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Marine remote sensing and photogrammetric survey of an UCH site: A cluster of cannons in the SW Gulf of Patras, Greece

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***Abstract* – This study combines marine remote sensing and photogrammetry to investigate underwater cultural heritage (UCH) sites in the Gulf of Patras, Greece. The research utilized multibeam echosounders, side scan sonar, and marine magnetometers to detect potential UCH sites, followed by visual inspections using a remotely operated vehicle (ROV) equipped with a GoPro camera. Photogrammetry techniques were applied to create high-quality 3D models of the identified UCH site, revealing sunken cannons within a *Posidonia oceanica* meadow. Despite shape alteration caused by concretions and biological colonization, the 3D models provided valuable morphometric data. This integrated approach demonstrates the effectiveness of marine remote sensing and photogrammetry in mapping and documenting UCH sites, contributing to the preservation and exploration of underwater heritage.**

I. INTRODUCTION

Underwater cultural heritage comprises all traces of human existence in underwater environment having, historical or archaeological character and importance which have been partially or totally under water, periodically or continuously, for at least 100 years. UCH sites can be shipwrecks as well as submerged settlements and other facilities (harbours, cities, shipbuilding sites), offering valuable insights into sea battles, trade routes, navigation and shipbuilding [1] Preserving and mapping UCH is crucial for the Blue Economy, as they hold cultural and ecological significance. Remote sensing emerges as a powerful and non-intrusive tool in underwater archaeology and UCH sites detection, mapping and documentation [2], [3].

A. Marine Remote Sensing

Marine remote sensing surveys overcome the depth limitations of conventional diving, enabling comprehensive and efficient data collection over large areas in a cost-effective and time-efficient manner [4]–[6]. They detect submerged targets of potential interest, even if buried beneath the seafloor, and provide detailed mapping of seafloor texture, regardless of environmental variables like light, water clarity, and currents. Marine geophysical methods, that play a key role in marine remote sensing surveys, utilizing echosounders, side scan sonar and other tools, are particularly effective in identifying and mapping UCH sites [2], [7]. Side-scan sonar is an ideal acoustic sensor for historical and ancient shipwrecks lying on the seafloor [8], [16].

The sub-bottom profiler is used to assess the seafloor's stratigraphy and potential expansion of wrecks and/or settlements beneath the seafloor, providing information on sedimentary layers [8]. Marine magnetometers detect deviations from the Earth's magnetic field caused by ferromagnetic materials, enabling the identification of metallic objects and magnetic anomalies associated with ancient shipwrecks and submerged archaeological sites (Gregory & Manders, 2015).

Remote sensing techniques have played a crucial role in mapping and investigating underwater cultural heritage (UCH) in Greece, leading to the discovery and documentation of submerged archaeological sites. The, Laboratory of Marine Geology & Physical Oceanography (Oceanus-Lab) has conducted extensive research in Greek Seas, exploring UCH sites in coastal areas and deep waters and even in inhospitable environments [2], [7], [9]–[12] [13]

B. Photogrammetry

Photogrammetry combines art, science, and precise data acquisition to obtain high-quality information through the analysis of photographic material [14]. It enables the production of accurate 3D models and photomosaics of areas or detailed representations of individual objects, using common reference points among acquired images [15], [16]. The methodology is cost-effective and efficient, making it suitable for documenting otherwise inaccessible targets and providing valuable data for scientific research and analysis [17].

In underwater archaeology Photogrammetry is an essential tool for the documentation of Underwater Cultural Heritage (UCH) sites, providing valuable data for lifelike models using optical sensors [18], [19].

Photogrammetric methods in the underwater environment enable the production of high-quality 3D visual representations of challenging sites such as underwater structures and shipwrecks [15], [20]–[24]. These methods also allow for the extraction and documentation of metric information about artifacts, such as anchors, cannons, and wooden planks, facilitating historical and technical research [25]. The development of precise and lifelike models enhances the dissemination of underwater archaeological data and enables non-diving individuals to explore and study submerged sites [21]. Efficient data capture and generation of detailed plans and photo-mosaics offer advantages to underwater archaeological projects, particularly those with time and financial constraints. Technological advancements are reducing costs and improving data accuracy, making digital surveys of submerged remains a common practice in underwater archaeology [24]. Embracing these advancements fosters the ongoing development of the discipline.

II. SURVEY AREA AND SURVEY DESIGN

The survey area has an extend of 1 km^2 with water depth ranging from 2.70m to 32m and is situated in the southwest coastal zone of the Gulf of Patras in western Greece (Figure 1). It extends westward, opening into the Kefallinia Basin of the Ionian Sea and is connected to the Gulf of Corinth through the Rion Straits.

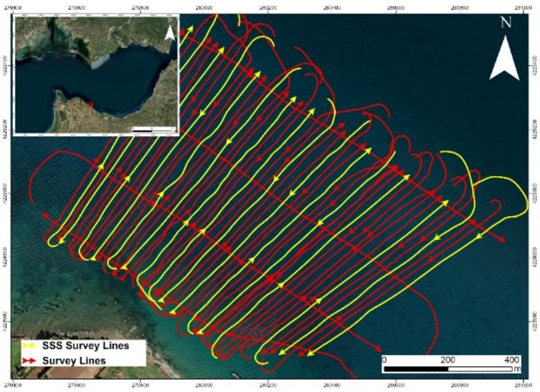

Figure 1: Map showing the study area and the tracklines of the marine geophysical survey.

The remote sensing survey was organized into two separate phases. First a systematic survey of the sea floor was carried out using multibeam echsosounder (MBES), side-scan sonar (SSS), a sub-bottom profiler (SBP) and a marine magnetometer (MM). The second phase consisted of visual inspection of specific sites based on the results of the first phase. This methodological approach provides a cost-effective tool to rapidly survey areas of potential archaeological and historical interest. During the first phase, the survey area was systematically surveyed and potential targets for further investigation were located. During the second phase (ground truthing), the ROV hovered over these locations and the targets were identified on the video camera collecting data for the photogrammetry.

III. MATERIALS AND METHODS

A. Phase A

During the marine remote sensing survey (Figure 2), the LEICA GS14 GNSS system operated in RTK mode, providing reliable vessel positioning with corrections from the METRICANET/PART OF SMARTNET EUROPE network. The HYPACK 2014 navigation software package facilitated vessel navigation, while motion and heading sensors compensated for various movements. Side scan sonar (SSS) data was acquired using an Edgetech 4200 SP SSS operating at frequencies of 100 kHz and 400 kHz simultaneously. The Edgetech 4200 software handled data acquisition, while SeaView software (Version 3.7) was used for post-processing and mosaicking. Swathe bathymetry was carried out using the ELAC Seabeam SB1185 equiangular multi-beam echosounder, which had a maximum depth rate of 300m. This configuration resulted in 106° or 126° equiangular soundings per swath, corresponding to data point densities ranging from 0.4 to 3.2 points/m. Magnetic mapping employed the SeaSPY2 marine magnetometer (Marine Magnetics), towed alongside the side scan sonar. The system incorporated an overhauser sensor with accuracy down to 0.1nT. Data acquisition was managed with Sealink software, and post-processing and map production were conducted using MagPick software (Geometrics). Customized software tools developed by the Oceanus-Lab team were utilized for data correction and the generation of fully corrected and consistent magnetic maps.

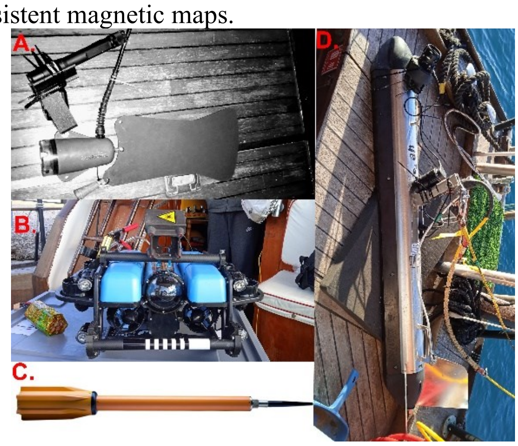

Figure 2: Equipment used in the survey: (A) SeaViewer towed camera, (B) BlueROV2 ROV, (C) SeaSPY2 marine magnetometer and (D) Edgetech 4200 SP SSS.

B. Phase B and 3D Model Creation

The BlueROV2 ROV combined with a specially designed GoPro camera featuring two parallel scaling lasers, provided full HD video footage of the inspected targets. The towed camera (TUC) extension SeaViewer, equipped with a GoPro, was used to cover long tracks along the seafloor. The Blueprint Seatrac X010 Ultra Short Base Line (USBL) Sub Surface positioning system was used for positioning the ROV and tow camera systems, offering a tracking range of 1km and a positional accuracy of 1m. Live viewing and recording of data from both devices were facilitated by the open-source software for ROV, ArduSub.

After the visual inspection of the targets detected in Phase A, an important UCH site was confirmed and selected for photogrammetric investigation. Additional dives were conducted in the target site using the ROV system equipped with a GoPro to capture video data for 3D reconstruction. A predefined set of maneuvers ensured maximum coverage and overlap of the video frames. To prepare the video for 3D object creation, each video was split into individual frames using the scene video filter in VLC player, extracting around 1-2 frames per second with an extraction ratio of 15. The extracted frames were saved in a dedicated folder. Next, a processing step was performed to eliminate blurry or irrelevant images that did not have direct visual contact with the target feature. The final selection of images was then loaded into the photogrammetry software, Agisoft Metashape Professional, to initiate the synthesis of the three-dimensional object.

In Agisoft Metashape Professional a manual color correction was performed to reduce underwater light diffraction offsets. The frames were aligned according to the camera's orientation and relative position of the target object using the Align Photos workflow. The aligned photos were then used in the Build Dense Cloud process to identify common points (Tie Points) and generate a dense cloud, while removing unrelated points.

Depth maps were generated, and the dense cloud was computed to extract the target's surface geometric data. Mild depth filtering was applied to preserve fine details. The point data was converted into an initial Mesh, and unnecessary geometry was removed. The finalized 3D object was textured using the Build Texture command. The scale of the model was adjusted using images acquired at a later date for size estimation. The model creation process resulted in a high-resolution 3D object with 207,536 points. It comprised 298 depth maps and a dense cloud of 11,249,580 points. The 3D model had 5,020,113 faces and 2,510,645 vertices. The texture was finalized using original photos, producing 2 files with a resolution of 8,192×8,192 pixels, combined to achieve a total resolution of 16,384×16,384 pixels. Point confidence calculations enhanced the reliability of the generated geometry, attributing moderate to high confidence.

The geometry was exported to CloudCompare Version 2.12.4 for further analysis, where Laplacian smoothing was applied to reduce surface morphology. The resulting 3D object, consisting of approximately 5 million points, was compared to the original to assess the degree of change.

IV. RESULTS

A. Marine remote sensing survey

The SSS mosaics of both frequencies (100kHz and 400kHz) (Figure 3) showed that the entire survey area was consisted of a *Posidonia oceanica* meadow, with dense and healthy *Posidonia* shoots along with Cymodocea nodosa in sandy regions. The *Posidonia* matte was generally consistent, with scattered sand gaps having semi-circular to oval shape. Based on backscatter and shape characteristics, certain features of the seafloor were considered as targets of anthropogenic origin for further investigation.

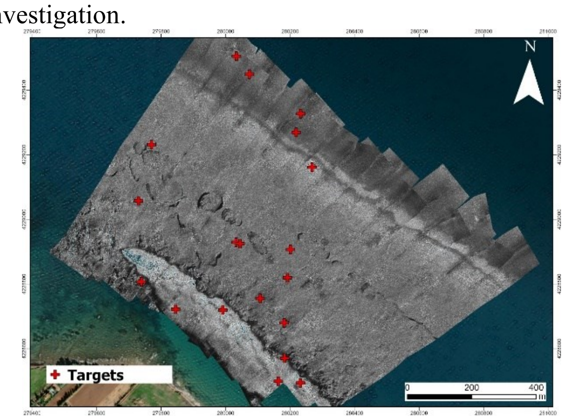

Figure 3: 100 kHz side scan sonar mosaic showing the targets of potential anthropogenic origin.

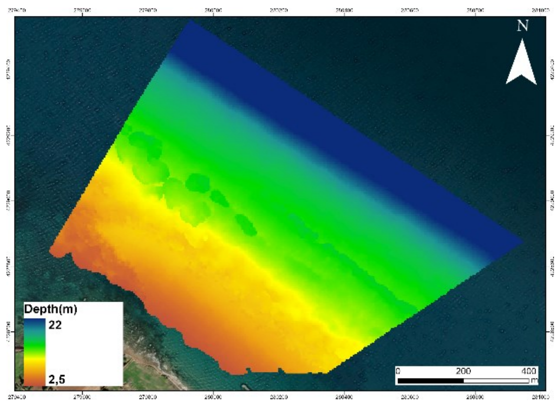

Figure 4: MBES swath bathymetry map.

The area appears to have mild bathymetry (Figure 4) spanning from ~2.50m in the shallowest part and ~31m at its deepest limit. The seafloor presents smooth inclination of 1.8° which is abruptly cut of in certain areas from hole-like features, semi-circular to oval in shape, displaying a depth anomaly of ~1-1.5m. These features correspond to sandy gaps inside the *P. oceanica* meadows. The magnetic survey showed low values of magnetic susceptibility in the area. Notably, 11 high-intensity targets were detected. Out of those 11 targets, a metallic one was identified as a cluster of two (2) sunken cannons partially embedded in the Posidonia matte. The first cannon was stood almost in vertical position and was covered by marine organisms, primarily sponges and solidified sediment, which altered its original shape. The surface of the cannon was encrusted with concretions, providing a substrate for colonizing taxa. Ghost nets were wrapped around the base of the cannon, causing apparent damage and leaving track-like marks.

The second cannon, found in horizontal position very close proximity to the first cannon, and was semi-buried by the *Posidonia*. It exhibited a similar degree of concretion on its surface, with seashells buried in the solidified sediment. The base and trunnion of this cannon were not visible, and the *Posidonia* oceanica matte seemed to be gradually enveloping it, incorporating it into the meadow. The estimated visible length of the second cannon was 59.24cm, with a barrel measuring 20cm and a bore diameter of 5.38cm. Both cannons appeared to be colonized by similar groups of organisms, primarily *Chondrosia reniformis* sponges and coralligenous formations (Figure 5), which had altered their original appearance.

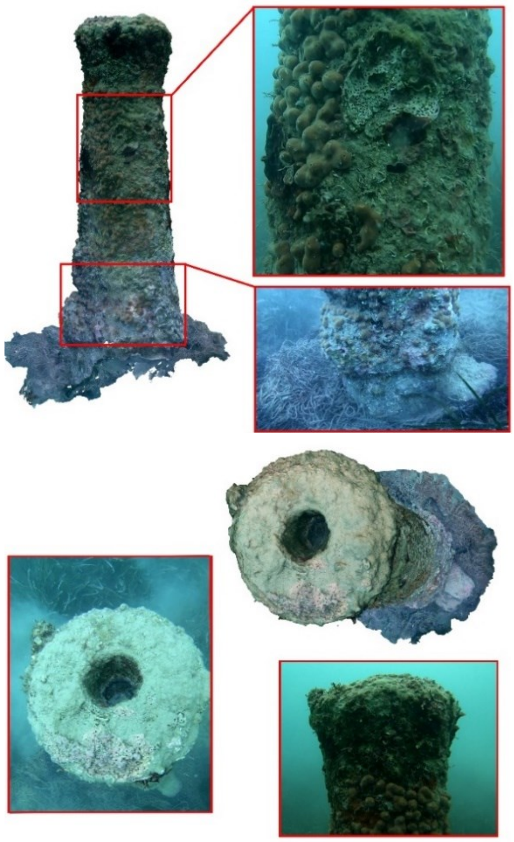

Figure 5: Close up views of the cannon with *Chondrosia reniformis* sponges and coralligenous formations.

B. Photogrammetry - 3D Model

The cannon (Figure 6) was scaled to match the original, measuring approximately 98.5cm in length down to the trunnion, with a barrel length of 29.55cm and a bore diameter of approximately 8.4-7.38cm.

Figure 6: Multiple view of the 3D model produced by Agisoft Metashape Professional.

These data were then utilized in the CloudCompare software to generate a comparative image in 3D space. This image aimed to assess the alteration of the cannons' original form, primarily caused by colonization by marine organisms (Figure 7). On average, the cross-shape distances between the 3D artifact and its smoothed counterpart were calculated to be approximately 1.13cm, including the majority of the exposed section. The more significant alteration appeared to be concentrated near the muzzle and base of the cannon, while the main length of the barrel displayed a relatively uniform distribution of alterations across its span.

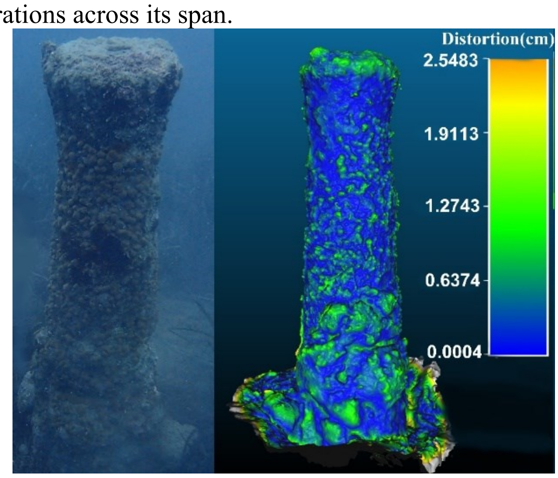

Figure 7: CloudCompare cloud distance results.

V. CONCLUSION

A marine remote sensing and photogrammetric survey was carried out in the SW part of the Gulf of Patras. The survey was organized in two separate phases; during the first phase, the survey area was systematically surveyed using marine geophysical equipment and potential targets for further investigation were located. During the second phase, the ROV hovered over these locations and the targets were identified on the video camera collecting data for the photogrammetry. The survey revealed 21 targets of anthropogenic origin located within a continuous field of *Posidonia oceanica,* making their identification challenging using geophysical methods alone. The magnetic survey showed that 11 out of 21 targets were high magnetic intensity or metallic targets. The ground truthing survey showed that out of those 11 targets, a metallic one was identified as a cluster of two (2) sunken cannons partially embedded in the Posidonia matte. Moreover, several anchor marks and fishing tools were discovered scattered throughout the *Posidonia* oceanica meadow. Some of these features/objects appear to intersect with the cannon, causing scrapes on its bottom near the trunnion, as observed in the video frames.

The visual dataset provided by the ROV was used to generate a 3D model of the cannon, enabling the extraction of morphometric data. The cannon, found in a vertical position, has been significantly affected by its century-long exposure to the marine environment. Concretions and biological colonization have altered its surface. The degree of alteration of the morphometric characteristics of the cannon have been also estimated based on 3D model.

VI. ACKNOWLEDGMENTS

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