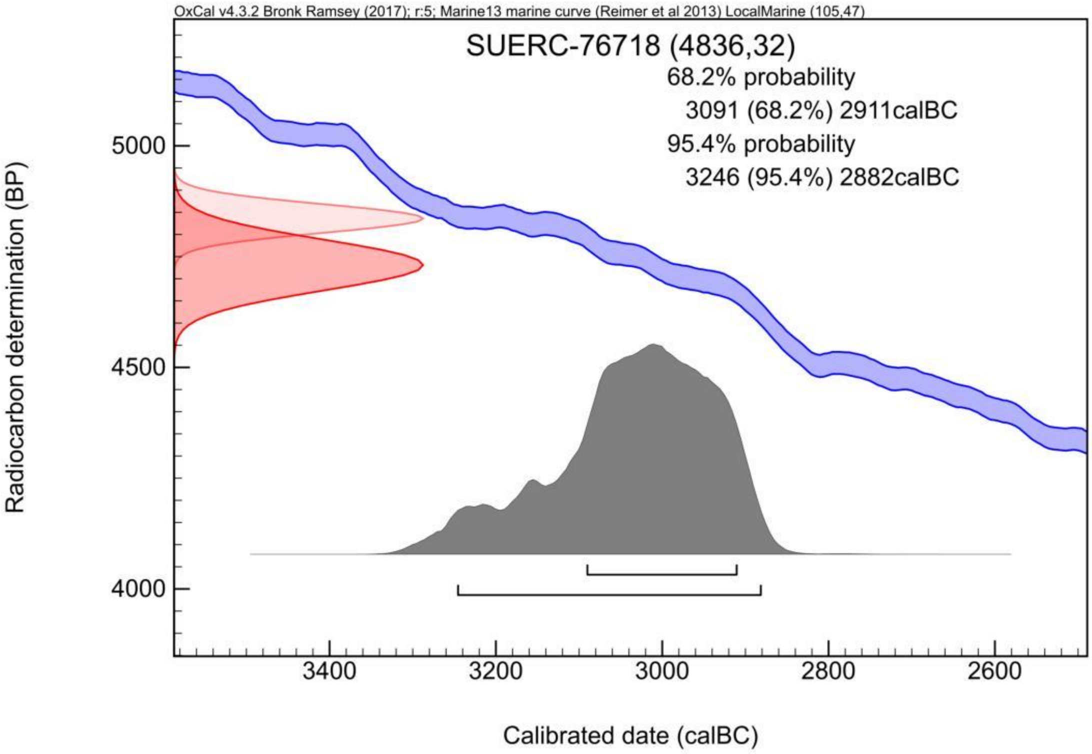

The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the Marine13 calibration curve.†

A regional marine offset (ΔR) of 105 ± 47 years has been used in the calibration.

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

Scottish Universities Environmental Research Centre
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Director: Professor F M Stuart Tel: +44 (0)1355 223332 Fax: +44 (0)1355 229898 www.glasgow.ac.uk/suerc

RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	GU46017
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-1, sample 067, 266-268cm
Sample Reference	ZAM-1, 2
Material	Unknown material
Result	Failed due to insufficient carbon.

N.B. Any questions directed to the laboratory should quote the GU coding given above.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Checked and signed off by : P. Naysmith

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RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	SUERC-76722 (GU46018)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-1, sample 039, 420-421cm
Sample Reference	ZAM-1, 3
Material	Peat (fibrous) : Humic acid dated
$\delta^{13}C$ relative to VPDB	-28.2 ‰
Radiocarbon Age BP	4714 ± 32

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

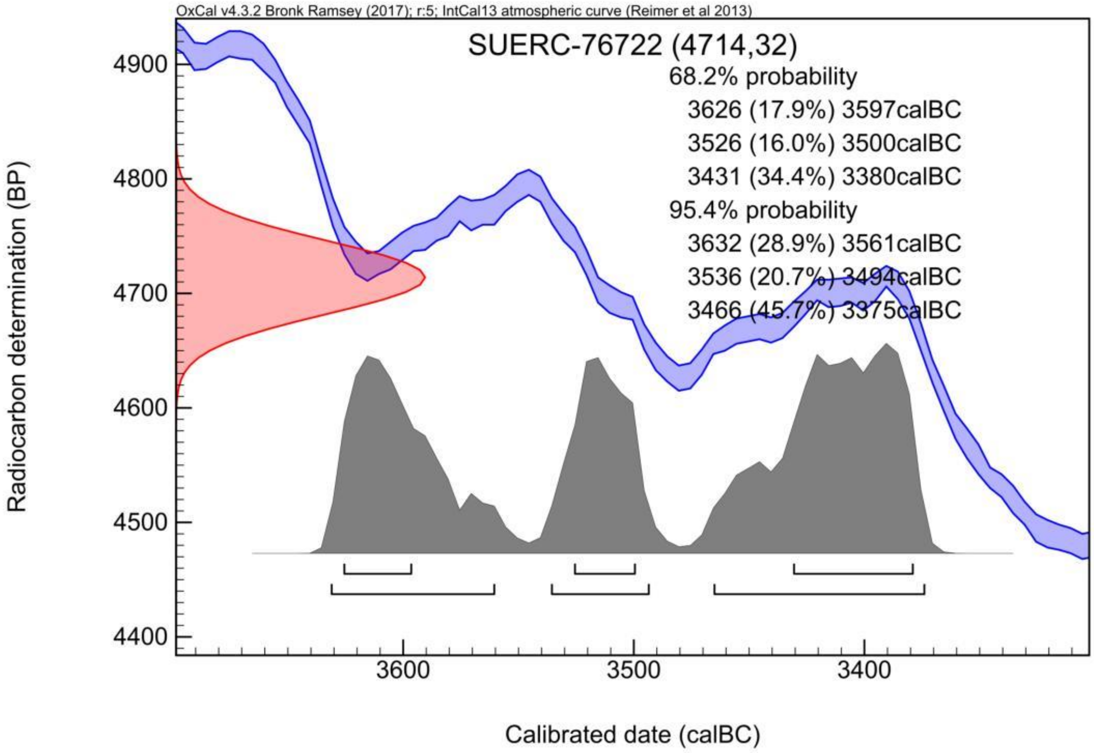
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by : P. Naysmith



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	SUERC-76723 (GU46019)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-2, sample 48&50, 31-33cm
Sample Reference	ZAM-2, 1
Material	Shells, snails
$\delta^{13}C$ relative to VPDB	1.4 ‰
Radiocarbon Age BP	3575 ± 32

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

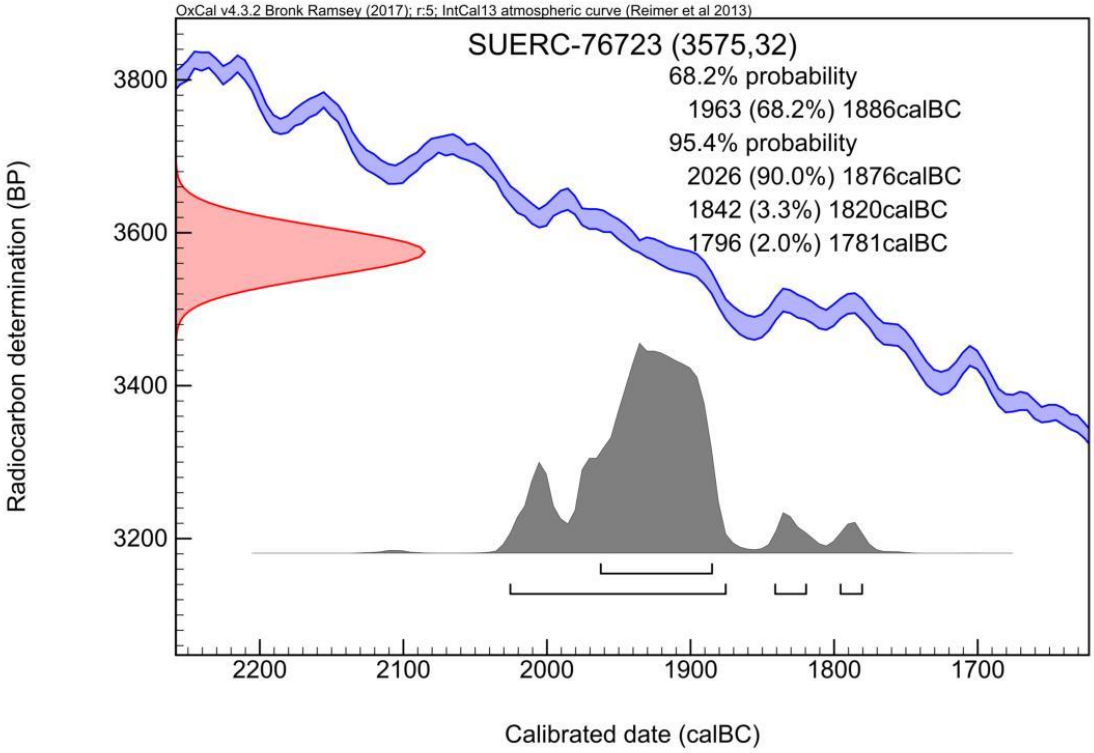
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by : P. Naysmith



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	GU46020
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-2, sample 62, 81-82cm
Sample Reference	ZAM-2, 2
Material	Unknown material
Result	Failed due to insufficient carbon.

N.B. Any questions directed to the laboratory should quote the GU coding given above.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Checked and signed off by : P. Naysmith

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RADIOCARBON DATING CERTIFICATE
22 January 2018

Laboratory Code	SUERC-76724 (GU46021)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija, Croatia
Context Reference	ZAM-2, sample 75&77, 109-111cm
Sample Reference	ZAM-2, 3
Material	Shells, snail
$\delta^{13}C$ relative to VPDB	1.6 ‰
Radiocarbon Age BP	1873 ± 32

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

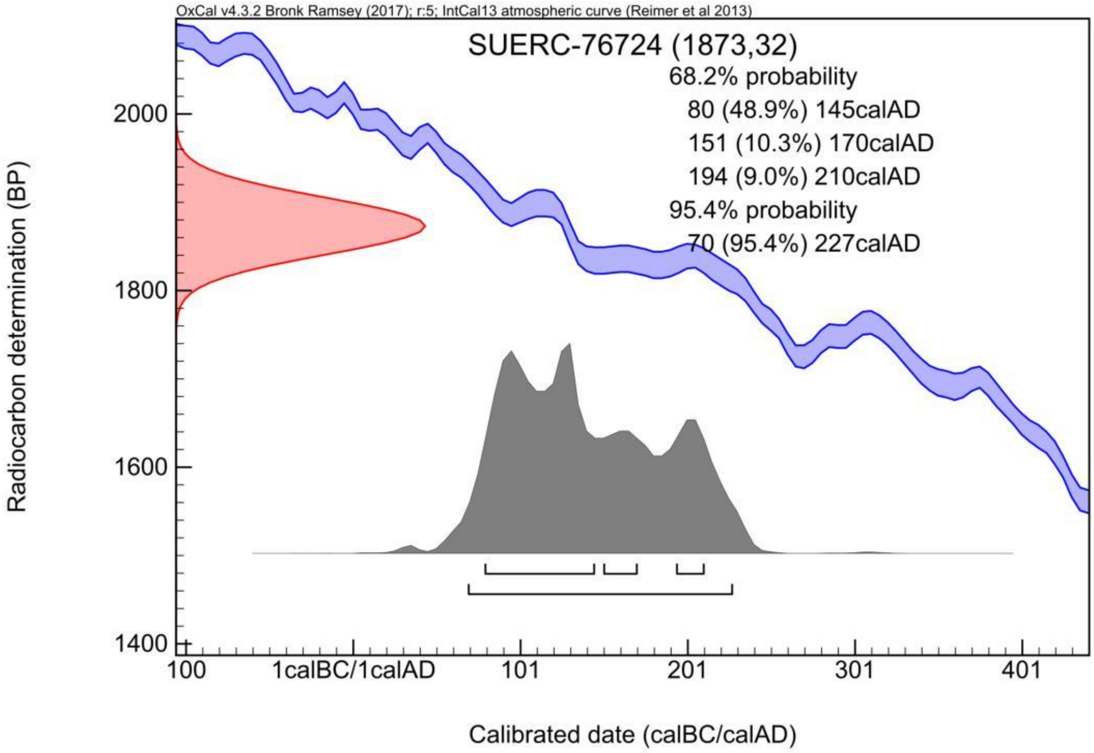
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by : P. Naysmith



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
14 March 2018

Laboratory Code	SUERC-77772 (GU46526)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija
Context Reference	Dendro sample No. 18,
Sample Reference	ZAM Dendro 1
Material	Wood
$\delta^{13}C$ relative to VPDB	-26.5 ‰
Radiocarbon Age BP	5310 ± 32

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

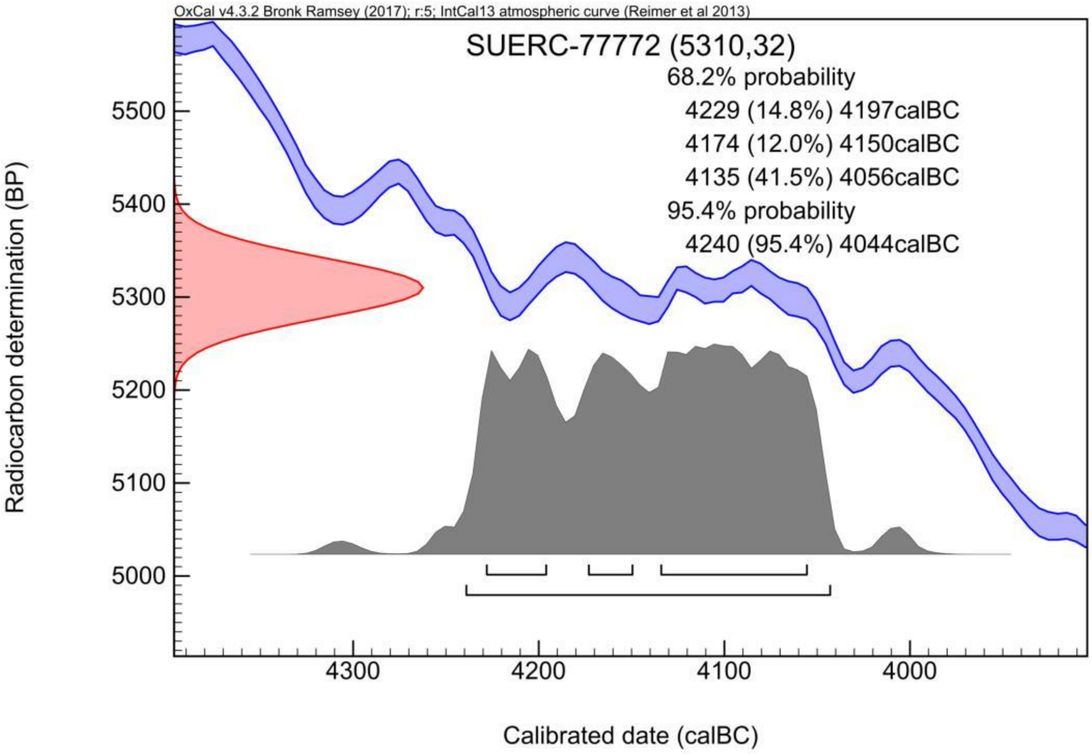
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by : P. Naysmith



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
14 March 2018

Laboratory Code	SUERC-77773 (GU46527)
Submitter	Katarina Jerbić Flinders University Antuna Augustinčića 34 42000 Varaždin Croatia
Site Reference	Zambratija
Context Reference	Dendro sample No. 29,
Sample Reference	ZAM Dendro 2
Material	Wood
$\delta^{13}C$ relative to VPDB	-26.9 ‰
Radiocarbon Age BP	5129 ± 34

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

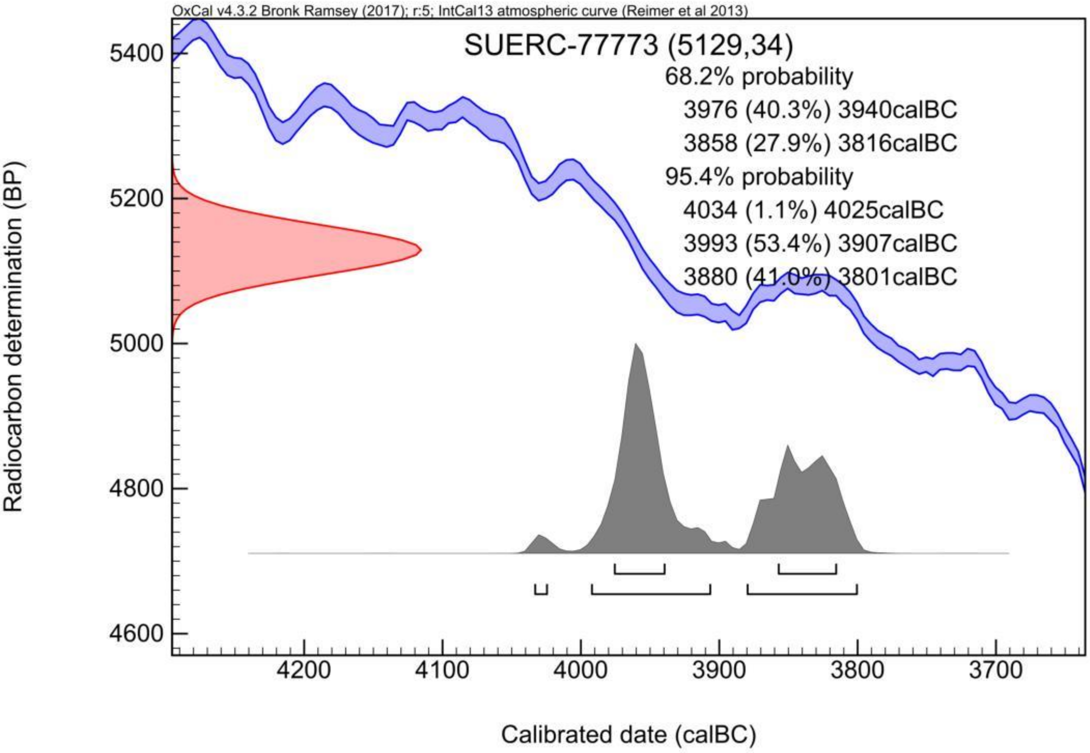
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by : P. Naysmith



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
11 September 2018

Laboratory Code	SUERC-81648 (GU48799)
Submitter	Katarina Jerbić Flinders University
Site Reference	Zambratija
Context Reference	95-96 cm, cultural layer
Sample Reference	ZAM-7, SAMPLE 055
Material	Charcoal
$\delta^{13}C$ relative to VPDB	-26.7 ‰
Radiocarbon Age BP	5157 ± 28

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

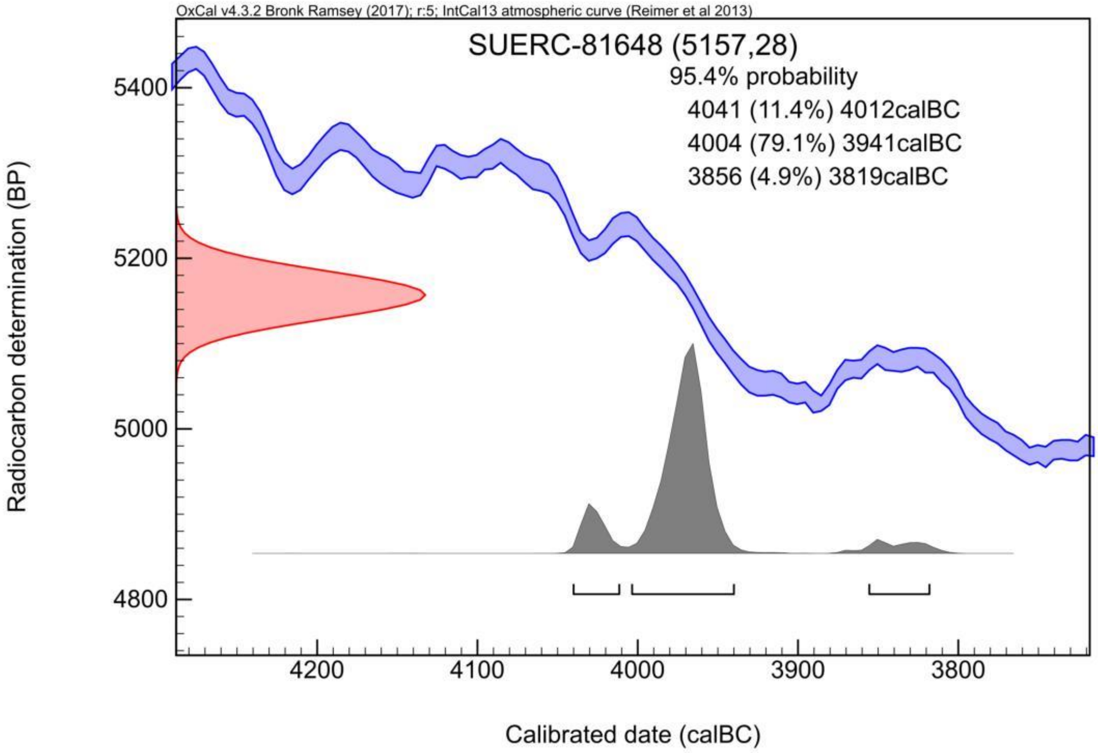
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by :



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
11 September 2018

Laboratory Code	SUERC-81649 (GU48800)
Submitter	Katarina Jerbić Flinders University
Site Reference	Zambratija
Context Reference	148-149 cm, brackish
Sample Reference	ZAM-7, SAMPLE 025
Material	Leaf
$\delta^{13}C$ relative to VPDB	-28.7 ‰
Radiocarbon Age BP	5583 ± 28

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

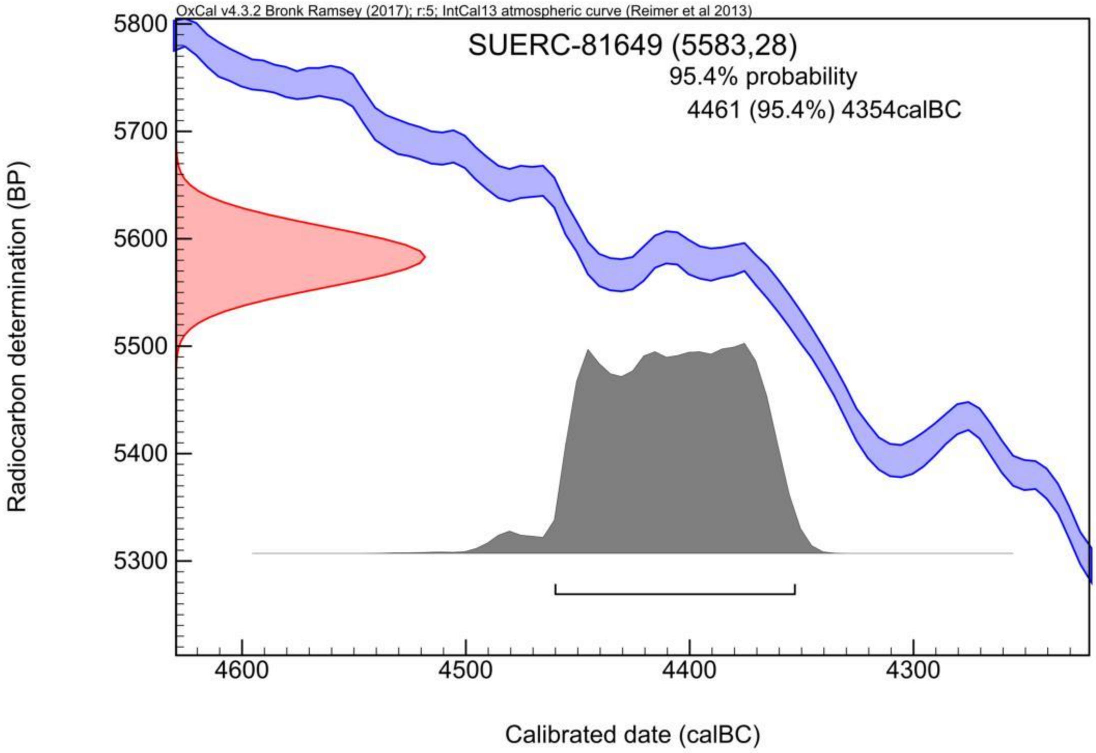
Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by :



The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

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RADIOCARBON DATING CERTIFICATE
11 September 2018

Laboratory Code	SUERC-81653 (GU48801)
Submitter	Katarina Jerbić Flinders University
Site Reference	Zambratija
Context Reference	260-261 cm, freshwater
Sample Reference	ZAM-7, SAMPLE 022
Material	Plant Macrofossils
$\delta^{13}C$ relative to VPDB	-28.7 ‰
Radiocarbon Age BP	6703 ± 28

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

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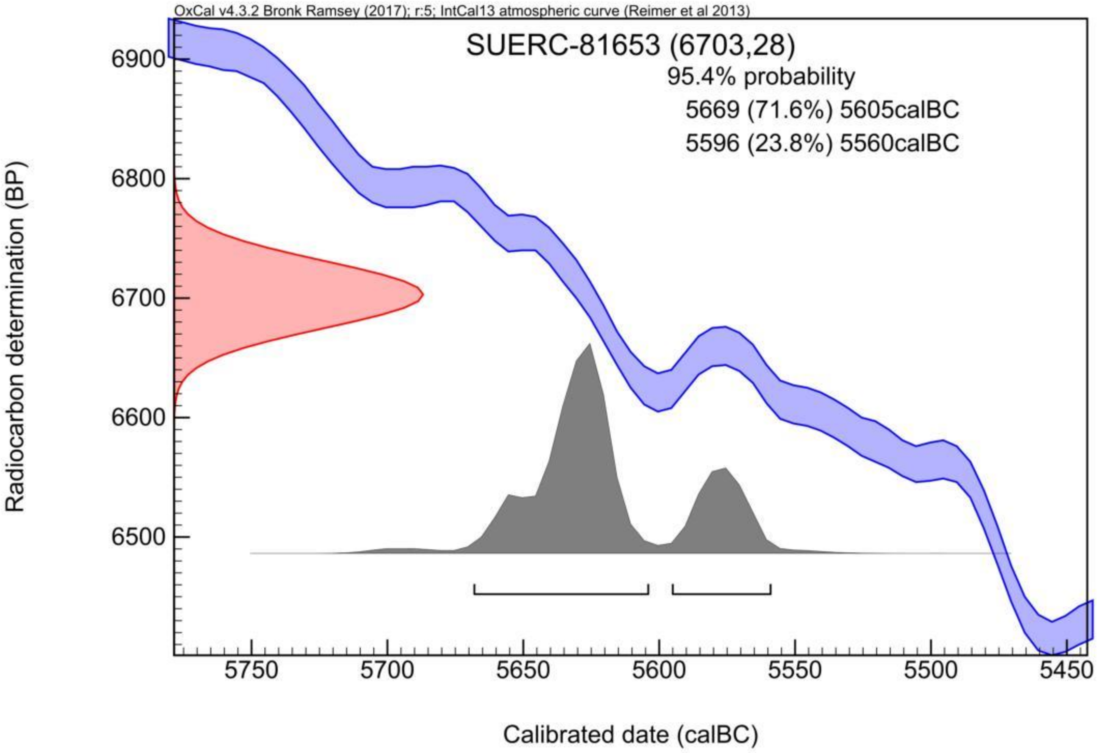
For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by : E. Dunbar

Checked and signed off by :



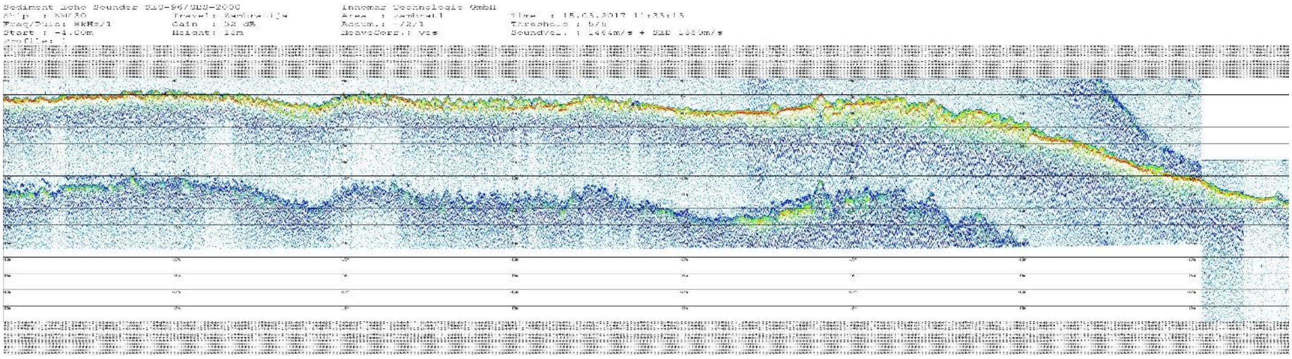
The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.†

Please contact the laboratory if you wish to discuss this further.

* Bronk Ramsey (2009) *Radiocarbon 51(1) pp.337-60*
† Reimer et al. (2013) *Radiocarbon 55(4) pp.1869-87*

Appendix XIV All sub-bottom profiles.



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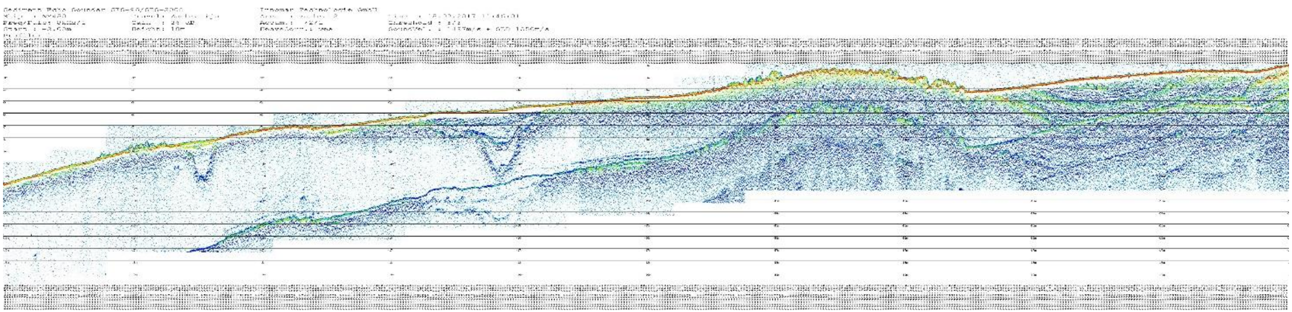

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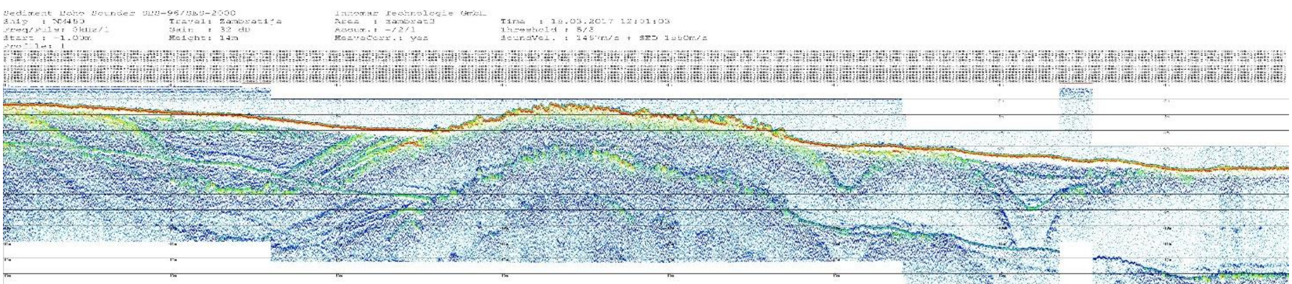

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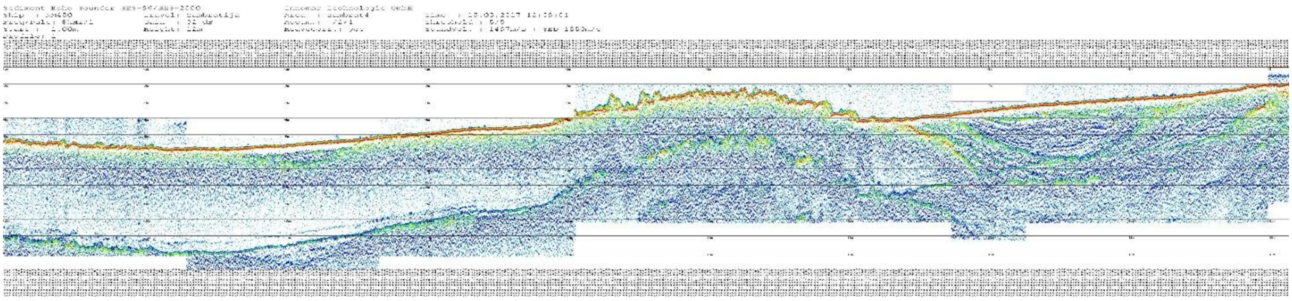

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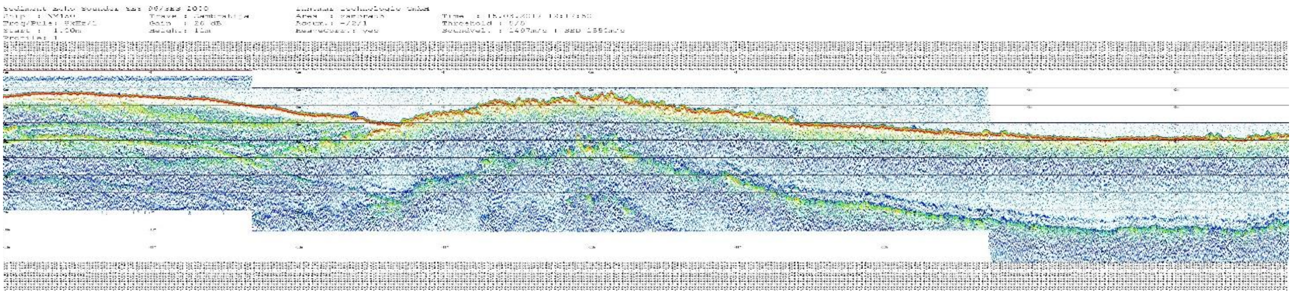

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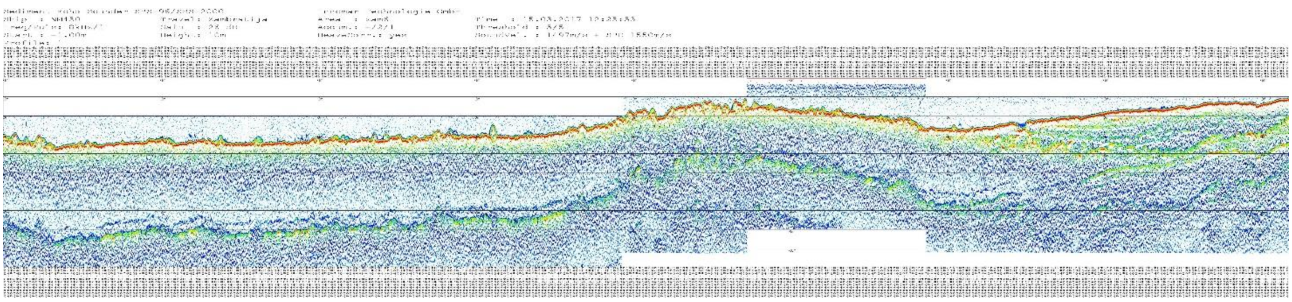

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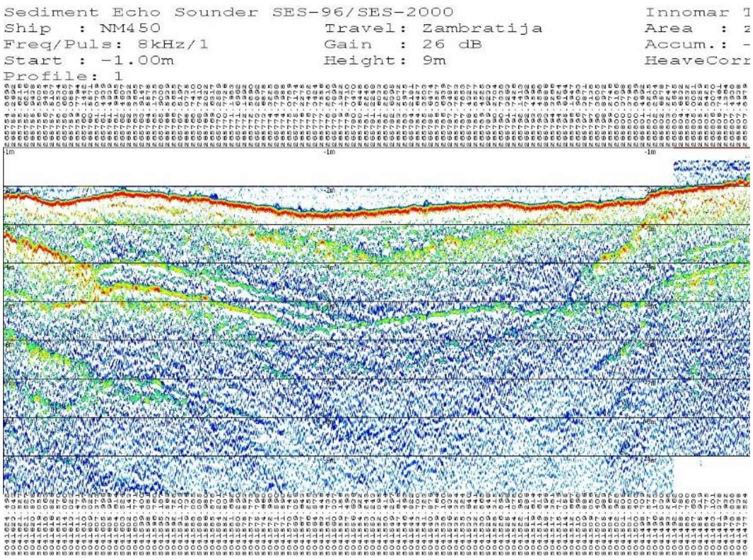

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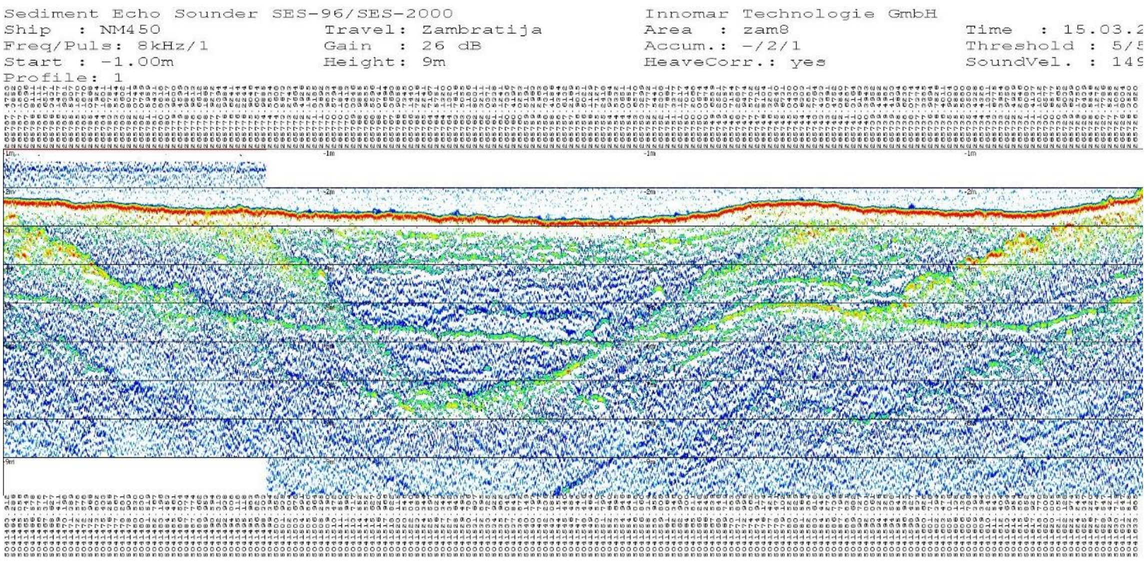

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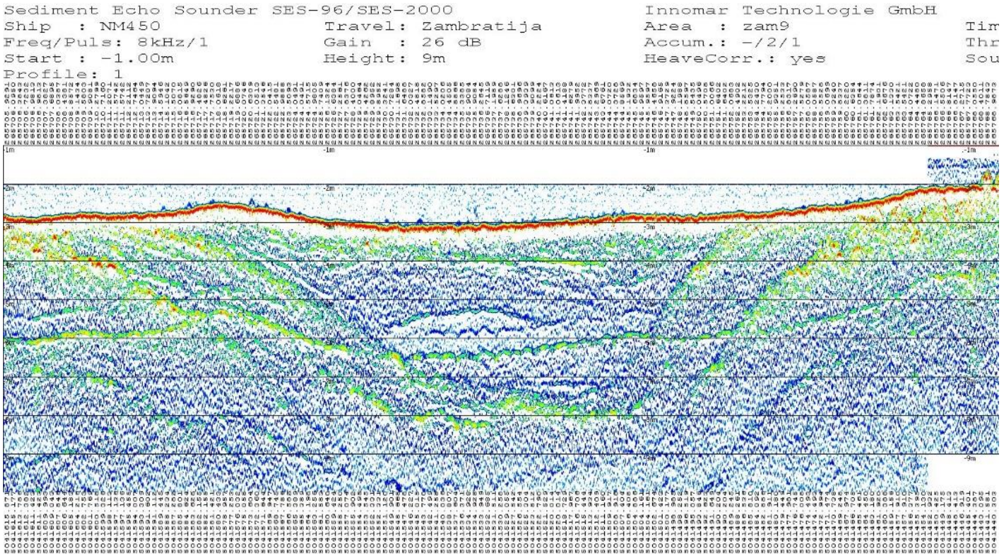

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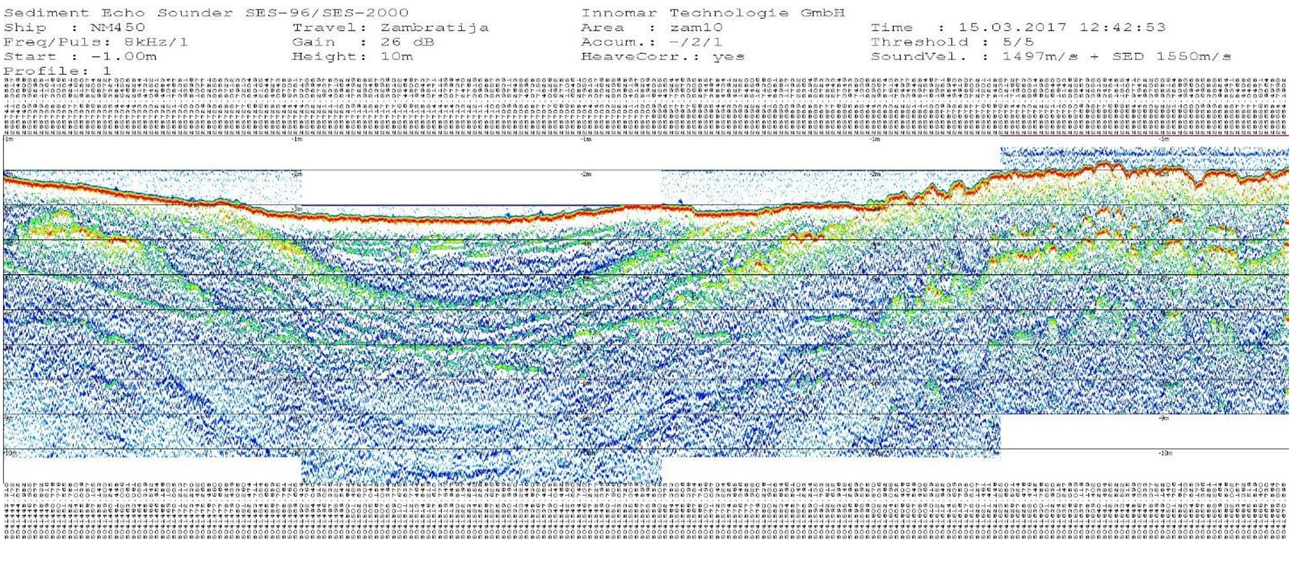

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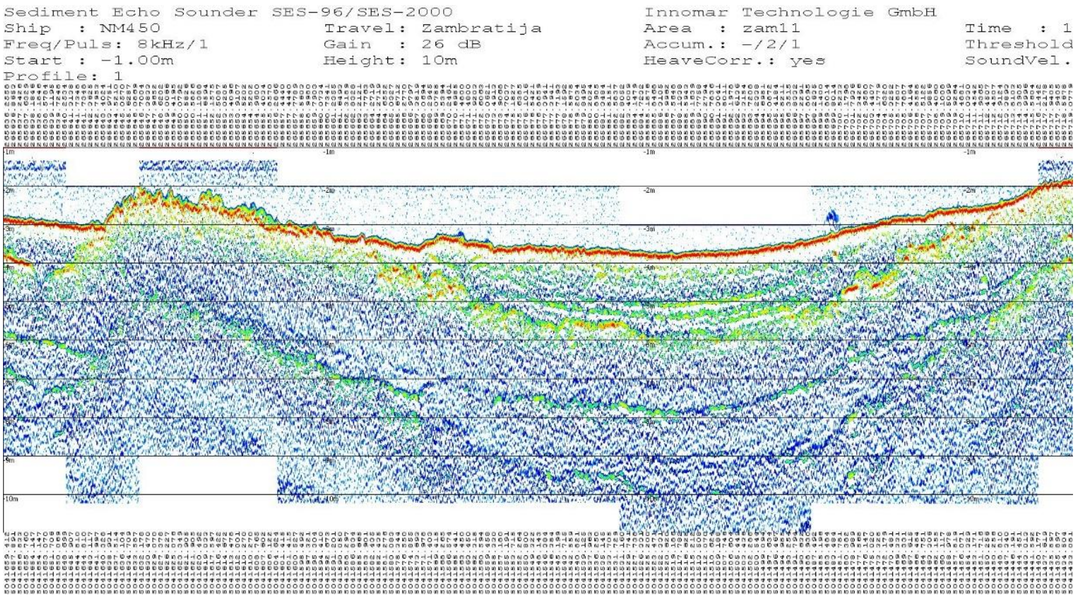

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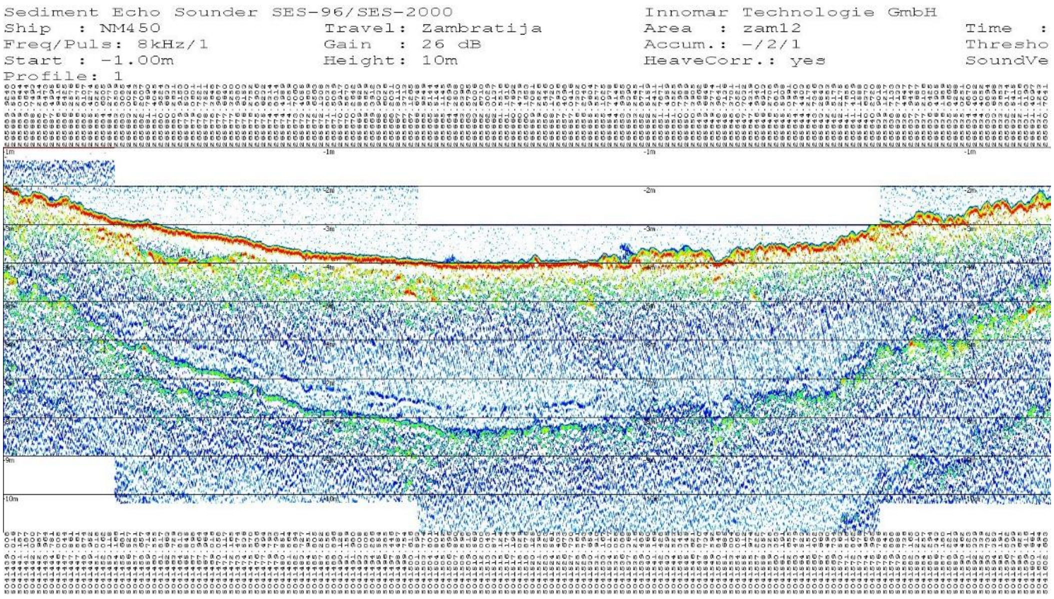

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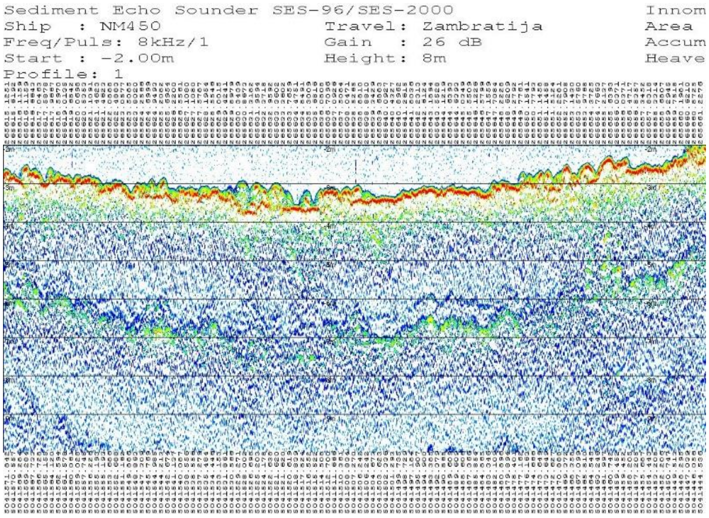

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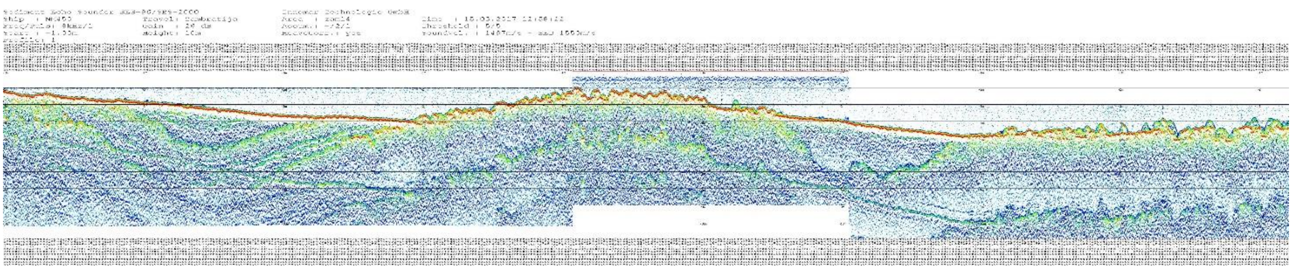

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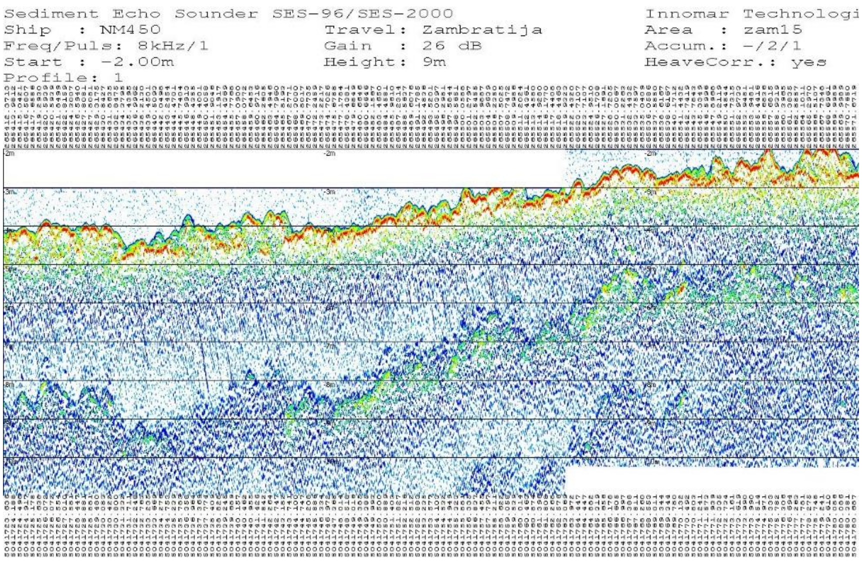

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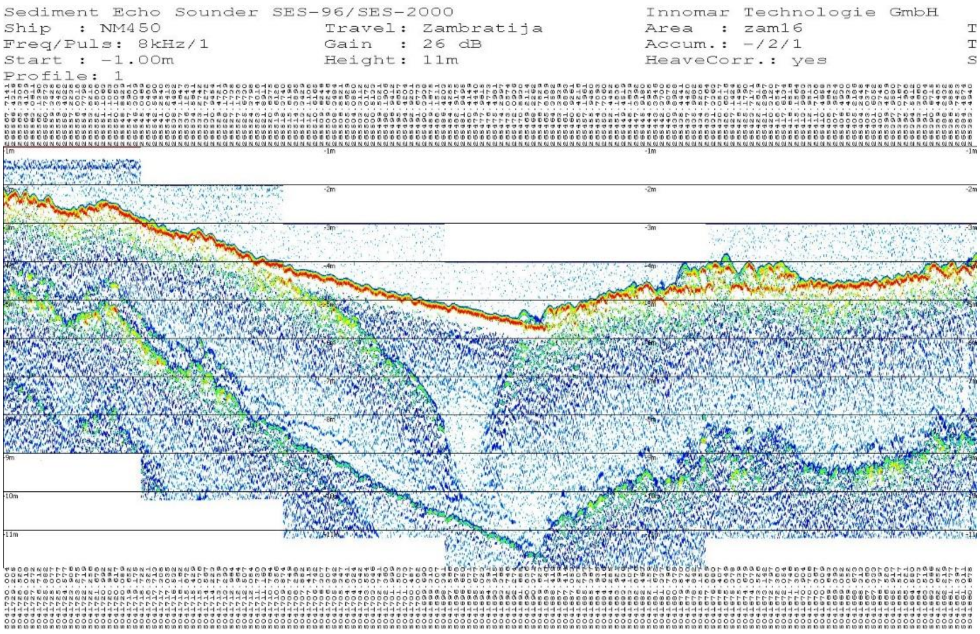

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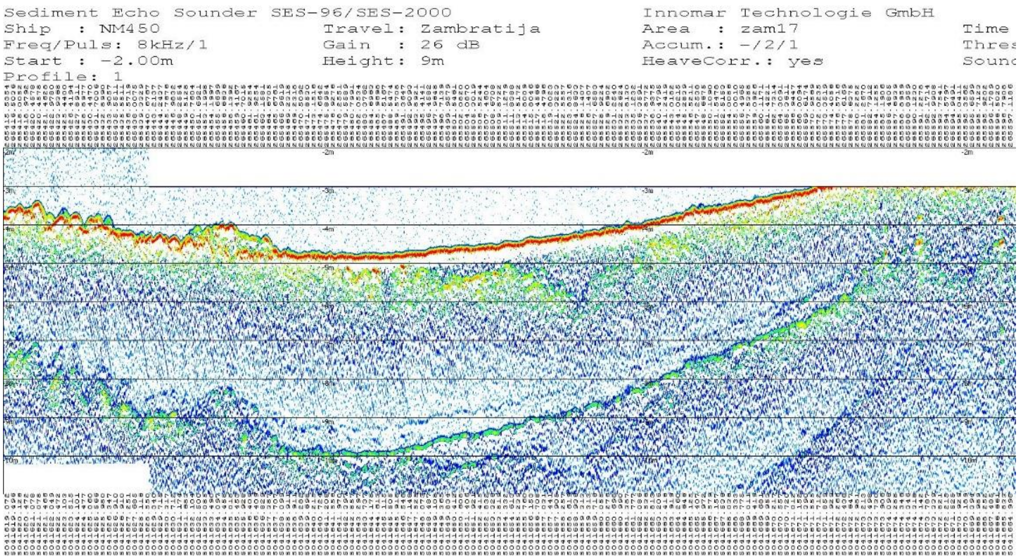

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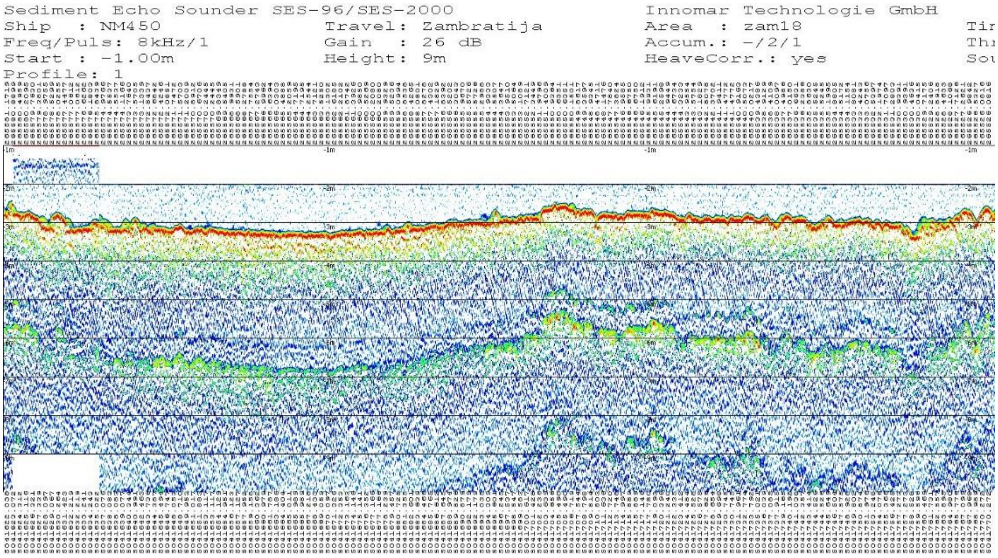
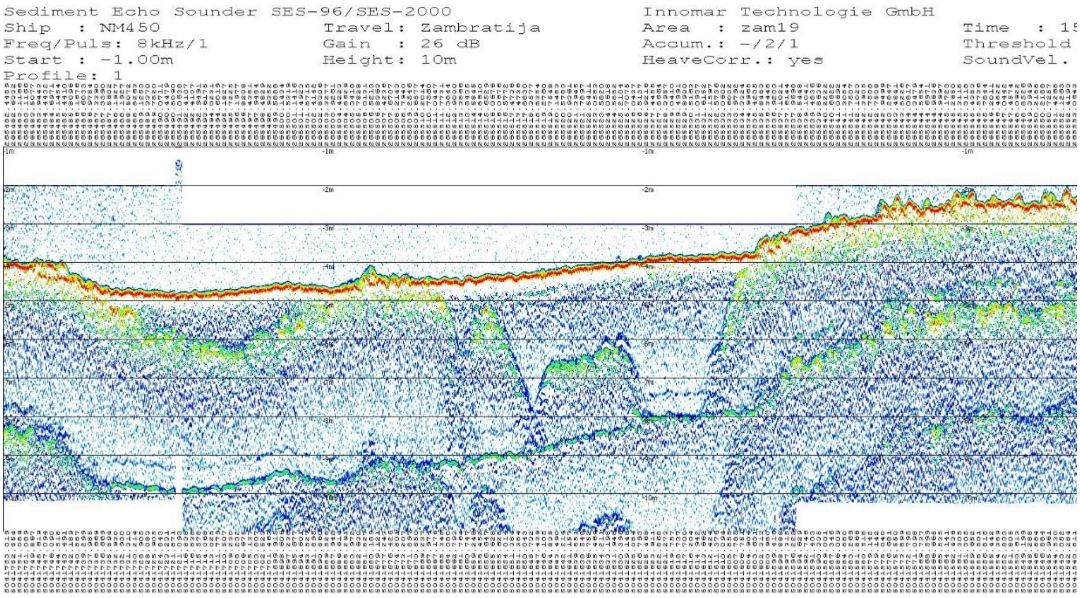
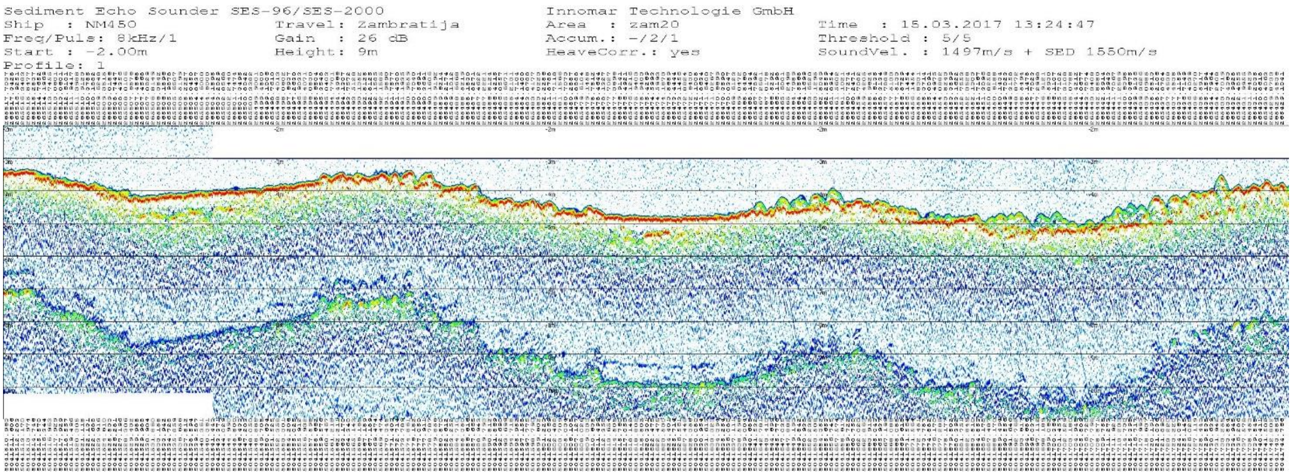


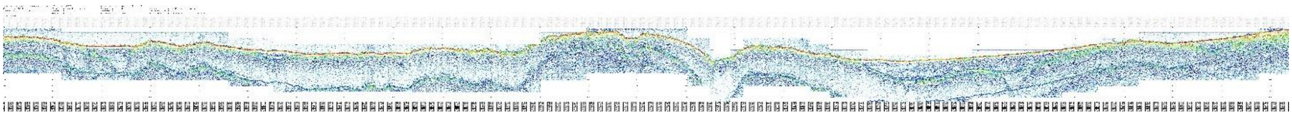
Profile 15032017131746



Profile 15032017132113

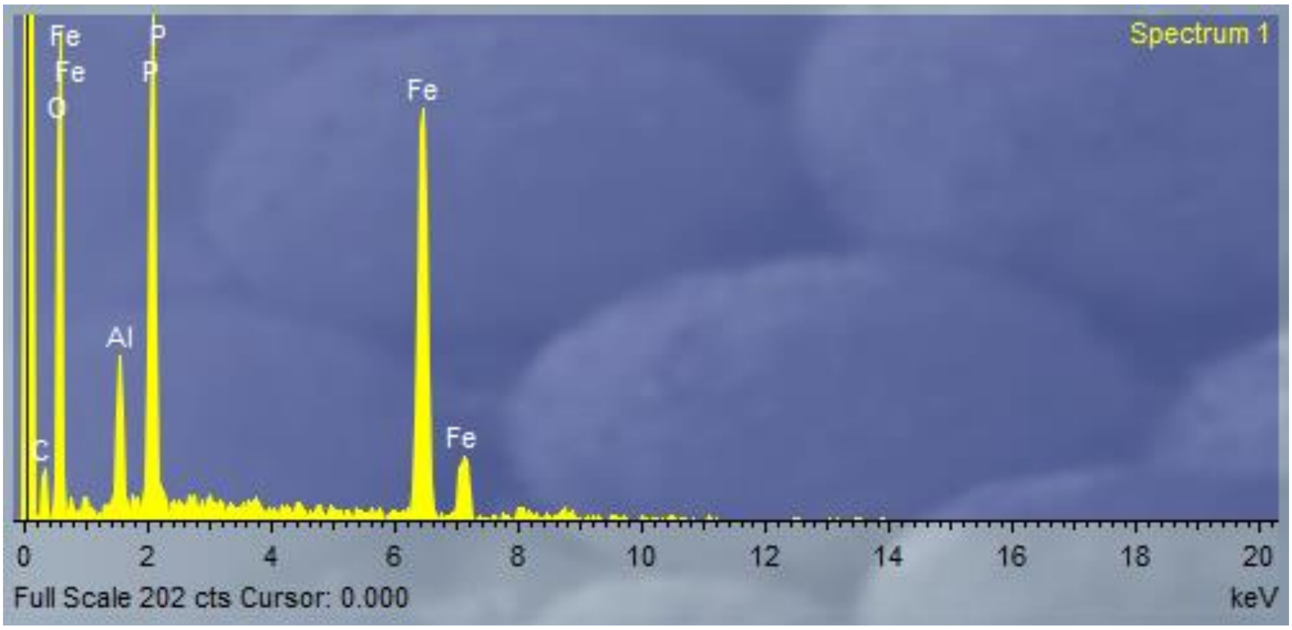


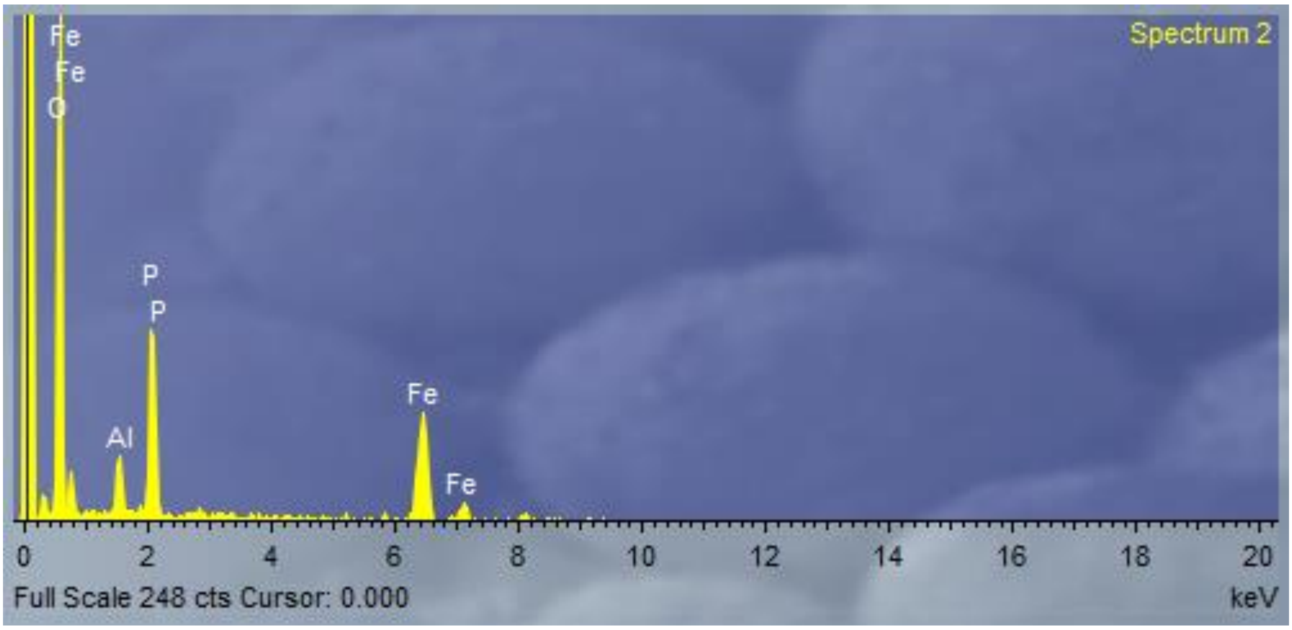
Profile 15032017132447



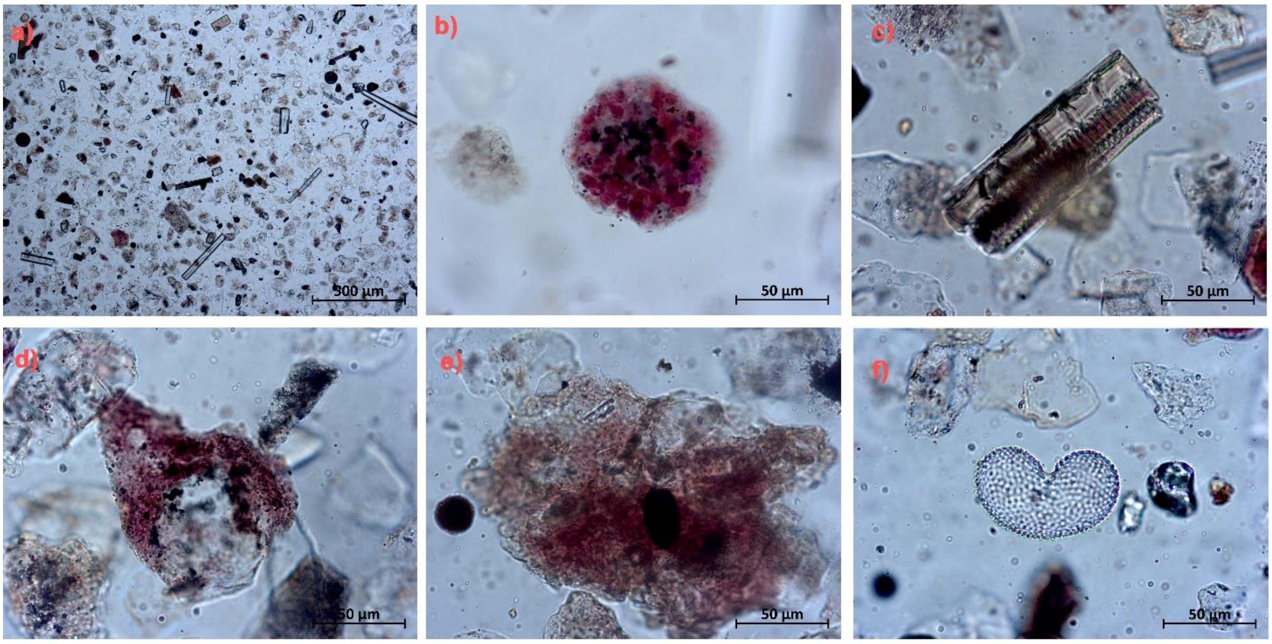
Profile 15032017133143

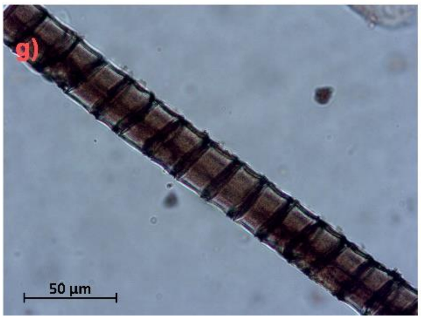
Appendix XV Vivianite spectrum graphs.





Appendix XVI Microflotation of ZAM-7 discrete sample 105–106 cm.





a) uzorak 105-106 (006)

b) keramika?

c) i g) čudan skelet

d) kremen okružen s kriptokristalastim kremenom i glinom (najbolji dokaz za keramiku?)

e) keramika?

f) pelud?

REFERENCES

Abelli, L., M.V. Agosto, D. Casalbore, C. Romagnoli, A. Bosman, F. Antonioli, M. Pierdomenico, A. Sposato and F.L. Chiocci 2016 Marine geological and archaeological evidence of a possible pre-Neolithic site in Pantelleria Island, Central Mediterranean Sea. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.97–110. London: Geological Society.

Adobe 2018. Retrieved from <https://www.adobe.com/au>.

Alve, E. and J.W. Murray 1999 Marginal marine environments of the Skagerrak and Kattegat: a baseline study of living (stained) benthic foraminiferal ecology. *Palaeogeography, Palaeoclimatology, Palaeoecology* 146:171–193.

Andersen, S.H. 1985 Tybrind Vig. A Preliminary Report on a Submerged Ertebølle Settlement on the West Coast of Fyn. *Journal of Danish Archaeology* 4:52–69.

Andersen, S.H. 2011 Ertebølle Canoes and Paddles from the Submerged Habitation Site of Tybrind Vig, Denmark. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.1–14. Oxbow Books.

Andersen, S.H. 2013 *Tybrind Vig submerged mesolithic settlements in Denmark*. Hojbjerg: Jutland Archaeological Society.

Andrijašević, N. 1910 O vertikalnom pomicanju obalne crte u historičko doba na sjevero-istoku jadranskoga mora (Doktorska dizertacija, odobrena od filozofskoga fakuteta hrv. sveučilišta Franje Josipa I. u Zagrebu). *Supplemento al Bullettino di archeologia e storia dalmata* XXXIII:1–45.

Antolín, F., R. Buxó, S. Jacomet, V. Navarrete and M. Saña 2014 An integrated perspective on farming in the early Neolithic lakeshore site of La Draga (Banyoles, Spain). *Environmental Archaeology* 19(3):241–255.

Antonioli, F., M. Anzidei, K. Lambeck, R. Auriemma, D. Gaddi, S. Furlani, P.E. Orrù, E. Solinas, A. Gaspari, S. Karinja, V. Kovačić and L. Surace 2007 Sea-level change during the Holocene in Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data. *Quaternary Science Reviews* 26:2463–2486.

Antonioli, F., L. Ferranti, A. Fontana, A. Amorosi, A. Bondesan, C. Braitenberg, A. Dutton, G. Fontolan, S. Furlani, K. Lambeck, G. Mastronuzzi, C. Monaco, G. Spada and P. Stochhi 2009 Holocene relative sea-level changes and vertical movements along the Italian and Istrian coastlines. *Quaternary International* 206:102–133.

Antonioli, F., V. Lo Presti, M.G. Morticelli, L. Bonfiglio, M.A. Mannino, M.R. Palombo, G. Sannino, L. Ferranti, S. Furlani, K. Lambeck, S. Canese, R. Catalano, F.L. Chiocci, G. Mangano, G. Scicchitano and R. Tonielli 2016 Timing of the emergence of the Europe–Sicily bridge (40–17 cal ka BP) and its implications for the spread of modern humans. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.111–144. London: Geological Society.

Arnold, B. and F. Langenegger 2012 *Bevaix-Sud: plongée dans le passé, fouille subaquatique d'un village du Bronze final*. Hauterive: Office et museé cantonal d'archéologie de Neuchâtel.

Aspes, A. 1984 *Il Veneto nell'antichità: preistoria e protostoria. II*: Banca Popolare di Verona.

Auriemma, R. and E. Solinas 2009 Archaeological remains as sea level change markers: A review. *Quaternary International* 206:134–146.

Bailey, G.N. 1983 Problems of Site Formation and the Interpretation of Spatial and Temporal Discontinuities in the Distribution of Coastal Middens. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.559–582. Academic Press.

Bailey, G.N. 2011 Continental Shelf Archaeology: where next? In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.311–331. Oxbow Books.

Bailey, G.N. 2014 New Developments in Submerged Prehistoric Archaeology: An Overview. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.291–300. Springer.

Bailey, G.N. and N.C. Flemming 2008 Archaeology of the continental shelf: Marine resources, submerged landscapes and underwater archaeology. *Quaternary Science Reviews* 27:2153–2165.

Bailey, G.N., J. Harff and D. Sakellariou 2017a Archaeology and Palaeolandscapes of the Continental Shelf: An Introduction. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.1–17. Springer.

Bailey, G.N., J. Harff and D. Sakellariou (eds) 2017b *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*. Coastal Research Library: Springer.

Bailey, G.N., D. Sakellariou, A. Alsharekh, S. Al Nomani, M. Devès, P. Georgiou, M. Kallergis, S. Kalogirou, L. Manousakis, P. Mantopoulos, M. Meredith-Williams, G. Momber, I. Morfis, I. Pampidis, I. Panagiotopoulos, P. Renieris, G. Rousakis, V. Stasinos and S. Stavrakakis 2017c Africa-Arabia Connections and Geo-Archaeological Exploration in the Southern Red Sea: Preliminary Results and Wider Significance. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.361–373. Springer.

Barber, E.J.W. 1992 *Prehistoric Textiles: the development of cloth in the Neolithic and Bronze Ages with Special Reference to the Aegean*. Princeton, New Jersey: Princeton University Press.

Barfield, L.H. 1994 The Iceman reviewed. *Antiquity* 68:10–26.

Barfield, L.H., S. Manning, E. Valzolgher and T. Higham 2010 A wiggle-matched date for the Copper Age cemetary at Manerba del Garda, Northern Italy. *Radiocarbon* 52(2–3):984–1001.

Bass, G.F. 1966 *Archaeology Under Water. Ancient People and Places*. London: Thames and Hudson.

Batović, Š. 1979 Jadranska zona. In A. Benac (ed.), *Praistorija jugoslavenskih zemalja*, pp.473–635. Sarajevo: Svetlost.

Becker, B., A. Billamboz, H. Egger, P. Gassmann, A. Orcel, C. Orcel and U. Ruoff (eds) 1985 *Dendrochronologie in der Ur- und Frühgeschichte. Die absolute Datierung von Pfahlbausiedlungen nördlich der Alpen im Jahrringkalender Mitteleuropas*. Antiqua. Basel: Schweizerische Gesellschaft für Ur- und Frühgeschichte.

Bekić, L. 2017 Šimuni, new Bronze Age underwater site in Zadar county. *Diadora* 31:41–50.

Bekić, L., M. Ilkić, Z. Brusić, M. Meštrov, A. Parica, M. Pešić and R. Scholz 2011 New Underwater Archaeological Research in Pakoštane near Zadar *Submerged Heritage* 1:25–30.

Bekić, L. and I. Miholjek (eds) 2009 *Istraživanje podvodne kulturne baštine u Hrvatskoj*. Zadar.

Bekić, L., M. Pešić, R. Scholz and M. Meštrov 2015 Underwater archaeological research at the Prehistoric site of Pakoštane-Janice. *Diadora* 29:7–22.

Benac, Č., M. Juračić and T. Bakran-Petricioli 2004 Submerged tidal notches in the Rijeka Bay NE Adriatic Sea: indicators of relative sea-level change and of recent tectonic movements. *Marine Geology* 212:21–33.

Benjamin, J. 2010 Submerged Prehistoric Landscapes and Underwater Site Discovery: Reevaluating the 'Danish Model' for International Practice. *Journal of Island & Coastal Archaeology* 5:253–270.

Benjamin, J., L. Bekić, D. Komšo, I. Koncani Uhač and C. Bonsall 2011a Investigating the Submerged Prehistory of the Eastern Adriatic: progress and prospects. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.193–206. Oxbow Books.

Benjamin, J. and C. Bonsall 2009 A Feasibility Study for the Investigation of Submerged Sites along the Coast of Slovenia. *The International Journal of Nautical Archaeology* 38(1):163–172.

Benjamin, J., C. Bonsall, C. Pickard and A. Fischer (eds) 2011b *Submerged Prehistory*: Oxbow Books.

Benjamin, J. and M. Črešnar 2009 Submerged prehistoric site discovery and a proposed application in the Croatian Adriatic. In L. Bekić (ed.), *Jurišićev zbornik. Zbornik radova u znak sjećanja na Marija Jurišića*, pp.52–67. Zagreb: Croatian Conservation Institute and the International Centre for Underwater Archaeology.

Benjamin, J., M.J. O'Leary, I. Ward, J. Hacker, S. Ulm, P. Veth, M. Holst, J. McDonald, P.J. Ross and G.N. Bailey 2018 Underwater archaeology and submerged landscapes in Western Australia. *Antiquity* 92(363):1–9.

Benjamin, J., A. Rovere, A. Fontana, S. Furlani, M. Vacchi, R.H. Inglis, E. Galili, F. Antonioli, D. Sivan, S. Miko, N. Mourtzas, I. Felja, M. Meredith-Williams, B. Goodnan-Tchernov, E. Kolaiti, M. Anzidei and R.

Gehrels 2017 Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: An interdisciplinary review. *Quaternary International* xxx:1–29.
Berger, A. 1988 Milankovitch Theory and Climate. *Review of Geophysics* 26(4):624–657.
Berger, R. 1983 Sea Levels and Tree-ring Calibrated Radiocarbon Dates. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.51–61. Academic Press.
Biagi, P., M. Cremaschi and R. Nisbet 1993 Soil exploitation and early agriculture in northern Italy. *The Holocene* 3(2):164–168.
Bicket, A., G. Shaw and J. Benjamin 2017 Prospecting for Holocene Palaeolandscapes in the Sound of Harris, Outer Hebrides. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.179–195. Springer.
Billamboz, A. 2004 Dendrochronology in Lake-dwelling Research. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.117–131. Routeledge.
Billamboz, A. 2008 Dealing with heteroconnections and short tree-ring series at different levels of dating in the dendrochronology of the Southwest German pile-dwellings. *Dendrochronologia* 26:145–155.
Billamboz, A. and N. Martinelli 2015 Dendrochronology and Bronze Age pile-dwellings on both sides of the Alps: from chronology to dendrotypology, highlighting settlement developments and structural woodland changes. In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.68–84. Oxbow Books.
Blott, S.J. and K. Pye 2001 Gradistat: A Grain Size Distribution and Statistics Package for the Analysis of Unconsolidated Sediments. *Earth Surface Processes and Landforms* 26:1237–1248.
Boetto, G., I. Koncani Uhač and M. Uhač 2015 *Sewn Ships from Istria (Croatia): the Shipwrecks of Zambratija and Pula*. 14th International Symposium on Boat and Ship Archaeology: Baltic and Beyond. Change and Continuity in Shipbuilding., Gdansk.
Bolšec-Ferri, N. 2007 Zambratija - antička vila. In J. Mesić (ed.), *Croatian Archaeological Yearbook*, pp.418–419. Zagreb: Ministry of Culture. Directorate for Archives and Archaeological Heritage.
Boscato, P., C. Carioni, A. Brandolini, L. Sadori and M. Rottoli 2008 Molecular markers for the discrimination of *Triticum turgidum* L. subsp. *dicoccum* (Schrank ex Schu¨bl.) Thell. and *Triticum timopheevii* (Zhuk.) Zhuk. subsp. *timopheevii*. *Journal of Archaeological Science* 35:239–246.
Boswijk, G. and D. Johns 2018 Assessing the potential to calendar date New Zealand Māori waka (canoes) using dendrochronology. *Journal of Archaeological Science: Reports* 17:442–448.
Brunović, D., S. Miko, N. Ilijanić, V. Hajek-Tadesse, O. Hasan, I. Razum, K. Bakrač and M. Šparica Miko 2015 *Micropalaeontological and geochemical record of Holocene salt-marsh and marine stages in submerged sinkholes (Osor, Island of Cres)*. Osijek.
Brusić, Z. 1977 Prethistorijski podmorski nalazi na području južne Liburnije. *Radovi Centra Jugoslavenske akademije znanosti i umjetnosti u Zadru* 24:53–60.
Budja, M. 2015 Archaeology and rapid climate changes: from the collapse concept to a panarchy interpretative model. *Documenta Praehistorica* XLII:171–184.
Budja, M. and D. Mlekuž 2010 Lake or floodplain? Mid-Holocene settlement patterns and the landscape dynamic of the Ižica floodplain (Ljubljana marshes, Slovenia). *The Holocene* 20(8):1269–1275.
Bulić, F. 1899 Tre sarcofaghi romani nel villagio di Vranjic (Urania?) sotto il livello del mare. *Bulletino di archeologia e storia dalmata* 22:105–111.
Bulić, F. 1900 Ritrovamenti risguardanti i sarchofaghi romani sotto il livello del mare nel vilaggio di Vranjic presso Salona. *Bulletino di archeologia e storia dalmata* 23:141–142.
Buršić-Matijašić, K. 1994 La ceramica a striature in Istria. In I.i.d.p.e. protostoria (ed.), *Atii della XXIX riunione scientifica: preistoria e protostoria del Friuli-Venezia Giulia e dell'Istria: 28–30 settembre 1990*, pp.247–260. Firenze: Istituto italiano di preistoria e protostoria.
Buršić-Matijašić, K. 1998 *Gradina Monkodonja*. Pula: The Archaeological Museum of Istria.
Buršić-Matijašić, K. 2007 *Gradine Istre, Povijest prije povijesti*. Pula: Zavičajna naklada “Žakan Juri” d.o.o.
Buršić-Matijašić, K. 2012 Neki aspekti naselja i nastambi u Istri u prapovijesti. *Tabula* 10:7–38.
Buršić-Matijašić, K. and H. Žerić 2013 Pogrebni obredi i ukopi na istarskim gradinama u brončano doba. *Tabula* 11:67–92.
Bynoe, R., J.K. Dix and F. Sturt 2016 Of mammoths and other monsters: historic approaches to the submerged Palaeolithic. *Antiquity* 90(352):857–875.

Cambi, N. 1970 *Priručnik za hidroarheološka istraživanja* Zagreb.
Carabias, D., I. Cartajena, R. Simonetti, P. López, C. Morales and C. Ortega 2014 Submerged Paleolandscapes: Site GNL Quintero 1 (GNLQ1) and the First Evidences from the Pacific Coast of South America. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.131–149. Springer.
Cassen, S., A. Baltzer, A. Lorin, J. Fournier and D. Sellier 2011 Submarine Neolithic Stone Rows near Carnac (Morbihan), France: preliminary results from acoustic and underwater survey. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.100–110. Oxbow Books.
Čečuk, B. and D. Radić 2005 *Vela Spila, višeslojno pretpovijesno nalazište*. Vela Luka: Centar za kulturu.
Čelhar, M., A. Parica, M. Ilkić and D. Vujević 2017 A Bronze Age underwater site near the islet of Ričul in northern Dalmatia (Croatia). *Skyllis* 17(1):21–34.
CGS, C.G.S. 2018 *LoLADRIA – Lost Lake Landscapes of the Eastern Adriatic Shelf*. Retrieved February 8 2019 from <https://loladria.wordpress.com/>.
Chamley, H. 1989 *Clay Sedimentology*. Berlin Heidelberg GmbH: Springer-Verlag.
Chapman, J. and J. Müller 1990 Early farmers in the Mediterranean Basin: the Dalmantian evidence. *Antiquity* 64:127–134.
Childe, V.G. 1936 *Man Makes Himself*. London: Watts.
Chiocci, F.L., D. Casalbore, F. Marra, F. Antonioli and C. Romagnoli 2017 Relative Sea Level Rise, Palaeotopography and Transgression Velocity on the Continental Shelf. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.39–51. Springer.
Chiocci, F.L. and A.R. Chivas 2014 An overview of the continental shelves of the world. In F.L. Chiocci and A.R. Chivas (eds), *Continental Shelves of the World. The evolution during the last glacio-eustatic cycle*, pp.1–5. London: The Geological Society.
Clark, P.U., A. Marshall McCabe, A.C. Mix and A.J. Weaver 2004 Rapid rise of sea-level 19000 years ago and its Global implications. *Science* 304:1141–1144.
Cliquet, D., S. Coutard, M. Clet, J. Allix, B. Tessier, F. Lelong, A. Baltzer, Y. Mear, E. Poizot, P. Auguste, P. Alix, J. Olive and J. Guesnon 2011 The Middle Palaeolithic Underwater Site of La Mondrée, Normandy, France. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.112–128. Oxbow Books.
Clottes, J., A. Beltrán, J. Courtin and H. Cosquer 1992 The Cosquer Cave on Cape Morgiou, Marseilles. *Antiquity* 66:583–598.
Coles, B. 2004 The Development of Wetland Archaeology in Britain. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.98–114. London and New York: Routledge.
Coles, J. and B. Coles 1995 *Enlarging the Past. The contribuution of wetland archaeology*. Exeter: Society of Antiquaries Scotland.
Connoly, J. and M. Lake 2006 *Geographical Information Systems in Archaeology*. Cambridge.
Ćosović, V., M. Juračić, A. Moro, M. Hernitz Kučenjak, S. Rukavina, N. Pugliese, N. Stuper and I. Vlahov 2006 Recent foraminifera from the Croatian Adriatic seacoast. *Anuário do Instituto de Geociências* 29(1):531–532.
Ćosović, V., D. Zavodnik, A. Borčić, J. Vidović, S. Deak and A. Moro 2011 A checklist of Foraminifera of the Eastern Shelf of the Adriatic Sea. *Zootaxa* 3035:1–56.
Crumley, C.L. 2006 Historical Ecology: Integrated Thinking at Multiple Temporal and Spacial Scales. In A. Hornborg and C.L. Crumley (eds), *The World System and the Earth System: Global Socioenvironmental Change and Sustainability since the Neolithic*, pp.15–28. Walnut Creek, CA: Left Coast Press.
Crumley, C.L. 2017 Historical ecology and the study of landscape. *Landscape Research* 42(S1):565–573.
Čučković, Z. 2007 *Umag - šire područje*, Ministry of Culture. Directorate for Archives and Archaeological Heritage, Zagreb.
Čufar, K., B. Kromer, T. Tolar and A. Velušček 2010 Dating of 4th millenium BC pile-dwellings on Ljubljansko barje, Slovenia. *Journal of Archaeological Science* 37:2031–2039.
Čufar, K., W. Tegel, M. Merela, B. Kromer and A. Velušček 2015 Eneolithic pile dwellings south of the Alps precisely dated with tree-ring chronologies from the north. *Dendrochronologia* 35:91–98.

Čuka, M. 2009 A Typological Analysis of Selected Prehistoric Pottery Fragments from Pećina Ispod Sela Srbani. *Histria archaeologica* 40:13–44.
Dalan, R.A. and S.K. Banjeree 1998 Solving Archaeological Problems Using Techniques of Soil Magnetism. *Geoarchaeology: An International Journal* 13(1):3–36.
deMenocal, P.B. 2001 Cultural Responses to Climate Change During the Late Holocene. *Science* 292:667–673.
Dennel, R. 1997 The world's oldest spears. *Nature* 385:767–768.
Denton, G.H., R.F. Anderson, J.R. Toggweiler, R.L. Edwards, J.M. Schaefer and A.E. Putnam 2010 The Last Glacial Termination. *Science* 25:1652–1656.
Dillian, C. and C. Bello 2008 Blue Vivianite in Prehistoric Clay. *North American Archaeologist* 29(3–4):327–341.
Dimitrijević, S. 1979 Problem eneolita na istočnoj jadranskoj obali. In A. Benac (ed.), *Praistorija jugoslavenskih zemalja*, pp.367–379. Sarajevo: Akademija nauka Bosne i Hercegovina.
Dincauze, D.F. 2000 *Environmental Archaeology. Princinples and Practice*. Cambridge: Cambridge University Press.
Dixon, J.E. and K. Monteleone 2014 Gateway to the Americas: Underwater Archaeological Survey in Beringia and the North Pacific. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.95–114. Springer.
Donati, V. 1750 *Della Storia Naturale Marina dell'Adriatico*. Venezia: T.&G. Edizioni.
Doneus, M., I. Miholjek, G. Mandlburger, N. Doneus, G. Verhoeven, C. Briese and M. Pregesbauer 2015 *Airborne laser bathymetry for documentation of submerged archaeological sites in shallow water*. Underwater 3D Recording and Modeling, 16–17 April 2015, Piano di Sorrento, Italy, Piano di Sorrento, Italy: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.
Doran, J. 1970 Systems Theory, Compuuter Simulations and Archaeology. *World Archaeology* 1(3):289–298.
Draganov, V. 1995 Submerged coastal settlements from the final Eneolithic and the Early Bronze Age in the sea around Sozopol and Urdoviza Bay near Kiten. In D.W. Bailey and I. Panayotov (eds), *Prehistoric Bulgaria*, pp.225–242. Madison: Prehistoric Press.
Dunbar, E., G.T. Cook, P. Naysmith, B.G. Tripney and S. Xu 2016 AMS 14C Dating at the Scottish Universities Environmental Research Centre (SUERC) Radiocarbon Dating Laboratory. *Radiocarbon* 51(1):9–23.
Dunbar, J.S., S.D. Webb and M.K. Faught 1992 Inundated Prehistoric Sites in Apalachee Bay, Florida, and the Search for the Clovis Shoreline. In L. Lewis Johnson and M. Stright (eds), *Paleoshorelines and Prehistory: An investigation of method*, pp.117–146. Boca Raton: CRC Press.
Duplančić Leder, T., T. Ujević and M. Čala 2004 Coastline Lenghts and Areas of Islands in the Croatian Part of the Adriatic Sea Determined from the Topographic Maps at the scale of 1 : 25 000. *Geoadria* 9(1):5–32.
Dyke, A.S., J.T. Andrews, P.U. Clark, J.H. England, G.H. Miller, J. Shaw and J.J. Veillette 2002 The Laurentide and Innuitian ice sheets during the Last Glacial Maximum. *Quaternary Science Reviews* 21:9–31.
Egger, M., T. Jilbert, T. Behrends, C. Rivard and C.P. Slomp 2015 Vivianite is a major sink for phosphorus in methanogenic coastal surface sediments. *Geochimica et Cosmochimica Acta* 169:217–235.
Emery, K.O. and R.L. Edwards 1966 Archaeological Potential of the Atlantic Continental Shelf. *American Antiquity* 31(5, Part 1):733–737.
Erič, M., L. Jaklič and N. Paskali 2017 *One boat-building tradition? How can Lake Lugu in Yunnan/Sichuan province, Lake Suwa in Nagano prefecture, Lake Ohrid in Macedonia and Lake Cerknica in Sloveina be connected? Preliminary research*. 3rd Asia-Pacific Regional Conference on Underwater Cultural Heritage, Hong Kong.
Evans, A.M., J.C. Flatman and N.C. Flemming (eds) 2014 *Prehistoric Archaeology on the Continental Shelf: A Global Review*: Springer.
Evershed, R.P., S. Payne, A.G. Sherratt, M.S. Copley, J. Coolidge, D. Urem-Kotsu, K. Kotsakis, M. Özdoğan, O. Nieuwenhuyse, P.M.M.G. Akkermans, D. Bailey, R.-R. Andeescu, S. Campbell, S. Farid, I. Hodder, N. Yalman, M. Özbaşaran, E. Bıçakçı, Y. Garfinkel, T. Levy and M.M. Burton 2008 Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature* 455:528–531.
Fairbanks, R.G. 1989 A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* 342:637–642.

Faivre, S., T. Bakran-Petricioli and N. Horvatinčić 2010 Relative Sea-Level Change During the Late Holocene on the Island of Vis (Croatia) - Issa Harbour Archaeological Site. *Geodinamica Acta* 23(5–6):209–223.

Faivre, S., E. Fouache, M. Ghilardi, F. Antonioli, S. Furlani and V. Kovačić 2011 Relative sea level change in Istria (Croatia) during the last millenium. *Quaternary International* 232:132–143.

Faught, M.K. 2004 The Underwater Archaeology of Paleolandscapes, Apalachee Bay, Florida. *American Antiquity* 69(2):275–289.

Faught, M.K. 2014 Remote Sensing, Target Identification and Testing for Submerged Prehistoric Sites in Florida: Process and Protocol in Underwater CRM Projects. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.37–52. Springer.

Faught, M.K. and N.C. Flemming 2008 Submerged Prehistoric Sites: 'Needles In Haystacks' for CRMs and Industry. *Sea Technology*:37–42.

Faught, M.K. and A.E. Gusick 2011 Submerged Prehistory in the Americas. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.145–157. Oxbow Books.

Felja, I., A. Fontana, S. Furlani, Z. Bajraktarević, A. Paradžik, E. Topalović, S. Rossato, V. Ćosović and M. Juračić 2015 Environmental changes in the lower Mirna River valley (Istria, Croatia) during the Middle and Late Holocene. *Geologia Croatica* 68(3):209–224.

Feulner, F. 2017 Investigations of Submerged Palaeoshorelines in the Kiel Fjord. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.155–163. Springer.

Fischer, A. 2011 Stone Age on the Continental Shelf: an eroding resource. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.298–310. Oxbow Books.

Fischer, A., J. Benjamin, C. Pickard and C. Bonsall 2011 Epilogue. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.332–338. Oxbow Books.

Flannery, K.V. 1968 Archaeological systems theory and Mesoamerica. In B. Meggers (ed.), *Anthropological Archaeology in the Americas*, pp.67–87. Washington DC: Anthropological Society.

Flatman, J.C. and A.M. Evans 2014 Prehistoric Archaeology on the Continental Shelf: The State of the Science in 2013. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A global Review*, pp.1-–12. Springer.

Flaux, C., P. Rouchet, T. Popova, M. Sternerg, F. Guibal, B. Talon, A. Baralis, K. Panayotova, C. Morhange and A.V. Riapov 2016 An Early Bronze Age pile-dwelling settlement of discovered in Alepu lagoon (municipality of Sozopol,department of Burgas), Bulgaria. *Méditeranée* 126:57–70.

Fleming, K., P. Johnston, D. Zwartz, Y. Yokoyama, K. Lambeck and J. Chappell 1998 Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites. *Earth and Planetary Science Letters* 163:327–342.

Flemming, N.C. 1983a Preliminary Geomorphological Survey of an Early Neolithic Submerged Site in the Sporades, N. Aegean. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.233–268. Academic Press.

Flemming, N.C. 1983b Survival of Submerged Lithic and Bronze Age Artifact Sites: A Review of Case Histories. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.135–173. Academic Press.

Flemming, N.C. 2011 Research Infrastructure for Systematic Study of the Prehistoric Archaeology of the European Submerged Continental Shelf. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.287–297. Oxbow Books.

Flemming, N.C., G.N. Bailey, V. Courtillot, G. King, K. Lambeck, F. Ryerson and C. Vita-Finzi 2003 Coastal and marine palaeo-environments and human dispersal points across the Africa-Eurasia boundary. In C.A. Brebbia and T. Gambin (eds), *Maritime Heritage*, pp.61–73. Wessex Institute of Technology & The University of Malta.

Flemming, N.C., J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds) 2017 *Submerged Landscapes of the European Continental Shelf: Quaternary Palaeoenvironments*. Oxford: Wiley Blackwell.

Florido, E., R. Auriemma, S. Faivre, I. Radić Rossi, F. Antonioli and S. Furlani 2011 Istrian and Dalmatian fishtanks as sea level markers. *Quaternary International* 232(105–113).

Foglini, F., M. Prampolini, A. Micallef, L. Angeletti, V. Vandelli, A. Deidun, M. Soldati and M. Taviani 2016 Late Quaternary coastal landscape morphology and evolution of the Maltese Islands (Mediterranean Sea) reconstructed from high-resolution seafloor data. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.77–95. London: Geological Society.

Folk, R.L. and W.C. Ward 1957 A Study in the Significance of Grain-Size Parameters. *Journal of Sedimentary Petrology* 27:3–26.

Forenbaher, S. 1999–2000 "Nakovana culture"-state of research. *Opuscula Archaeologica* 23–24:373–385.

Forenbaher, S. 2002 Prehistoric Populations of the Island of Hvar - An Overview of Archaeological Evidence. *Collegium Antropologicum* 26:361–378.

Forenbaher, S. 2009 Archaeological Record of the Adriatic Offshore Islands as an Indicator of Long-distance Interaction in Prehistory. *European Journal of Archaeology* 11(2–3):223–244.

Forenbaher, S. and T. Kaiser 2003 *Spila Nakovana: ilirsko svetište na Pelješcu*. Zagreb: V.B.Z.

Forenbaher, S. and T. Kaiser 2006 The pottery of Pupićina cave. In P.T. Miracle and S. Forenbaher (eds), *Prehistoric Herders of Northern Istria. The archaeology of Pupićina cave*, pp.163–224. Monografije i Katalozi. Pula: Archaeological Museum of Istria.

Forenbaher, S. and T. Kaiser 2010 Grapčeva, Nakovana i neolitik istočnog Jadrana, Arheološka istraživanja u Dubrovačko-neretvanskoj županiji. In D. Perkić (ed.), *Izdanja Hrvatskog Arheološkog društva*, pp.25–31. Zagreb: Hrvatsko arheološko društvo.

Forenbaher, S., T. Kaiser and P.T. Miracle 2013 Dating the East Adriatic Neolithic. *European Journal of Archaeology* 16(4):589–609.

Forenbaher, S. and P.T. Miracle 2005 The spread of farming in the Eastern Adriatic. *Antiquity* 79:514–528.

Fortis, A. 1774 *Viaggio in Dalmazia*. Venezia: Marsilio Editori.

Frelih, M. 1986 Breg pri Škofljici – mezolitsko najdišče na Ljubljanskom barju. *Poročilo o raziskovanju paleolita, neolita in eneolita v Sloveniji* 14:21–57.

Furlani, S., A. Ninfo, E. Zavagno, P. Paganini, L. Zini, S. Biolchi, F. Antonioli, F. Coren and F. Cucchi 2014 Submerged notches in Istria and the Gulf of Trieste: Results from the Geoswim project. *Quaternary International* 332:37–47.

Gaffney, V., R. Allaby, R. Bates, M. Bates, E. Ch'ng, S. Fitch, P. Garwood, G. Momber, P. Murgatroyd, M. Pallen, E. Ramsey, D. Smith and O. Smith 2017 Doggerland and the Lost Frontiers Project (2015–2020). In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.305–319. Springer.

Galili, E., J. Benjamin, I. Hershkovitz, M. Weinstein-Evron, I. Zohar, V. Eshed, D. Cvikel, J. Melamed, Y. Kahanov, J. Bergeron, C. Ruggles, A. Ronen and L.K. Horwitz 2017a Atlit-Yam: A Unique 9000 Year Old Prehistoric Village Submerged off the Carmel Coast, Israel – The SPLASHCOS Field School (2011). In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.85–102. Springer.

Galili, E., L.K. Horwitz, V. Eshed and B. Rosen 2017b Submerged Pottery Neolithic Settlements off the Coast of Israel: Subsistence, Material Culture and the Development of Separate Burial Grounds. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.105–130. Springer.

Galili, E. and B. Rosen 2011 Submerged Neolithic Settlements off the Carmel Coast, Israel: cultural and environmental insights. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.272–286. Oxbow Books.

Galili, E., M. Şevketoğlu, A. Salamon, D. Zviely, H.K. Mienis, B. Rosen and S. Mosckovitz 2016 Late Quaternary beach deposits and archaeological relicts on the coasts of Cyprus, and the possible implications of sea-level changes and tectonics on the early populations. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.179–218. London: Geological Society.

Garrison, E.G. 1992 Recent Archaeogeophysical Studies of Paleoshorelines of the Gulf of Mexico. In L. Lewis Johnson and M. Stright (eds), *Paleoshorelines and Prehistory: An investigation of method*, pp.103–116. Boca Raton: CRC Press.

Gaspari, A., M. Erič and B. Odar 2011 A Palaeolithic Wooden Point from Ljubljansko Barje, Slovenia. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.186–192. Oxbow Books.
Gately, I. and J. Benjamin 2017 Archaeology Hijacked: Addressing the Historical Misappropriations of Maritime and Underwater Archaeology. *Journal of Maritime Archaeology* 13(1):15–35.
Gearey, B.R., E.-J. Hopla, I. Boomer, D. Smith, P. Marshall, S. Fitch, S. Griffiths and D.R. Tappin 2017 Multi-proxy palaeoecological approaches to submerged landscapes: a case study from 'Doggerland', in the southern North Sea. In M. Williams, T. Hill, I. Boomer and I.P. Wilkinson (eds), *The Archaeological and Forensic Applications of Microfossils: A Deeper Understanding of Human History*, pp.35–53. The Micropalaeontological Society, Special Publications. Geological Society, London.
Geddes, D.S., J. Guilaine and A. Monaco 1983 Early Neolithic Occupation on the Submerged Continental Plateau of Roussillon (France). In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.175–187. Academic Press.
Gehrels, R. 2000 Using foraminiferal transfer functions to produce high-resolution sea-level records from salt-marsh deposits, Maine, USA. *The Holocene* 10(3):367–376.
Gehrels, R. and A. Long 2008 Sea level is not level: the case for a new approach to predicting UK sea-level rise. *Geography* 93(Part 1 Spring):11–16.
Gifford, J. 1983 Core Sampling of a Holocene Marine Sedimantary Sequence and Underlying Neolithic Cultural Material off Franchthi Cave, Greece. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.269–281. Academic Press.
Gillespie, R. 1984 *Radiocarbon user's handbook*: Oxbow Books.
Glørstad, H. 2016 Deglaciation, sea-level change and the Holocene colonization of Norway. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shel*, pp.9–25. London: Geological Society.
Glørstad, H., J. Gundersen and F. Kvalø 2017 The Northern Coasts of Doggerland and the Colonisation of Norway at the End of the Ice Age. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.285–303. Springer.
Gnirs, A. 1908 Beobachtugen über den Fortschritt einer säkularen Niveauschwankung des Meeres wärhend der letzten zwei Jahrtausende. *Mitteilungen der Geographischen Gesellschaft in Wien* 51:1–56.
Goldhammer, J. and S. Hartz 2017 Fished up from the Baltic Sea: A New Ertebølle Site near Stohl Cliff, Kiel Bay, Germany. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.145–154. Springer.
Greb, S.F., W.A. DiMichele and R.A. Gastaldo 2006 Evolution and importance of wetlands in earth history. *Geological Society of America Special Paper* 399.
Green, J. 2004 *Maritime Archaeology. A Technical Handbook.*: Elsevier Academic Press.
Grissino-Mayer, H.D., P.R. Sheppard and M.K. Claeveland 2004 A dendrochronological re-examination of the "Messiah" violin and other instruments attributed to Antonio Stradivari. *Journal of Archaeological Science* 31:167–174.
Grizelj, A., K. Bakrač, M. Horvat, R. Avanić and I. Hećimović 2017 Occurrence of vivianite in alluvial Quaternary sediments in the area of Sesvete (Zagreb, Croatia). *Geologia Croatica* 70(1):41–52.
Grosse-Brauckmann, G. 1974 Über pflanzliche Makrofossilien mitteleuropäischer Torfe. II. Weitere Reste (Früchte und Samen, Moose u.a.) und ihren Bestimmungsmöglichkeiten. *Telma* 4:51–117.
Hafner, A. 2004 Underwater Archaeology. Lake-dwellings Below the Water Surface. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.178–193. Routeledge.
Hafsten, U. 1970 A sub-division of the Late Pleistocene period on a synchronous basis, intended for global and universal usage. *Palaeogeography, Palaeoclimatology, Palaeoecology* 7(4):279–296.
Håkanson, L. and M. Jansson 2002 *Principles of Lake Sedimentology*. New Jersey: The Blackburn Press.
Hamon, C. 2008 Functional analysis of stone grinding and polishing tools from the earliest Neolithic of north-western Europe. *Journal of Archaeological Science* 35(6):1502–1520.

Haneca, K., K. Čufar and H. Beeckman 2009 Oaks, tree-rings and wooden cultural heritage: a review of the main characteristics and applications of oak dendrochronology in Europe. *Journal of Archaeological Science* 36:1–11.

Hänsel, B., B. Teržan and K. Mihovilić 2005 Radiokarbonski datumi ranijeg i srednjeg brončanog doba u Istri. *Histria archaeologica* 36:5–46.

Hansson, A., S. Björck, H. Linderson, M. Rundgren, B. Nilsson, A. Sjöström and D. Hammarlund 2017 Early Holocene Landscape Development and Baltic Sea History Based on High-Resolution Bathymetry and Lagoonal Sediments in the Hanö Bay, Southern Sweden. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.197–209. Springer.

Hansson, A., B. Nilsson, A. Sjöström, S. Björck, S. Holmgren, H. Linderson, O. Magnell, M. Runtgren and D. Hammarlund 2016 A submerged Mesolithic lagoonal landscape in the Baltic Sea, southeastern Sweden e Early Holocene environmental reconstruction and shore-level displacement based on a multiproxy approach. *Quaternary International* xxx:1–14.

Harff, J., G.N. Bailey and F. Lüth (eds) 2016a *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*. Geological Society Special Publications. London: Geological Society.

Harff, J., G.N. Bailey and F. Lüth 2016b Geology and archaeology: submerged landscapes of the continental shelf: an introduction. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.1–8. London: Geological Society.

Harff, J., N.C. Flemming, A. Groh, B. Hünicke, G. Lericolais, M. Meschede, A. Rosentau, D. Sakellariou, S. Uścinowicz, W. Zhang and E. Zorita 2017 Sea Level and Climate. In N.C. Flemming, J. Harff, D. Moura, A. Burgess and G.N. Bailey (eds), *Submerged Landscapes of the European Continental Shelf. Quaternary Paleoenvironments*, pp.11–49. Oxford: Wiley Blackwell.

Harmand, S., J.E. Lewis, C.S. Feibel, C.J. Lepre, S. Prat, A. Lenoble, X. Boës, R.L. Quinn, M. Brenet, A. Arroyo, N. Taylor, S. Clément, G. Daver, J.-P. Brugal, L. Leakey, R.A. Mortlock, J.D. Wright, S. Lokorodi, C. Kirwa, D.V. Kent and H. Roche 2015 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. *Nature* 521:311–316.

Hasan, O. 2017 Holocene palaeo-environmental reconstruction of the Karin Sea, Novigrad Sea and Velebit Channel catchments, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb.

Hays, J.D., J. Imbrie and N.J. Shackleton 1976 Variations in the Earth's orbit: pacemaker of the ice ages. *Science* 194:1121–1131.

Henderson, J.C., C. Gallou, N.C. Flemming and E. Spondylis 2011 The Pavlopetri Underwater Archaeology Project: investigating an ancient submerged town. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.207–218. Oxbow Books.

Hepp, D.A., U. Warnke, D. Hebbeln and T. Mörz 2017 Tributaries of the Elbe Palaeovalley: Features of a Hidden Palaeolandscape in the German Bight, North Sea. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.211–222. Springer.

Hewitt, G. 2000 The genetic legacy of the Quaternary ice ages. *Science* 405:907–913.

Hodder, I. and S. Hutson 2003 *Reading the Past. Current Approaches to Interpretation in Archaeology*. Cambridge: Cambridge University Press.

Hole, F. 1984 A Reassessment of the Neolithic Revolution. *Paléorient* 10(2):49–60.

Holliday, V.T. and W. Gartner 2007 Methods of soil P analysis in archaeology. *Journal of Archaeological Science* 34:301–333.

Holmlund, J., B. Nilsson and J. Rönnby 2017 Joint Explorations of the Sunken Past: Examples of Maritime Archaeological Collaboration Between Industry and Academia in the Baltic. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.53–63. Springer.

Hughes, P.D. and P.L. Gibbard 2015 A stratigraphical basis for the Last Glacial Maximum (LGM). *Quaternary International* 383:174–185.

Hulina, M., S. Forenbaher and P.T. Miracle 2011 Prehistoric pottery from the interior section of Pupićina cave (2001 excavation). *Histria archaeologica* 42:137–184.

Hull, K.L. 1987 Identification of Cultural Site Formation Processes through Microdebitage Analysis. *American Antiquity* 52(4):772–783.
Imbrie, J. 1982 Astronomical Theory of the Pleistocene Ice Ages: A Brief Historical Review. *Icarus* 50:408–422.
Imbrie, J., J.D. Hays, D.G. Martinson, A. McIntyre, A.C. Mix, J.J. Morley, N.G. Pisias, W.L. Prell and N.J. Shackleton 1984 The oribital theory of Pleistocene climate: support from a revised chronology of the martime d^{18}O record. In A. Berger, J. Imbrie, J.D. Hays, G. Kukla and B. Saltzman (eds), *Milankovich and Climate. Part 1*, pp.269–305. Dordrecht: D. Riedel Publishing Company.
IPCC 2007 *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland.
IPCC 2014 *Climate Change 2014: Synthesis Repot. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland.
Iveša, N., I. Knežević, I. Koncani Uhač and Ž. A 2017 *Zona Posebnog Upravljanja U Uvali Zambratija (Umag)*. Novigrad: Lokalna akcijska grupa u ribarstvu "Pinna nobilis".
Jacomet, S. 2004 Archaeobotany. A vital tool in the investigation of lake-dwellings. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.162–177. Routledge.
Jarman, R., A.K. Moir, J. Webb and F.M. Chambers 2017 Sweet chestnut (Castanea sativa Mill.) in Britain: its dendrochronological potential. *Arboricultural Journal* 39(2):100–124.
Jerbić Percan, K. 2011 Prehistoric pottery from the Jačmica Cave *Histria archaeologica* 42:5–87.
Jöns, H. and J. Harff 2014 Geoarchaeological Research Strategies in the Baltic Sea Area: Environmental Changes, Shoreline-Displacement and Settlement Strategies. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.173–192. Springer.
Jordanova, N., E. Petrovsky, M. Kovacheva and D. Jordanova 2001 Factors Determining Magnetic Enhancement of Burnt Clay from Archaeological Sites. *Journal of Archaeological Science* 28:1137–1148.
Jorissen, F.J. 1987 The Distribution of Benthic Foraminifera in the Adriatic Area. *Marine Micropaleontology* 12:21–48.
Juggins, S. 2011 *C2 data analysis (version 1.7.4)*. Newcastle uponvTyne, UK: Newcastle University.
Kaennel, M. and F.H. Schweingruber 1995 *Multilingual Glossary of Dendrochronology. Terms and Definitions in English, German, French, Spanish, Italian, Portugese and Russian*. Berne, Stuttgart, Vienna: Paul Haupt Publishers.
Kaiser, T. and S. Forenbaher 2016 Rite to memory: Neolithic depositional histories of an Adriatic cave. In G. Nash and A. Townsend (eds), *Decoding Neolithic Atlantic and Mediterranean Island Ritual*, pp.138–159. Oxford & Philadelphia: Oxbow Books.
Karavanić, I., I. Janković, J.C.M. Ahern and F.H. Smith 2014 Current research on the Middle Paleolithic cave, open-air and underwater site in Dalmatia, Croatia. *The Dolní Věstonice Studies* 20:31–36.
Karkanas, P., K. Pavlopoulos, K. Kouli, M. Ntinou, G. Tsartsidou, Y. Facorellis and T. Tsouru 2011 Palaeoenvironments and Site Formation Processes at the Neolithic Lakeside Settlement in Dispilo, Kastoria, Northern Greece. *Geoarchaeology: An International Journal* 26(1):83–117.
Karle, M. and J. Goldhammer 2017 The Wadden Sea of North-West Germany: An Intertidal Environment of High Archaeological Research Potential. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.223–231. Springer.
Keegan, W.F. 1992 Lucayan Settlement Patterns and Recent Coastal Changes in the Bahamas. In L. Lewis Johnson and M. Stright (eds), *Paleoshorelines and Prehistory: An investigation of method*, pp.5–14. Boca Raton: CRC Press.
Keller, F. 1854 *Die Keltische Pfahlbauten in den Schweizerseen*.
Keller, O. and E. Krayss 1993 The Rhine-Linth Glacier in the Upper Wurm: A model of the last Alpine glaciation. *Quaternary International* 18:15–27.
Komšo, D. 2004 Vrčevan - nalazište na otvorenom iz razdoblja ranog neolitika. *Histria archaeologica* 35:5–30.
Komšo, D. 2006 The Mesolithic in Croatia. *Opuscula Archaeologica* 30:55–92.
Komšo, D. 2007 *Kargadur*, Zagreb.

Komšo, D. 2008 *Pećina Laganiši - mjesto života i smrti* Pula: Archaeological Museum of Istria in Pula.
Komšo, D. and N. Vukosavljević 2011 Connecting coast and inland: Perforated marine and freshwater snail shells in the Croatian Mesolithic. *Quaternary International* 244:117–125.
Koncani Uhač, I. 2008 *Zambratija - uvala*, Ministry of Culture. Directorate for Archives and Archaeological Heritage., Zagreb.
Koncani Uhač, I. 2009 Podvodna arheološka istraživanja u uvali Zambratija. *Histria Antiqua* 17:263–268.
Koncani Uhač, I. and R. Auriemma 2015 Savudrija - Its Port and Coastal Landscape in Roman Times. *Archaeologia Adriatica* 9:127–166.
Koncani Uhač, I., G. Boetto and M. Uhač 2017a *Zambratija. Prehistoric sewn boat.* Pula: Archaeological Museum of Istria.
Koncani Uhač, I. and M. Čuka 2015 A contribution to a better understanding of the underwater Eneolithic site at the Zambratija cove. *Histria archaeologica* 46:25–73.
Koncani Uhač, I., K. Jerbić, M. Čuka and D. Komšo 2017b *Investgating Prehistory - A Multidimensional Approach to a Submerged Prehistoric Site in Croatia*. Nicosia, Cyprus.
Koncani Uhač, I. and M. Uhač 2012 Prapovijesni brod iz uvale Zambratija - prva kampanja istraživanja *Histria Antiqua* 21:533–538.
Köninger, J. 2015 Bronze Age lacustrine settlements in the Circum-Alpine region: chronology, architectural styles, occupational patterns, and much more. In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.31–93. Oxbow Books.
Korošec, J. 1952 Nova neolitska kulturna grupa na području Dalmacije. *Vjesnik za arheologiju i historiju dalmatinsku* 54:90–119.
Kraft, J.C., D.F. Belknap and I. Kayan 1983 Potentials of Discovery of Human Occupation Sites on the Continental Shelves and Nearshore Coastal Zone. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.87–120. Academic Press.
Kromer, B. 2009 Radiocarbon and dendrochronology. *Dendrochronologia* 27:15–19.
Kul'kova, M., A. Mazurkevich and P. Dolukhanov 2001 Chronology and Palaeoclimate of Prehistoric Sites in Western Dvina-Lovat' Area of North-Western Russa. *Geochronometria* 20:87–94.
Lacroix, D., T. Bell, J. Shaw and K. Westley 2014 Submerged Archaeological Landscapes and the Recording of Precontact History: Examples from Atlantic Canada. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.13–35. Springer.
Lamb, A.L., G.P. Wilson and M.J. Leng 2006 A review of coastal palaeoclimate and relative sea-level reconstruction using δ13C and C/N ratios in organic material. *Earth-Science Reviews* 75:29–57.
Lambeck, K., F. Antonioli, A. Purcell and S. Silenzi 2004a Sea-level change along the Italian coast for the past 10,000 yr. *Quaternary Science Reviews* 23:1567–1598.
Lambeck, K., M. Anzidei, F. Antonioli, A. Benini and A. Esposito 2004b Sea level in Roman time in the Central Mediterranean and implications for recent change. *Earth and Planetary Science Letters* 224:563–575.
Lambeck, K. and J. Chappell 2001 Sea Level Change Through the Last Glacial Cycle. *Science* 292:679–686.
Lambeck, K., T.M. Esat and E.-K. Poter 2002 Links between climate and sea levels for the past three million years. *Nature* 419:199–206.
Lambeck, K. and A. Purcell 2005 Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. *Quaternary Science Reviews* 24:1969–1988.
Larrasoaña, J.C., A.P. Roberts, R.J. Musgrave, E. Gràcia, E. Piñero, M. Vega and F. Martínez-Ruiz 2007 Diagenetic formation of greigite and pyrrhotite in gas hydrate marine sedimentary systems. *Earth and Planetary Science Letters* 261(3–4):350–366.
Larsson, L. 1983 Mesolithic Settlement on the Sea Floor in the Straight of Öresund. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.283–301. Academic Press.
Leineweber, R., H. Lübke, M. Hellmund, H.-J. Döhle and S. Klooß 2011 A Late Neolithic Fishing Fence in Lake Arendsee, Sachsen-Anhalt, Germany. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.173–185. Oxbow Books.
Lentfer, C.J. and W.E. Boyd 1998 A Comparison of Three Methods for the Extraction of Phytoliths from Sediments. *Journal of Archaeological Science* 25:1159–1183.

Lewis Johnson, L. 1992 Preface. In L. Lewis Johnson and M. Stright (eds), *Paleoshorelines and Prehistory: An investigation of method*, pp.v–vii. Boca Raton, Florida: CRC Press Inc.

Lewis Johnson, L. and M. Stright (eds) 1992 *Palaeoshorelines and Prehistory: An investigation of method*. Boca Raton: CRC Press.

Lisiecki, L.E. and J.V. Stern 2016 Regional and global benthic d^{18}O stacks for the last glacial cycle. *Paleoceanography* 31:1–27.

Ljubić, Š. 1879 *Kip morske boginje s jednozubnim sidrom*. Zagreb: Hrvatsko Arheološko Društvo.

Locke, G. 2004 Wetland Archaeology and Computers. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.194–204. Routledge.

Lübke, H., U. Schmölcke and F. Tauber 2011 Mesolithic Hunter-Fishers in a Changing World: a case study of submerged sites on the Jäckelberg, Wismar Bay, northeastern Germany. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.21–37. Oxbow Books.

Lubos, C., S. Dreibrodt and A. Bahr 2016 Analysing spatio-temporal patterns of archaeological soils and sediments by comparing pXRF and different ICP-OES extraction methods. *Journal of Archaeological Science: Reports* 9:44–53.

Magny, M. 2004 Holocene climate variability as reflectedby mid-European lake-level fluctuations andits probable impact on prehistoric human settlements. *Quaternary International* 113:65–79.

Magny, M. 2015 Climatic variations in the Circum-Alpine area during the period 4500–2500 cal BP, as reflected by palaeohydrological changes. In, *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.115–133. Oxbow Books.

Magny, M., B. Vannière, G. Zanchetta, E. Fouache, G. Touchais, L. Petrika, C. Coussot, A.-V. Walter-Simonnet and F. Arnaud 2009 Possible complexity of the climatic event around 4300–3800 cal. BP in the central and western Mediterranean. *The Holocene* 19(6):823–833.

Malone, C. 2003 The Italian Neolithic: A Synthesis of Research. *Journal of World Prehistory* 17(3):235–312.

Mange, M.A. and H.F.W. Maurer 1992 *Heavy Minerals in Colour*: Springer-Science+Business Media, B.V.

Manzanilla, L. 1996 Soil analyses to identify ancient human activities. *Canadian Journal of Soil Science* 76:107–108.

Marchesetti, C. 1903 *I castellieri preistorici di Trieste e della regione Giulia*. Trieste: Kessinger Publishing (2010).

Maritan, L. and C. Mazzoli 2004 Phosphates in Archaeological Finds: Implications for Environmental Conditions of Burial. *Archaeometry* 46(4):673–683.

Marović, I. 2002 Sojeničko naselje na Dugišu kod Otoka (Sinj). *Vjesnik za arheologiju i historiju dalmatinsku* 94(1):217–296.

Marriner, N., C. Morhange, S. Faivre, C. Flaux, M. Vacchi, S. Miko, V. Dumas, G. Boetto and I. Radić Rossi 2014 Post-Roman sea-level changes on Pag Island (Adriatic Sea): Dating Croatia's "enigmatic" coastal notch? *Geomorphology* 221:83–94.

Martorelli, E., F. Falese and F.L. Chiocci 2014 Overview of the variability of the Late Quaternary continental shelf deposits of the Italian peninsula. In F.L. Chiocci and A.R. Chivas (eds), *Continental Shelves of the Word: The Evolution During the Last Eustatic Cycle*, pp.171–186. Geological Society Memoir. London: Geological Society.

Marzatico, F. 2004 150 Years of Lake-Dwelling Research in Northern Italy. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.83–97. Routledge.

Massey, A.C., R.W. Gehrels, D.J. Charman and S.V. White 2006 An intertidal foraminifera-based transfer function for reconstructing Holocene sea-level change in Southwest England. *Journal of Foraminiferal Research* 36(3):215–232.

Masters, P.M. and N.C. Flemming 1983a Preface. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology. Towards the prehistory of land bridges and continental shelves*, pp.ix–xii. London: Academic Press.

Masters, P.M. and N.C. Flemming (eds) 1983b *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*: Academic Press.

Masters, P.M. and N.C. Flemming 1983c Summary and Conclusions. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.601–629.

Matthews, G.V.T. 2013 *The Ramsar Convention on Wetlands: its History and Development*. Gland, Switzerland: The Ramsar Convention Bureau.
Mayewski, P.A., E.E. Rohling, J.C. Stager, W. Karlén, K.A. Maasch, L.D. Meeker, E.A. Meyerson, F. Gasse, S. van Kreveld, K. Holmgren, J. Lee-Thorp, G. Rosqvist, F. Rack, M. Staubwasser, R.R. Schneider and E.J. Steig 2004 Holocene climate variability. *Quaternary Research* 62:243–255.
Mazurkevich, A. and E. Dolbunova 2011 Underwater Investigations in Northwest Russia: lacustrine archaeology of Neolithic pile dwellings. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.158–172. Oxbow Books.
Mazurkevich, A., E. Dolbunova, Y. Maigrot and D. Hookk 2011 The Results of Underwater Excavations at Serteya II, and Research into Pile-dwellings in Northwest Russia. *Archaeologia Baltica* 14:47–64.
McCarthy, J. and J. Benjamin 2014 Multi-image Photogrammetry for Underwater Archaeological Site Recording: An Accessible, Diver-Based Approach. *Journal of Maritime Archaeology* 9:95–114.
McClure, S.B., C. Magill, E. Podrug, A.M.T. Moore, T.K. Harper, B.J. Culleton, D.J. Kennett and K.H. Freeman 2018 Fatty acid specific $\delta^{13}C$ values reveal earliest Mediterranean cheese production 7,200 years ago. *PLoS ONE* 13(9):e0202807.https://doi.org/10.1371/journal.pone.0202807.
McClure, S.B., E. Podrug, A.M. Moore, B.J. Culleton and D.J. Kennett 2014 AMS ^{14}C Chronology and Ceramic Sequences of Early Farmers in the Eastern Adriatic. *Radiocarbon* 56(3):1019–1038.
McGowan, G. and J. Prangnell 2006 The Significance of Vivianite in Archaeological Settings. *Geoarchaeology: An International Journal* 21(1):93–111.
Menotti, F. 2001 The *Pfahlbauproblem* and the History of Lake-Dwelling Research in the Alps. *Oxford Journal of Archaeology* 20(4):319–328.
Menotti, F. 2004a Displacement, Readaptation and Cultural Continuity. A Lake-Dwelling Perspective. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.207–217. Routledge.
Menotti, F. 2004b The Lake-Dwelling Phenomenon and Wetland Archaeology. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.1–6. Routledge.
Menotti, F. (ed.) 2004c *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*: Routledge.
Menotti, F. 2009 Climate variations in the Circum-Alpine region and their influence on Neolithic-Bronze Age lacustrine communities: displacement and/or cultural adaptation. *Documenta Praehistorica* XXXVI:61–66.
Menotti, F. 2012 *Wetland Archaeology and Beyond. Theory and Practice.*: Oxford University Press.
Menotti, F. 2015a The 3500-year-long lake-dwelling tradition comes to an end: what is to blame? In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.287–302.
Menotti, F. 2015b The lake-dwelling phenomenon: myth, reality and ... archaeology. In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.14–30. Oxbow Books.
Menotti, F., Z. Baubonis, D. Brazaitis, T. Higham, M. Kvedaravicius, H. Lewis, G. Motuzaite and E. Pranckenaite 2005 The First Lake-dwellers of Lithuania: Late Bronze Age Pile Settlements on Lake Luokesas. *Oxford Journal of Archaeology* 24(4):381–403.
Meyers, P.A. and J.L. Teranes 2001 Sediment Organic Matter. In W.M. Last and J.P. Smol (eds), *Tracking Environmental Change Using Lake Sediments: Volume 2: Physical and Geochemical Methods*, pp.239–270. Dordrecht; Boston: Kluwer Academic Publishers.
Middleton, W.D. 2004 Identifying Chemical Activity Residues on Prehistoric House Floors: A Methodology and Rationale for Multi-elemental Characterization of a Mild Acid Extract of Anthropogenic Sediments. *Archaeometry* 46:47–65.
Milankovitch, M. 1930 Matematische Klimalehre und astronomische Theorie der Klimaschwankungen. In K. W and R. Geiger (eds), *Handbuch der Klimmatologie*, pp.1–176. Berlin: Gebrüder Borntraeger.
Milošević, A. 1999 Archäologische Probeuntersuchungen im Flussbett der Cetina (Kroatien) Zwichen 1990 und 1994. *Archäologisches Korrespondenzblatt* 29(2):203–210.
Mirnik, I. 1972 *Prve hidroarheološke zabilješke kod nas*. 3**:**13.
Missiaen, T., M. Pieters, F. Maes, P. Kruiver, P. De Maeyer and J. Seys 2017a The SeArch Project: Towards an Assessment Methodology and Sustainable Management Policy for the Archaeological Heritage of the North Sea in Belgium. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.415–424. Springer.

Missiaen, T., D. Sakellariou and N.C. Flemming 2017b Survey Strategies and Techniques in Underwater Geoarchaeological Research: An Overview with Emphasis on Prehistoric Sites. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.21–37. Springer.

Momber, G. 2011 Submerged Landscape Excavations in the Solent, Southern Britain: climate change and cultural development. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.85–98. Oxbow Books.

Momber, G. 2014 Submerged Archaeology and Cultural Responses to Climatic Amelioration. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.193–212. Springer.

Monegato, G., G. Scardia, I. Hajdas, F. Rizzini and A. Piccin 2017 The Alpine LGM in the boreal ice-sheets game. *Nature Scientific Reports* 7(2078):1–8.

Montagnari Kokelj, E. 2003 Why settling a Karstic area? Considerations on the Trieste Karst (north-eastern Italy) in the Late Prehistory. *Histria Antiqua* 11:75–93.

Moore, A.M., M. Menđušić, J. Smith and E. Podrug 2007 Project "Early Farming in Dalmatia". Danilo Bitinj 2004–2005. *Vjesnik Arheološkog Muzeja u Zagrebu* 40(1):15–24.

Moore, D.M. and R.C. Reynolds 1997 *X-ray diffraction and identification and analysis of clay minerals*. New York: Oxford University Press.

Morhange, C. and N. Marriner 2015 Archaeological and biological relative sea-level indicators. In I. Shennan, A. Long and B.P. Horton (eds), *Handbook of Sea Level Research*, pp.146–156. Wiley.

Moseley, M.E., D. Wagner and J.B. Richardson III 1992 Space Shuttle Imagery of Recent Catastrophic Change Along the Arid Andean Coast. In L. Lewis Johnson and M. Stright (eds), *Paleoshorelines and Prehistory: An investigation of method*, pp.215–235. Boca Raton: CRC Press.

Muckelroy, K. 1978 *Maritime Archaeology*. Cambridge: Cambridge University Press.

Munsell Color Co., I. 1992 *Munsell soil color charts (revised ed.)*. Baltimore.

Nicholas, G.P. 1998 Wetlans and Hunter-Gatherers: A Global Perspective. *Current Anthropology* 39(5):720–731.

Nikolanci, M. 1953 Podmorska arheologija u svijetu i kod nas. *Vjesnik za arheologiju i historiju dalmatinsku* 55:166–179.

Novak, G. 1955 *Prehistoric Hvar*: Academia scientiarum et artium jugoslavica.

Novaković, P. 2011 Archaeology in the New Countries of Southeastern Europe: A Historical Perspective. In L.R. Lozny (ed.), *Comparative Archaeologies. A Sociological View of the Science of the Past.*, pp.339–461. Springer.

Nutley, D. 2014 Inundated Site Studies in Australia. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.255–273. Springer.

Nymoen, P. and B. Skar 2011 The Unappreciated Cultural Landscape: indications of submerged Mesolithic settlement along the Norwegian southern coast. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.38–54. Oxbow Books.

O'Shea, J.M., A.K. Lemke, E.P. Sonnenburg, R.G. Reynolds and B.D. Abbott 2014 A 9,000-year-old caribou hunting structure beneath Lake Huron. *Proceedings of the National Academy of Sciences* 111(19):6911–6915.

Obelić, B., M. Krznarić Škrivanko, B. Marijan and I. Krajcar Bronić 2004 Radiocarbon Dating of Sopot Culture Sites (Late Neolithic) in Eastern Croatia. *Radiocarbon* 46(1):245–258.

Palomo, A., R. Piqué, X. Terradas, À. Bosch, R. Buxó, J. Chinchilla, M. Saña and J. Tarrùs 2014 Prehistoric Occupation of Banyoles Lakeshore: Results of Recent Excavations at La Draga Site, Girona, Spain. *Journal of Wetland Archaeology* 14:58–73.

Pearson, C.E., R.A. Weinstein, S.M. Gagliano and D.B. Kelley 2014 Prehistoric Site Discovery on the Outer Continental Shelf, Gluf of Mexico, United States of America. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.53–72. Springer.

Peretto, C., P. Biagi, G. Boschian and A. Broglio 2004 Living-Floors and Structures From the Lower Paleolithic to the Bronze Age in Italy. *Collegium Antropologicum* 28(1):63–88.

Pešić, M. 2012 Underwater Archaeological Research at the Janice Site in Pakoštane. *Submerged Heritage* 2:39–43.

Pešić, M. 2013 Research of the Waters of the Islet of Babuljaš near Pakoštane. *Submerged Heritage* 3:25–30.
Pešić, M. 2015 Babuljaš Investigation Continues. *Submerged Heritage* 5:29–33.
Pešić, M. 2016 New Results from Babuljaš Waters Archaeological Investigation. *Submerged Heritage* 6:17–21.
Pétrequin, P. and M. Bailly 2004 Lake-dwelling Research in France. From climate to demography. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.36–49. Routledge.
Petrić, N. 1976 Prethistorijske kulture Pelješca. *Pelješki zbornik* 1:295–313.
Petrić, N. 1979 Introduzione alla preistoria dell'Istria. *Atti di Centro di richerche storiche* 9:185–379.
Petrić, N. 2001 Počeci podvodne arheologije u Hrvatskoj: Povijesno-arheološke bilješke. *Histria archaeologica* 32:109–131.
Petrić, N. 2002 Zanimljivi crteži na pretpovijesnoj keramici Hvarske kulture: prikazi kometa iz približno 3000. g. pr. Kr. *Vjesnik Arheološkog Muzeja u Zagrebu* XXXV(3):11–18.
Pini, R. 2004 Late Neolithic vegetation history at the pile-dwelling site of Palù di Livenza (northeastern Italy). *Journal of Queternary Science* 19(8):769–781.
Piva, A., A. Asioli, F. Trincardi, R.R. Schneider and L. Vigliotti 2008 Late-Holocene climate variability in the Adriatic Sea (Central Mediterranean). *The Holocene* 18(1):153–167.
Plog, F.T. 1975 Systems Theory in Archaeological Research. *Annual Review of Anthropology* 4:207–224.
Podrug, E. 2010 Čista mala – Velištak: prve tri istraživačke kampanje na nalazištu hvarske kulture. *Diadora* 24:7–25.
Potrebica, H. 2003 Požeška Kotlina i Donja Dolina u komunikacijskoj mreži starijeg željeznog doba. *Opuscula Archaeologica* 27:217–242.
Primorac, J., N. Obuljen and N. Švob-Đokić 2014 *Country Profile: Croatia*.
Quinn, R., W. Forsythe, C. Breen, M. Dean, M. Lawrence and S. Liscoe 2002 Comparison of the Maritime Sites and Monuments Record with Side-Scan Sonar and Diver Surveys: A Case Study from Rathlin Island, Ireland. *Geoarchaeology: An International Journal* 17(5):441–451.
Radić Rossi, I. 2008 Arheološka baština u podmorju Kaštelanskog zaljeva. *Archaeologia Adriatica* II:489–506.
Radić Rossi, I. 2012a Underwater Cultural Heritage and Maritime Archaeology in Croatia: An Overview. *European Journal of Archaeology* 15(2):285–308.
Radić Rossi, I. 2012b Underwater/Submarine, Maritime and Nautical Archaeology: Discussing some Terminological Issues. *Archaeologia Adriatica* 6:207–230.
Radić Rossi, I. and N. Cukrov 2017 Archaeological Potential of the Anchialine Caves in Croatia. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.255–266.
Raymo, M.E. and P. Huybers 2008 Unlocking the mysteries of the ice ages. *Nature* 451(17):284–285.
Reid, C. 1913 *Submerged Forests*. Cambridge: Cambridge University Press.
Reimer, P.J., M.G.L. Baillie, E. Bard, A. Bayliss, J.W. Beck, C.J.H. Bertrand, P.G. Blackwell, C.E. Buck, G.S. Burr, K.B. Cutler, P.E. Damon, R.L. Edwards, R.G. Fairbanks, M. Friedrich, T.P. Guilderson, A.G. Hogg, K.A. Hughen, B. Kromer, G. McCormac, S. Manning, C.B. Ramsey, R.W. Reimer, S. Remmele, J.R. Southon, M. Stuiver, S. Talamo, F.W. Taylor, J. van de Plicht and C.E. Weyhenmeyer 2004 IntCal04 terrestrial radiocarbon age calibration, 0–26 kyr BP. *Radiocarbon* 46(3):1029–1058.
Reitz, E.J. and M. Shackley 2012 *Environmental Archaeology*: Springer.
Richter, D.D., H. Lee Allen, J. Li, D. Markewitz and J. Raikes 2006 Bioavailability of slowly cycling soil phosphorus: major restructuring of soil P fractions over four decades in an aggrading forest. *Oecologia* 150(2):259–271.
Roberts, N. 1998 *The Holocene: An Environmental History*: Blackwell Publishers.
Rodrigues, J. 2005 *The UNESCO Convention on the Protection of the Underwater Cultural Heritage: a one-day workshop held on 23 May 2004*, Western Australian Maritime Museum.
Rothe, M., A. Kleeberg and M. Hupfler 2016 The occurrence, identification and environmental relevance of vivianite in waterlogged soils and aquatic sediments. *Earth-Science Reviews* 158.
Rovere, A., M.E. Raymo, M. Vacchi, T. Lorscheid, P. Stocchi, L. Gómez-Pujol, D.L. Harris, E. Casella, M.J. O'Leary and P.J. Hearty 2016a The analysis of Last Interglacial (MIS 5e) relative sea-level indicators: Reconstructing sea-level in a warmer world. *Earth-Science Reviews* 159:404–427.

Rovere, A., P. Stocchi and M. Vacchi 2016b Eustatic and Relative Sea Level Changes. *Current Climate Change Reports* 2:221–231.
Ruoff, U. 2004 Diversity in Unity. Regional frontiers in lake-dwelling research. Lake-dwellings in Switzerland since "Meilen 1854". In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.9–21. Routledge.
Ruttkay, E., O. Cichocki, E. Pernicka and E. Pucher 2004 Prehistoric Lacustrine Villages on the Austrian Lakes. Past and present research developments. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.50–68. Routledge.
Ryabchuk, D., V. Zhamoida, A. Amantov, A. Sergeev, T. Gusentsova, P. Sorokin, M. Kulkova and D. Gerasimov 2016 Development of the coastal systems of the easternmost Gulf of Finland, and their links with Neolithic–Bronze Age and Iron Age settlements. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shel*, pp.51–76. London: Geological Society.
Sakellariou, D. and N. Galanidou 2016 Pleistocene submerged landscapes and Palaeolithic archaeology in the tectonically active Aegean region. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.145–178. London: Geological Society.
Salmon, M.H. 1978 What Can Systems Theory do For Archaeology? *American Antiquity* 43(2):174–183.
Salter, E., P. Murphy and H. Peeters 2014 Researching, Conserving and Managing Submerged Prehistory: National Approaches and International Collaboration. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.151–172. Springer.
Samonig, B. 2003 Zum Terminologie des Jungneolithikums. In, *Studien zur Pfahlbauforschung in Österreich. Materialen II - Die Pfahlbaustation des Keutschacher Sees*, pp.38–41. Vienna: Austrian Academy of Sciences Press.
Satchell, J. 2017 Education and Engagement: Developing Understanding and Appreciation of Submerged Prehistoric Landscapes. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.391–402. Springer.
Schibler, J. 2004 Bones as Key for Reconstructing the Environment, Nutrition and Economy of the Lake-dwelling Societies. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.144–161. Routledge.
Schlichterle, H. 2004 Lake-dwellings in South-Western Germany. History of research and contemporary perspectives. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.22–35. Routledge.
Schweingruber, F.H. 1993 *Trees and Wood in Dendrochronology. Morphological, Anatomical, and Tree-Ring Analytical Characteristics of Trees Frequently Used in Dendrochronology*. Berlin Heidelberg: Springer-Verlag.
Scicchitano, G., E.F. Castagnino Berlinghieri, F. Antonioli, C.R. Spampinato and C. Monaco 2017 Sacred Landscapes and Changing Sea Levels: New Interdisciplinary Data from the Early Neolithic to the Present in South-Eastern Sicily. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.233–253. Springer.
Scudder, S. 2001 Evidence of Sea Level Rise at the Early Ostionan Coralie Site (GT-3), c. AD 700, Grand Turk, Turks and Caicos Islands. *Journal of Archaeological Science* 28(11):1221–1233.
Scudder, S. 2003 Sea level rise or shallow-water midden deposition? Archaeopedology at the Seminole Rest archaeological site, coastal East-Central Florida. *Journal of Archaeological Science* 30(12):1551–1557.
Šegota, T. and A. Filipčić 1991 Arheološki i geološki pokazatelji holocenskog položaja razine mora na istočnoj obali Jadranskog mora *Rad Hrvatske Akademije Znanosti i Umjetnosti* 458:148–172.
Shackleton, N.J. 1967 Oxygen isotope analyses and Pleistocene temperatures re-assessed. *Nature* 215:15–17.
Shackleton, N.J. 2006 Formal Quaternary stratigraphy - What do we expect and need? *Quaternary Science Reviews* 25:3458–3462.

Shackleton, N.J. and N.D. Opdyke 1976 Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale. *Quaternary Research* 3:39–55.

Shackley, M.S. (ed.) 2011 *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*. New York: Springer.

Shaw, T.A., J.R. Kirby, S. Holgate, P. Tutman and A.J. Plater 2016 Contemporary salt-marsh foraminiferal distribution from the Adriatic coast of Croatia and its potential for sea-level studies. *Journal of Foraminiferal Research* 46(3):314–332.

Sheldon, N.D. and N.J. Tabor 2009 Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. *Earth-Science Reviews* 95:1–52.

Shepard, F.P. 1964 Sea Level Changes in the Past 6,000 Years: Possible Archaeological Significance. *Science* 143(3606):574–576.

Sherratt, A. 2004 The Importance of Lake-dwellings in European Prehistory. In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 years of lake-dwelling research*, pp.267–275. Routledge.

Siddal, R. 2018 Mineral Pigments in Archaeology: Their Analysis and the Range of Available Materials. *Minerals* 8(201):1–35.

Smith, D., V. Gaffney, D. Grossman, A.J. Howward, A. Milošević, K. Ostir, T. Podobnikar, W. Smith, E. Tetlow, M. Tingle and H. Tinsley 2006 Assessing the later prehistoric environmental archaeology and landscape development of the Cetina Valley, Croatia. *Environmental Archaeology* 11(2):171–186.

Smith, D.E., S. Harrison, C.R. Firth and J.T. Jordan 2011 The early Holocene sea level rise. *Quaternary Science Reviews* 30:1846–1860.

Stanford, D., D. Lowery, M. Jodry, B.A. Bradley, M. Kay, T.W. Stafford and R.J. Speakman 2014 New Evidence for a Possible Paleolithic Occupation of the Eastern North American Continental Shelf at the Last Glacial Maximum. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.73–93. Springer.

Starnini, E., P. Biagi and N. Mazzucco 2018 The beginning of the Neolithic in the Po Plain (northern Italy): Problems and perspectives. *Quaternary International* 470:301–317.

Stein, J.K. 1986 Coring Archaeological Sites. *American Antiquity* 51(3):505–527.

Stocchi, P. and G. Spada 2007 Glacio and hydro-isostasy in the Mediterranean Sea: Clark's zones and role of remote ice sheets. *Annals of Geophysics* 50(6):741–761.

Stocchi, P. and G. Spada 2009 Influence of glacial isostatic adjustment upon current sea level variations in the Mediterranean. *Tectonophysics* 474:56–68.

Stocchi, P., G. Spada and S. Cianetti 2005 Isostatic rebound following the Alpine deglaciation: impact on the sea level variations and vertical movements in the Mediterranean region. *Geophysical Journal International* 162:137–147.

Stopp, B. 2015 Animal husbandry and hunting activities in the late Bronze Age Circum-Alpine Region. In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.223–257. Oxbow Books.

Straus, L.G. 1996 Preface. In L.G. Straus, B.V. Eriksen, J.M. Erlandson and D.R. Yesner (eds), *Humans at the End of the Ice Age. The Archaeology of the Pleistocene-Holocene Transition*, pp.vii–viii. New York and London: Plenum Press.

Sturt, F., J. Dix and M.J. Grant 2017 The History of Industry-Linked Research in English Waters: Lessons for the Future. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.425–436. Springer.

Sturt, F., N.C. Flemming, D. Carabias, H. Jöns and J. Adams 2018 The next frontiers in research on submerged prehistoric sites and landscapes on the continental shelf. *Proceedings of the Geologists' Association*:654–683.

Surić, M., T. Korbar and M. Juračić 2014 Tectonic constraints on the late Pleistocene-Holocene relative sea-level change along the north-eastern Adriatic coast (Croatia). *Geomorphology* 220:93–103.

Swierczynski, T., S. Lauterbach, P. Dulski and A. Brauer 2013 Late Neolithic Mondsee Culture in Austria: living on lakes and living with flood risk? *Climate of the Past* 9:1601–1612.

Tarrús, J. 2008 La Draga (Banyoles, Catalonia), an Early Neolithic Lakeside Village in Mediterranean Europe. *Catalan Historical Review* 1:17–33.

Teoh, M.L., S.B. McClure and E. Podrug 2014 Macroscopic, petrographic and XRD analysis of Middle Neolithic *figulina* pottery from Central Dalmatia. *Journal of Archaeological Science* 50:350–358.

Tessadri, R. 2000 Vivianite from the Iceman of the Tisenjoch (Tyrol, Austria): Mineralogical-chemical data. In S. Bortenschlager and K. Oeggl (eds), *The Iceman and his Natural Environment*, pp.137–141. Wien: Springer-Verlag.
Thali, M.J., B. Lux, S. Lösch, F.W. Rösing, J. Hürlimann, P. Feer, R. Dirnhofer, U. Königsdorfer and U. Zollinger 2011 ''Brienzi'' – The blue Vivianite man of Switzerland: Time since death estimation of an adipocere body. *Forensic Science International* 211:34–40.
Törnqvist, T.E. and M.P. Hijma 2012 Links between early Holocene ice-sheet decay, sea-level rise and abrupt climate change. *Nature Geoscience* 5:601–606.
Troels-Smith, J. 1955 Karakteriseing af lose jordater (Characterization of unconsolidated sediments). *Danmarks Geologiske Undersøgelse, IV Series* 3(10):1–73.
Turk, J. and A. Velušček 2013 Multidisciplinary investigations of the pile-dwellings at Ljubljansko barje (Slovenia). *Quaternary International* 294:183–189.
Turney, C.S.M. and H. Brown 2007 Catastrophic early Holocene sea level rise, human migration and the Neolithic transition in Europe. *Quaternary Science Reviews* 26:2036–2041.
Uldum, O., J. Benjamin, J. McCarthy, F. Feulner and H. Lübke 2017 The Late Mesolithic Site of Falden, Denmark: Results from Underwater Archaeological Fieldwork and a Strategy for Capacity-Building Based on the SPLASHCOS Mission. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.65–84. Springer.
Uldum, O.C. 2011 The Excavation of a Mesolithic Double Burial from Tybrind Vig, Denmark. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.15–20. Oxbow Books.
UN 1958 *Convention on the Continental Shelf*. Geneva: United Nations.
UNESCO 2017–2018 *Prehistoric Pile Dwellings around the Alps*. Retrieved from <https://www.palafittes.org>.
Urey, H.C. 1947 The Thermodynamic Properties of Isotopic Substances. *Journal of the Chemical Society* 0:562–581.
Vacchi, M., N. Marriner, C. Morhange, G. Spada, A. Fontana and A. Rovere 2016 Multiproxy assessment of Holocene relative sea-level changes in the western Mediterranean: Sea-level variability and improvements in the definition of the isostatic signal. *Earth-Science Reviews* 155:172–197.
Van Andel, T.H. and P.C. Tzedakis 1996 Palaeolithic Landscape of Europe and Environs, 150,0005–25,000 Years Ago: An Overview. *Quaternary Science Reviews* 15:481–500.
Van de Noort, R. 2011 Conceptualising climate change archaeology. *Antiquity* 85:1039–1048.
Van de Noort, R. 2013 *Climate Change Archaeology: Building Resilience from Research in the World's Coastal Wetlands*: Oxford University Press.
Velušček, A. 2004 Past and Present Lake-Dwelling Studies in Slovenia. Ljubljansko Barje (The Ljubljana Marsh). In F. Menotti (ed.), *Living on the Lake in Prehistoric Europe. 150 Years of Lake-Dwelling Research*, pp.69–82. Routledge.
Velušček, A. 2005 Iška Loka - bronastodobno naselje na obrobju Ljubljanskega barja. *Arheološki vestnik* 56:73–89.
Velušček, A. 2006a Resnikov Prekop - Sample Trenching, Archaeological Finds, Cultural and Chronological Classification. In A. Velušček (ed.), *Resnikov prekop, the oldest Pile-Dwelling settlement in the Ljubljansko barje*, pp.19–85. Opera Instituti Archaeologici Sloveniae. Ljubljana: Institute of Archaeology at ZRC SAZU in association with ZRC Publishing.
Velušček, A. (ed.) 2006b *Resnikov prekop, the oldest Pile-Dwelling Settlement in the Ljubljansko barje*. Opera Instituti Archaeologici Sloveniae. Ljubljana: Institute of Archaeology at ZRC SAZU in association with ZRC Publishing.
Verdonkschot, J. 2014 Studying Habitats and Dynamical Interaction in Neolithic Europe through the Material Culture of Pile-dwellings. *Estudos do Quaternario* 11:39–44.
Vilibić, I., J. Šepić, M. Pasarić and M. Orlić 2017 The Adriatic Sea: A Long-Standing Laboratory of Sea Level Studies. *Pure and Applied Geophysics* 174:3765–3811.
Visentini, P. 2001 *I siti di Bannia-Palazzine di Sopra e Palù di Livenza nel quadro del Neolitico recente e tardo del Friuli*. Il declino del mondo neolitico. Ricerche in Italia centro-settrentionale fra aspetti peninsulari, occidentali e nord-alpini, Pordenone: Quaderni del Museo Archeologico del Friuli Occidentale.
Vitasović, A. 1999 Gromače - neolitičko/eneolitičko naselje na Brijunima. *Histria archaeologica* 30:5–67.

Vogt, E. 1967 Ein Schema des Schweizerischen Neolithikums. *Germania* 45:1–20.
von Carnap-Bornheim, C., M.-L. Nosch, G. Grupe, A.-M. Mekota and M.M. Schweissing 2007 Stable strontium isotopic ratios from archaeological organic remains from the Thorsberg peat bog. *Rapid Communications in Mass Spectometry* 21(9):1541–1545.
Vrsalović, D. 2011 *Arheološka istraživanja u podmorju istočnog Jadrana*. Split: Književni Krug Split.
Ward, I., P. Larcombe and M. Lillie 2006 The dating of Doggerland - post-glacial geochronology of the southern North Sea. *Environmental Archaeology* 11(2):207–218.
Ward, I., P. Larcombe and P. Veth 2015 A New Model for Coastal Resource Productivity and Sea-Level Change: The Role of Physical Sedimentary Processes in Assessing the Archaeological Potential of Submerged Landscapes from the Northwest Australian Continental Shelf *Geoarchaeology: An International Journal* 30:19–31.
Ward, I. and P. Veth 2017 To the Islands: The Archaeology of the Archipelagos of NW Australia and its Implications for Drowned Cultural Landscapes. In G.N. Bailey, J. Harff and D. Sakellariou (eds), *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf*, pp.375–387. Springer.
Ward, I., P. Veth and T. Manne 2016 To the islands born: the research potential of submerged landscapes and human habitation sites from the islands of NW Australia. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.251–263. London: Geological Society.
Weertman, J. 1976 Milankovitch solar radiation variations and ice age ice sheet sizes. *Nature* 261:17–20.
Weiner, S. 2010 *Microarchaeology, Beyond the Visible Archaeological Record*. Leiden: Cambridge University Press.
Weltje, G.J. and R. Tjallingii 2008 Calibration of XRF core scanners for quantitative geochemical logging of sediment cores: Theory and application. *Earth and Planetary Science Letters* 274:423–438.
Werz, B., H. Cawthra and J. Compton 2014 Recent Developments in African Offshore Prehistoric Archaeological Research, with an Emphasis on South Africa. In A.M. Evans, J.C. Flatman and N.C. Flemming (eds), *Prehistoric Archaeology on the Continental Shelf: A Global Review*, pp.233–253. Springer.
Westley, K., T. Bell, R. Plets and R. Quinn 2011 Investigating Submerged Archaeological Landscapes: a research strategy illustrated with case studies from Ireland and Newfoundland, Canada. In J. Benjamin, C. Bonsall, C. Pickard and A. Fischer (eds), *Submerged Prehistory*, pp.129–144. Oxbow Books.
Wiemann, P. and P. Rentzel 2015 Micromorphological studies of wetland site formation processes: additional help for a better understanding of the lake-dwellings' final dissapearence. In F. Menotti (ed.), *The End of the Lake-Dwellings in the Circum-Alpine Region*, pp.134–160. Oxbow Books.
Wievegh, Z. (ed.) 2010 *Croatian Archaeological Yearbook 6/2009*. Zagreb: Ministry of Culture, Directorate for the Protection of Cultural Heritage.
Willis, K.J. and K.D. Bennett 1994 The Neolithic Transition - Fact or Fiction? Palaeoecological evidence from the Balkans. *The Holocene* 4(3):326–330.
Wreschner, E.E. 1983 The Submerged Neolithic Village "Newe Yam" on the Israeli Mediterranean Coast. In P.M. Masters and N.C. Flemming (eds), *Quaternary Coastlines and Marine Archaeology: Towards the Prehistory of Land Bridges and Continental Shelves*, pp.325–333. Academic Press.
Wurster, C.M. and M.I. Bird 2016 Barriers and bridges: early human dispersals in equatorial SE Asia. In J. Harff, G.N. Bailey and F. Lüth (eds), *Geology and Archaeology: Submerged Landscapes of the Continental Shelf*, pp.235–250. London: Geological Society.
X-Rite and Pantone® 2016 *A Guide to Understanding Color*.
Yamafune, K. 2016 Using Computer Vision Photogrammetry (Agisoft Photoscan) to Record and Analyze Underwater Shipwreck Sites, Department of Anthropology, Texas A&M University, College Station.
Zilhão, J. 2001 Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. *Proceedings of the National Academy of Sciences* 98(24):14180–14185.
Zlatunić, R. 2007 More recent archaeological research on the prehistorical site of Sv. Mihovil-Bale II faza (13.7.-1.9.2007). *Histria Antiqua* 15:457–472.
Zlatunić, R. 2008 Recent archaeological research in the hill of S. Michael near Bale (Sveti Mihovil, Bale) in 2007. *Histria Antiqua* 16:177–189.