ARCHAEOLOGICAL MARKERS BELOW THE LAGOON WATERS

Elisa Costa, Carlotta Lucarini

Abstract: This paper focuses on the documentation of some archaeological case studies in the northern part of the Venice lagoon, an extreme and at the same time vulnerable ecosystem. The study emphasises the challenges of working underwater in this environment and the necessity of incorporating both traditional and modern digital techniques. Through the use of different technologies, such as Multibeam Echo Sounder, topographic surveys with the total station and DGPS, and photogrammetry, it is possible to reach a high level of detail in the documentation and analysis of the archaeological contexts. The data management with GIS software allows an efficient and easier consultation and the effective dissemination of the research results. Thanks to the synergic use of these tools, it is possible to produce an entire overview of underwater archaeological sites, which implies enormous advantages for their understanding and analysis of archaeological markers. The methodology we tested in this highly complex environment turned out to be crucial also in monitoring the state of conservation and degradation of underwater archaeological heritage.

Keywords: Underwater archaeology, Digital techniques, Lagoonal landscape, Photogrammetry, GIS

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Introduction

Coastal stretches are rich in archaeological evidence that testifies to the long-lasting interactions of ancient communities with the aquatic environment. Nowadays, all these contexts are greatly influenced by ongoing climate and environmental changes, such as the rising sea level and several linked geological phenomena that affect both the landscape and the archaeological remains with increasing intensity. In order to study and understand these modifications, archaeological evidence in micro-tidal areas can provide significant information. Especially ancient coastal structures, such as maritime villas, piers, fish tanks, embankments and building foundations, can be crucial [2]. In particular, the analysis of submerged and semi-submerged archaeological contexts in lagoon waters, a very peculiar and enclosed environment, can testify to the impact of anthropic modifications on the landscape, but it can also enable the establishment of significant markers of ongoing sea level changes.

In this paper, we will analyse some case studies located in the northern part of the lagoon of Venice, Italy. This ecosystem poses a significant threat and requires protection and monitoring from both an ecological and environmental perspective, as well as an archaeological one. Our work focusses on the use of modern technologies applied in such peculiar environment. Working beneath the lagoon's waters is indeed particularly challenging due to multiple factors. The integration of traditional and digital techniques, along with the synergic use of the different survey methodologies, enables the acquisition of precise metric documentation and accurately dimensioned digital models, turning out to be indispensable for documenting underwater archaeological sites.

The use of GIS in the management of the different data resulting from these investigations and surveys allows, on the one hand, an immediate and easy visualization of the research results, and on the other hand, to carry out detailed analyses of the spatial data and assess the changes to which the contexts are subjected.

Materials and Methods

From 2020 Professor Carlo Beltrame from Ca' Foscari University coordinates different project in the northern part of the Venice lagoon[1]. An important part of the projects is carried out in collaboration with geomorphologist Paolo Mozzi of the University of Padova, to deeply analyse and reconstruct the paleo-environment of the lagoon and the relative sea level changes.

This area of the northern lagoon is highly affected by the tidal variation due to the proximity of the inlet. This implicates: strong currents, depending on the direction and the moment of the day, which affect the work operations; relevant tidal excursion, which has to be carefully identified for the acquisition of

[1] Interreg Italy-Croatia UnderwaterMuse Project; Prin 2022 - The lagoon of Venice in Antiquity. Settlement dynamics, adaptive behaviours, paleoenvironmental reconstructions; PNRR CHANGES SPOKE 1 - Historical Landscapes, Traditions and Cultural Identities.

measurement data; high erosion, which affects the state of preservation of the archaeological sites; and poor visibility (from a maximum of 2-3 metres near the sea, in optimal conditions, to a few tens of centimetres in the innermost parts) mostly due to the dense and thick sediment, which is constantly being moved by the currents. The general working conditions in this environment can be sometimes very difficult. Hence, based on the environmental and archaeological context, each dive must be meticulously planned, to identify the best methodology and the most suitable techniques for documenting the sites even in difficult circumstances [10].

The case studies consist of three contexts dated to Roman times, that are nowadays completely submerged in the lagoon waters. In particular, the analysis has been conducted in two channels: San Felice channel, which is part of the tidal delta created on the Lido-Treporti inlet, and Rigà channel, a branch of the first one (Figure 1).

Figure 1 – Localization of the archaeological sites in the northern lagoon of Venice (reconstruction of ancient shoreline elaborated from [18]).

The first site in San Felice channel consists of a Roman well-cistern built in bricks. This structure, discovered in 1984 by Franco Tonello and the subject of an investigation campaign promoted by the Archaeological Superintendence of Veneto in 1987 [13], is composed entirely of *sesquipedali* bricks[2]. It forms a rectangular base of approximately 7 x 8 m, which lies directly on the seabed without foundation piles. Following investigations conducted in 2020, it was

[2] It is a "provincial" type of brick which measures approximately 44 cm x 29,5 cm x 7,5 cm in thickness [19].

possible to reinterpret the site, initially identified as the base of a tower. Thanks to the many similarities found with some other Roman structures, it was possible to attribute to this artefact the function of a well-cistern, dating back to the 1st century AD or to a slightly later period [6].

The second one, located in Ca' Ballarin, in San Felice channel, is part of a bigger complex, in which another cistern has been found. The Roman pier and cistern, dated to the second half of the 1st century AD - 3rd century AD, have been discovered in 1997, and two excavation and restoration campaigns have been carried out in 2002 and 2003 [12, 13]. The site is composed of a well-cistern built in *sesquipedali* bricks and a fragmented longitudinal structure made of cement conglomerate and stone chips. Seven large blocks are collapsed towards the centre of the channel, while one is still in its original position, supported by structural poles, near the current shore. These remains can be ascribed to a quay or a pier and, together with the cistern, are presumably part of the ancient waterway network used for navigation, of which the San Felice well-cistern was perhaps also part.

The last case study is an *ostrearium*, again made of *sesquipedali* bricks associated with wooden structures at Lio Piccolo [7, 9, 16], in Rigà channel, at a bathymetry variable between -1 m and -4 m below main sea level. The site is currently being investigated and will be the subject of upcoming excavation campaigns. The structure is composed of a basin for the conservation of oysters connected to several wooden structural poles, which retain evidence of some foundation bricks.

The documentation of the sites was conducted through instrumental (multibeam), digital (photogrammetry), and topographic (total station, trilateration, and DGPS) investigations; the combined use of different technologies has been fundamental in order to obtain a composite and multifaceted archaeological documenttation.

Non-invasive acoustic investigation methods play a significant role in the mapping of submerged cultural heritage, also in lagoon areas at shallow depths [3, 21]. These systems allow visualising the submerged environment, mapping the bottom, and identifying and monitoring the archaeological heritage with high levels of detail through a dense point cloud. The depth and width of the S. Felice channel allowed an instrumental survey carried out in collaboration with the Elmar Marine Survey Company of Venice. Using a Multibeam Reson Seabat 8125, the seabed of an area of approximately 45000 m^2 was investigated in order to identify the portions of structures already documented in the 1980s.

The topographic survey of the targets positioned on the site is essential as a reference for an accurate scale, metric control, and local and global orientation of the photogrammetric model of the site. Furthermore, it is fundamental for the purposes of the overall survey of a submerged structure documented in portions (as San Felice well-cistern and Ca' Ballarin pier) and for the documentation of a stratigraphically excavated site (as Lio Piccolo *ostrearium*). In the underwater environment, we usually carry out the topographic survey through the Direct Survey Method (DSM), a trilateration technique with linear measurements, applied for the first time in 1982 and optimised in the late 1990s [5, 8, 17, 20]. It consists of the direct and inclined measurement of the targets through the use of a rib and a depth gauge. The positioning of the targets must follow a certain pattern so that the measurements allow obtaining the xyz coordinates of the points.

The shallow depth of the lagoon waters and the presence of a nearby shore allow the use of the total station and differential GPS for the topographic survey, improving the precision of the target coordinates [1, 5]. Following the experience obtained in the previous underwater activities [4], in the case studies examined, where the maximum depth is -4 m, we have applied the two different techniques. The first step was to use a total station with a pole long enough to keep the prism out of the water. To maintain the verticality of the rod, we applied a weight to the base and a polystyrene float to the top, where a spherical level was inserted for greater precision. Then, a differential GPS on a floating buoy with a tied rope on the underwater targets was used; for every target, we have realised between 20 and 30 measures to calculate the barycentre of the point cloud, delete the major errors, and obtain the most accurate point (Figure 2).

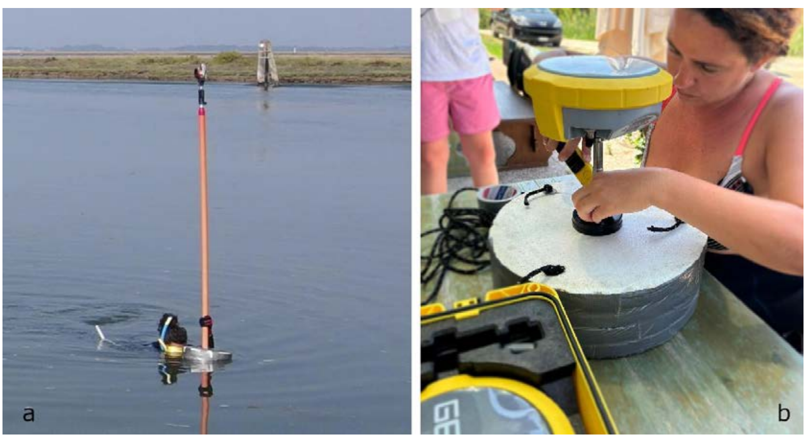

Figure 2 – The two instruments employed for the topographic survey: a. the long pole with prism of the total station; b. the buoy with DGPS.

The photogrammetric survey was realised following the limitations imposed by the tides[3]. It has been executed during the two favourable moments: the last phase of the rising tide, when the suspension is minimal because the water no longer carries the sediments of the lagoon bottom with it, and the inversion of the tide, when the strength of the current decreases until it reaches the moment of no current (called "dead water"), before changing direction. Despite this precaution, it was not always possible to document the sites on a daily basis because visibility was not sufficient or the speed of the current, and therefore the suspension, were excessive.

[3] For the methodology followed in data acquisition and processing, please refer to the procedures already described in [14], [11], and references.

The final stage of our study was the integration and correlation of all the data into a GIS environment, a tool that is quite common and indispensable in archaeology nowadays. We built our QGIS project by creating specific modules able to describe the archaeological sites in as much detail as possible, with the possibility of attaching images and other types of files. In addition, we created spaces that could house and manage all the elements derived from our studies: archival site plans, topographic and bathymetric data, photogrammetric models, orthophotos and photomosaics, point clouds, Digital Elevation Models (DEM), and vector and raster layers.

Results

Through the methodology and the techniques described, we can therefore claim to have established an effective procedure for detecting, documenting, georeferencing, analysing, monitoring and making visible the submerged heritage in lagoon waters.

From the MBES data acquisition we obtained a georeferenced DEM of the well-cistern in San Felice Channel and an accurate bathymetric map of the seabed. Through the survey of the surrounding area, we were able to discard the hypothesis of the presence of other related archaeological structures or anthropic elements, which had initially been presumed. From the obtained bathymetric profiles of the channel, we could also identify the structures that are in a more eroded condition, making them more susceptible to preservation threats.

The application of digital photogrammetry, despite the difficulties in a lagoon context, allowed us not only to obtain metrically correct digital 3D models and to create point clouds and DEMs with millimetric accuracy (Figure 3), but also to produce an entire overview of the underwater archaeological sites, which implies enormous advantages for its understanding and appreciation, in particular in this specific case, where a site is never completely visible.

The measurements taken using the total station and DGPS allowed us to obtain the correct positioning and orientation of the sites, which is essential for photogrammetric processing but also for correct georeferencing of the evidence.

The storage of all data in a GIS environment allows for easy management of documentation, interpolation of different types of data, and, above all, visualisation and interrogation (Figure 4). Along with the creation of digital models, it is also an effective tool for disseminating research results.

In the case of the Lio Piccolo site, where excavation activities have been going on for four years, the management of all documentation (planimetric and phase plans, location of the different structures and artefacts) is easy and immediate, which makes an underwater site where visibility never goes beyond one and a half meters, comparable to any stratigraphic excavation in a dry environment.

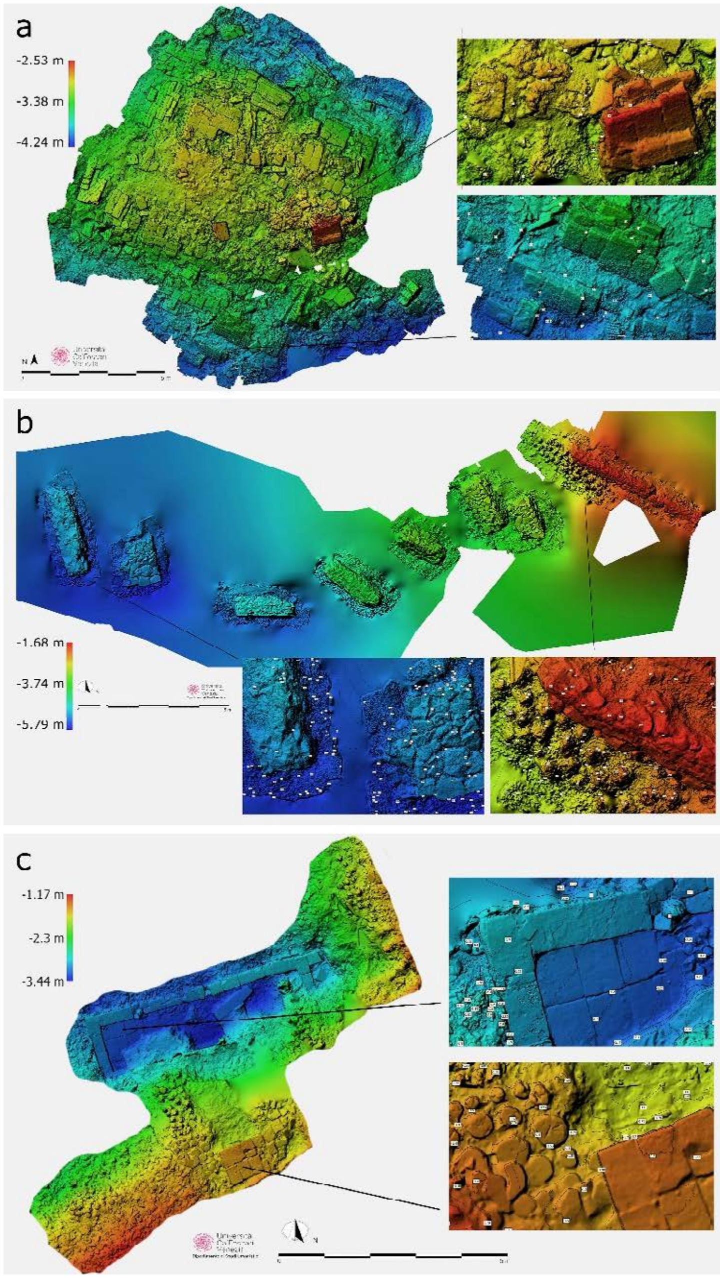

Figure 3 – DEM of the three case studies with detailed bathymetric measures. a. San Felice well-cistern. b. Ca' Ballarin pier. c. Lio Piccolo *ostrearium* (elaboration: authors).

Figure 4 – Digitised planimetric map of Lio Piccolo *ostearium* in GIS environment after the 2023 campaign. Base map: orthophoto from drone. In the tabs: detailed photos of the different elements (elaboration: authors).

Discussion

From the studies we are conducting in the northern lagoon of Venice, it arises that the use of digital photogrammetry turned out to be crucial for the documentation of the submerged archaeological contexts [10]. The combined use of this technique, together with MBES surveys of the areas, and the elaboration of DEM make it possible to achieve a centimetric level of detail in measurement and bathymetric data. The correct system of topographic survey consents to georeferencing exactly the evidence; the storage and management of all the different types of data through a GIS platform permit the analysis and monitoring of the situation in a very precise way; furthermore, it makes possible an easier and more immediate consultation and visualisation of the data and the effective dissemination of the research results. The combination of these factors allows for a comprehensive and precise understanding of the archaeological context, which would otherwise be impossible.

The documentation of the underwater cultural heritage, in fact, play a key role in studies on subsidence rates and variation in the RSL, turning these contexts into highly reliable archaeological markers. The base of the *ostrearium* at Lio Piccolo lies today at a depth of -2.95/-3.20 m below the main sea level, whereas the foundation bricks above wooden poles lie at a depth of 1.35 m below the main sea level. According to the studies carried out on Relative Sea Level (RSL) in Roman times for the Venetian lagoon, which is estimated to be around -1.4 ± 0.7 m [7, 15, 22], it emerges that the basin must have been in a submerged environment when it was built, whereas the foundations structures were just above the water level. This is perfectly in line with the function of the complex. In the same way, the portion of the pier in Ca' Ballarin, which is still in situ lying on the structural poles, can be considered an important marker for the analysis of the relative sea level in Roman times. This dock/pier structure, which now lies at -1.8 m, needs to be installed on the channel bank, and out of the water, in Roman times.

Moreover, with these digital technologies and methodologies, we can effectively monitor the underwater sites and heritage. In two cases, we have been able to identify the damage that the structures have suffered in recent years. After analysing the plans that were drowned during the excavation of the cistern and pier [12], we have detected that one of the blocks on the pier at Ca' Ballarin is now in a different position. Block A probably slipped along the side of the channel due to strong erosion; it lies capsize at a deeper bathymetry, and the foundation piles are now exposed (Figure 5). In the case of the San Felice well-cistern, photogrammetric surveys carried out over a two-month period revealed that a corner of the elevation wall, which was in the original position, collapsed towards the outside of the structure, probably due to anthropic causes, such as anchor mooring of boats, that have capsized the block of bricks (Figure 6).

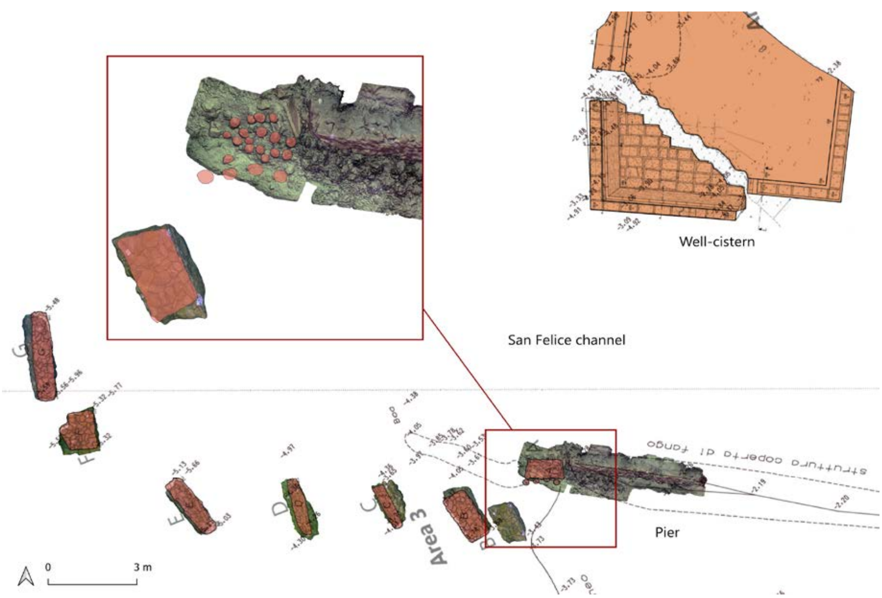

Figure 5 – Orthophoto from photogrammetric survey and digitization in GIS of the Ca' Ballarin well-cistern and pier. In the rectangular sections, the capsizing of block A of the pier is evident (elaboration: authors).

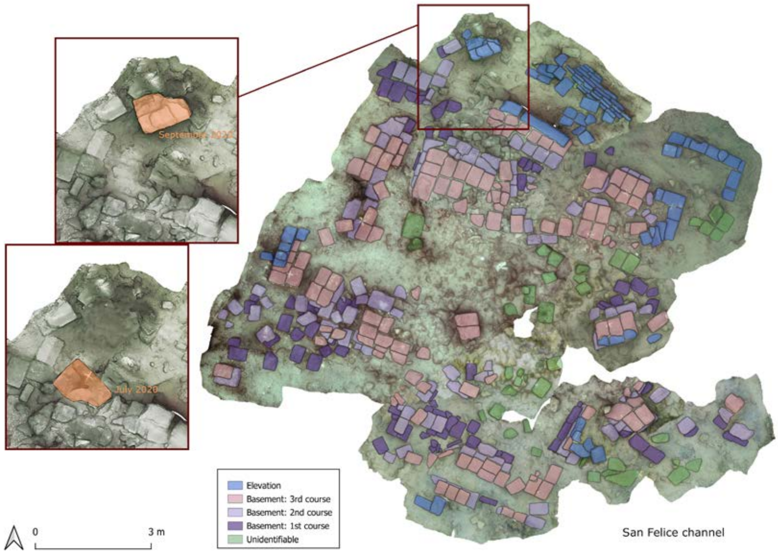

Figure 6 – Orthophoto from photogrammetric survey and digitization in GIS of the basement and wall of the San Felice well-cistern. In the rectangular sections, the movement of the corner of the wall from July to September is evident (elaboration: authors).

Conclusion

The search for a non-invasive data acquisition methodology that would facilitate accurate documentation of material evidence has always been a primary objective of archaeology. This study demonstrates that the most modern digital technologies respond perfectly to this request, allowing useful documentation for both study and conservation. Due to its unique and extreme characteristics, the lagoon environment requires careful selection of the strategy to implement. The integration of Multibeam Echo Sounder, topographic surveys with total stations and Differential GPS, and digital photogrammetry has proven crucial in documenting and analysing submerged archaeological contexts in lagoon environments with high accuracy. The methodology employed allows for the meticulous georeferencing, monitoring, and visualisation of underwater archaeological sites with a rigour and neatness never reached in the history of underwater archaeology in the lagoon of Venice. The use of GIS software has further enhanced data management, enabling efficient consultation, detailed analysis, and effective dissemination. The combination of these technologies has led to a comprehensive understanding of the submerged heritage, facilitating the monitoring of conservation and degradation states. Moreover, the digital technologies used have provided valuable insights into relative sea level changes, turning these archaeological contexts into reliable markers for studying environmental changes.

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References

[1] Abdelaziz M., Elsayed M. (2019) - *Underwater photogrammetry digital surface model (DSM) of the submerged site of the ancient lighthouse near Qaitbay fort in Alexandria, Egypt*, The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences XLII-2/W10, pp. 1-8, DOI: 10.5194/isprs-archives-XLII-2-W10-1-2019, 2019.

[2] Auriemma R., Solinas E. (2009) - *Archaeological remains as sea level change markers: A review*, Quaternary International, 206(1–2), 134–146.

[3] Ballard R. D., Stager L. E., Master D., Yoerger D., Mindell D., Whitcomb L. L., Singh H., Piechota D. (2002) - *Iron Age Shipwrecks in Deep Water off Ashkelon, Israel*, AJA, 106.2, pp. 151-168, DOI: 10.2307/4126241.

[4] Balletti C., Beltrame C., Costa E., Guerra F., Vernier P. (2016) - *3D reconstruction of marble shipwreck cargos based on underwater multi-image photogrammetry*, Digital Applications in Archaeology and Cultural Heritage, 3, 1-8, DOI: 10.1016/j.daach.2015.11.003.

[5] Beltrame C., Costa E. (2018) - *3D survey and modelling of shipwrecks in different underwater environments*, Journal of Cultural Heritage, 29, 82-88, DOI: 10.1016/j.culher.2017.08.005.

[6] Beltrame C., Medas S., Mozzi P., Ricci G. (2023) - *Roman 'Well-cisterns', Navigational Routes, and Landscape Modifications in the Venice Lagoon and Northeastern Adriatic*, International Journal of Nautical Archaeology. DOI: 10.1080/10572414.2023.2182984

[7] Beltrame C., Mozzi P. (2023) - *Recenti indagini su contesti archeologici sommersi di età romana nella laguna nord di Venezia,* Rivista di Archeologia, XLVII, 15-29, DOI: 10.26406/RdA47-3.

[8] Bowens A. (ed) (2009) - *Underwater Archaeology: The NAS Guide to Principles and Practice*, Wiley-Blackwell, Oxford.

[9] Canal, E. (2013) - *Archeologia della laguna di Venezia: 1960-2010*, Cierre edizioni, Sommacampagna (VE).

[10] Costa E. (2022) - *Survey and photogrammetry in underwater archaeological contexts at low visibility in the Venice lagoon,* Digital Applications in Archaeology and Cultural Heritage, 24, e00215. DOI: 10.1016/j.daach.2022.e00215

[11] Costa E. (2023) - *Il rilievo e la documentazione subacquea in ambiente lagunare*, Rivista di Archeologia, XLVII, 119-136, DOI: 10.26406/RdA47-9.

[12] D'Agostino M., Fozzati L., Medas S. (2020) - *Lio Piccolo, laguna di Venezia: indagini, rilievi e operazioni di restauro di un pozzo-cisterna di epoca imperiale*, Archeologia marittima mediterranea 17, 27-101, DOI: 10.19272/202004501003.

[13] D'Agostino M., Medas S. (2010) - *Roman Navigation in Venice Lagoon: the Results of Underwater Research*, International Journal of Nautical Archaeology, 39, 286-294. DOI: 10.1111/j.1095-9270.2009.00255.x

[14] Ditta M., Auer J. (2021) - *The 'Big Ship' of Wismar: a well-preserved 12th century cargo vessel from the harbour of Wismar*, in Boetto G., Pomey P., Poveda P. (eds.), Archaeonautica, 21, Paris, 191-195, DOI: 10.4000/archaeonautica.3180.
[15] Fontana A., Vinci G., Tasca G., Mozzi P., Vacchi M., Bivi G., Salvador S., Rossato S., Antonioli F., Asioli A., Bresolin M., Di Mario F., Hajdas I. (2017) - *Lagoonal settlements and relative sea level during Bronze Age in Northern Adriatic: Geoarchaeological evidence and paleogeographic constraints,* Quaternary International, 439, 17-36, DOI: 10.1016/j.quaint.2016.12.038.
[16] Goti Vola, V. (2019) - *La Villa Romana della Laguna Nord di Venezia. Apparati decorativi e contesto archeologico*, Il leggio, Chioggia (VE).
[17] Holt P. 2003, An assessment of quality in underwater archaeological surveys using tape measurements, International Journal of Nautical Archaeology, 32.2, 246-251.
[18] Primon S., Mozzi P. (2023) - *Antichi paesaggi a Jesolo. Trasformazioni ambientali alle foci del Piave dall'età romana al Medioevo*, All'Insegna del Giglio, Firenze.
[19] Previato, C. (2019) - *Modi d'uso e sistemi di messa in opera del laterizio in Italia settentrionale in età repubblicana*. Alle origini del laterizio romano: Nascita e diffusione del mattone cotto nel Mediterraneo tra IV e I secolo a.C., pp. 369-382.
[20] Rule N. (1989) - *The Direct Survey Method (DSM) of underwater survey, and its application underwater*, International Journal of Nautical Archaeology 18.2, 157-162.
[21] Stanley J.-D., Nickerson G. A. J., Bernasconi M. P., Fischer S., McClure N., Segal T. e Royal J. G. (2011) - *Multibeam Sonar Technology and Geology to Interpret Ancient Harbor Subsidence off Crotone Peninsula, Italy*, Méditerranée 117, 127-141, DOI: 10.4000/mediterranee.6041.
[22] Vacchi M., Marriner N., Morhange C., Spada G., Fontana A., Rovere A. (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.
DOI: 10.1016/j.earscirev.2016.02.002.