Marine geophysical and photogrammetric survey of UCH sites

By Alexandros Lamprianidis
A.M. 1065416

Committee Members
1. Prof. George Papatheodorou, Department of Geology (Thesis Advisor),
2. Prof. Maria Geraga, Department of Geology,
3. Prof. Ioannis Iliopoulos, Department of Geology

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1. 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. In addition, it demonstrates the need of detailed mapping of the costal marine environments in regard to protected habitats and potential archeological sites by providing a multi-platform approach. Advances in today's technology, has made it possible to acquire high quality visual and spatial data through the marine environment with relative ease. Surveying the ocean floor with a phenomenal amount of detail in the most cost-efficient way and highlighting targets of importance is a major key to underwater research. The coastal area of Achaia serves as the main area of focus in this current endeavor.
2. Introduction

Underwater cultural heritage (UCH) encompasses physical objects discovered in underwater habitats, such as shipwrecks, submerged aircrafts, ancient settlements, and various artifacts. These submerged remnants offer crucial insights into ancient shipbuilding, sea battles, trade routes and navigation (Kizildağ, 2022). Beyond their cultural value, UCH sites also function as artificial reefs, fostering diverse marine ecosystems (Burns et al., 2023). The preservation and mapping of UCH are therefore essential for the advancement of the Blue Economy, given their dual significance as cultural and ecological resources. In light of these aspects, remote sensing emerges as the future of underwater scientific research, serving as a powerful tool in underwater archaeology, marine environment exploration and UCH mapping (Geraga et al., 2015; Papatheodorou et al., 2014).

Remote sensing surveying offers a multitude of advantages, primarily due to its ability to surmount the physical constraint of water depth that may exceed the range attainable by conventional diving. By facilitating a comprehensive and expeditious surveying of large areas, these techniques enable the collection of copious quantities of data in a cost-effective and time-efficient manner (Bowens, 2008; Papatheodorou et al., 2017; Søreide, 2000). Furthermore, they allow for the detection of submerged targets that may be buried beneath the seafloor, while at the same time providing a wide range of seafloor coverage in great detail, preset by the researcher, regardless of environmental variables such as light, water clarity and current activity, which are the limiting factors of diving.

Regarding wreck sites, the application of marine remote sensing techniques in surveying these locations has been clearly demonstrated as a valuable tool. One of the primary benefits of marine geophysical surveys, conducted with a focus on this objective or incidentally, is the identification of numerous wreck sites irrespective of their water depth. The utilization of geo-acoustic equipment, such as single and multi-beam echosounders and side scan sonar, allows for the thorough investigation of the seafloor's surface, providing detailed mapping of the wreck site in non-intrusive ways and evaluation of the surrounding seafloor texture (Ferentinos et al., 2020; Geraga et al., 2015). Side-
scan sonars are particularly effective in unveiling the shape of a target through the presence of shadows, which serve as indicators of vertical relief within a sonar anomaly (Singh et al., 2000).

Another instrument used is sub-bottom profiler that enables assessments of the seafloor's stratigraphy and potential expansion of the wreck beneath the seafloor (Boldreel et al., 2021; Ferentinos et al., 2020; Sakellariou et al., 2007). Furthermore, it provides information regarding the qualities of the sedimentary layers in which the wreck is situated. Marine magnetometers are also valuable tools in underwater surveys, as they measure and record deviations from the Earth's magnetic field caused by the presence of ferromagnetic materials. They can detect metallic objects and identify magnetic anomalies associated with ancient shipwrecks, submerged harbors, and large-scale buried archaeological sites (Gregory & Manders, 2015).

Therefore, in a variety of cases in the Mediterranean Sea, remote sensing has been implemented for monitoring, mapping and discovering these archeological and historical sites. These cases include the exploration of shipwrecks that incorporated high-resolution side-scan sonar (SSS), sub-bottom profiler (SBP), and remotely operated vehicle (ROV) data to create 2d-3d models of objects or areas, accompanied by high quality acoustic mosaics (D'Urso et al., 2015; KIZILDAĞ, 2022; Mattei & Giordano, 2015; Taher et al., 2022) and morpho-bathymetric surveys to create Digital Elevation Model (DTM) of the seafloor (Passaro et al., 2013).

In the last two decades, research activities regarding mapping and investigating Underwater Cultural Heritage (UCH) in Greece have increasingly utilized remote sensing techniques. These methods have proven to be invaluable in uncovering and documenting submerged archaeological targets and enhancing our understanding of the cultural heritage associated with Greece's marine environment. This endeavor includes underwater structures located in the coastal areas of Greece, along with shipwrecks or their remains in much more inhospitable environments.

More specifically, in Papatheodorou et al., 2005, Ferentinos et al., 2020 Papatheodorou et al., 2021, Geraga et al., 2015, Geraga et al., 2020, Gkionis et al., 2021 shipwrecks were studied through the use of side-scan imagery and sub-bottom profiles as a part of Oceanus-Lab’s, Laboratory of Marine Geology & Physical Oceanography
(https://oceanus-lab.upatras.gr/) extensive research in Greek waters. In addition to shipwrecks, other UCH sites were also discovered and mapped through remote sensing techniques. For example, in Levy et al., 2022 many different artifacts were brought to light.

2.1 Visual census and Photogrammetry

Sonar technology is presently the preferred choice for archaeologists and oceanographers in the mapping of vast seafloor areas (Ballard, 2007; Green, 2016). Although the extensive range of acoustic signals enables rapid mapping of large areas, the processing and, more significantly, the interpretation of sonar data can be challenging due to the complexities arising from acoustic reflectivity and backscattering, which also introduce geometric inaccuracies (Capus et al., 2008; Mitchell & Somers, 1989; Sakellariou, 2007). In contrast, optical sensors offer high-resolution images that are easily interpretable, but their effective range is limited to a few meters due to light absorption and scattering in water. Consequently, short-range optical sensors need to be physically transported close to the underwater features under examination. Typically, this is accomplished by affixing the sensors to Remotely Operated Vehicles (ROV) or similar systems, which descend to the seabed from a vessel or a comparable operational platform (Ballard et al., 2002; Bingham et al., 2010; Royal, 2012). By employing a Remotely Operated Vehicle (ROV) as a data acquisition platform, the dependency on divers is eliminated, thereby overcoming two critical operational limitations, namely depth restrictions and bottom time constraints (Drap, 2012; Nornes et al., 2015). Furthermore, a notable advancement in marine archaeological documentation would be achieved by eliminating the need for a human pilot through the autonomous operation of an Autonomous Underwater Vehicle (AUV) to carry out this task.

Photogrammetry is a methodology that combines art, science, and precise data acquisition to obtain high-quality information about physical targets through the analysis of photographic material (McGlone, 2013). It enables the production of accurate, to-scale 3D models (Drap, 2012; Ullman, 1979) and photomosaics of extensive areas or detailed
representations of individual objects. The implementation only requires the use of a scale bar to compute the scale of the model.

The key to successful photogrammetry lies in identifying common reference points among the acquired images, allowing for accurate correlation and the creation of comprehensive high-resolution maps or structures from overlapping data points.

It offers a cost-effective and efficient approach for creating three-dimensional structures and maps, making it highly suitable for documenting otherwise inaccessible targets. It provides a reliable means of obtaining valuable data for scientific research and analysis.

Photogrammetry is an interdisciplinary approach that utilizes principles from optics and projective geometry. It involves a series of well-defined stages, including digital image capturing and photogrammetric processing, to generate 2D or 3D digital models of objects. Its underlying principle is triangulation (Suziedelyte-Visockiene et al., 2015), which involves acquiring multiple images of the same point of interest from different angles. By mathematically analyzing these images, it becomes possible to determine the 3D coordinate data of the final product (McGlone, 2013). These 3D coordinates represent the locations of the object points in three-dimensional space. Additionally, the image coordinates indicate the positions of the object points’ images on the film or electronic imaging device.

In the field of underwater archeology and exploration/documentation of UCH sites, photogrammetry (Figure 1) is an essential tool in modern day surveys, offering valuable data from a variety of optical sensors for the creation of lifelike models (Costa, 2019).
Figure 1: Example of underwater mapping through the use of Photogrammetry. Source: (Costa, 2019)

Through the implementation of photogrammetric methods in the underwater environment, it is possible to produce high quality 3D visual representation of otherwise challenging sites of interest such as underwater structures or shipwrecks (Balletti et al., 2015; Drap, 2012; Henderson et al., 2013; Radić Rossi et al., 2019; Wright et al., 2020; Yamafune et al., 2017), along with the depiction of any other artifacts in their vicinity. It becomes possible to extract to replicate objects such as anchors, cannons, building-blocks, wood planks etc., and document their exact metric information (Drap, 2012; Henderson et al., 2013; McCarthy & Benjamin, 2014) to be later applied into further historical and more technical research relative to their development and constant evolution (Radić Rossi et al., 2019; Yamafune et al., 2017; Yamafune, 2016). The development of precise and lifelike models of submerged features is a significant advancement in the field of underwater archaeology. These models are easily understandable by both archaeologists and the general public, enhancing the dissemination and presentation of underwater archaeological data. They have the potential to enable non-diving individuals to explore and study submerged sites, facilitating a greater appreciation for the underwater resources (Henderson et al., 2013).
The ability to efficiently capture data and generate detailed plans and accurate photo-mosaics of submerged sites in the field offers notable advantages to underwater archaeological projects, particularly those operating under time and financial constraints.

Each year, technological advancements result in improved data accuracy at reduced costs for users. While digital and robotic technologies continue to enhance their strengths, their limitations in terms of cost and utility for underwater archaeology are diminishing. Consequently, conducting digital surveys of submerged remains is transitioning from a specialized technical endeavor to a common practice, a shift that should be embraced by all underwater archaeologists in order to foster the discipline's ongoing development.

The paper's main area of focus, is the demonstration of application of geophysical methods in maritime surveys, with regards to sunken antiquities in the vicinity of Patra's Gulf near Kato Achaia. This study hopes to uncover previously unknown sunken targets of archeological importance, confirming their identity and origin through visual census and photogrammetric reconstruction via implementation of Remotely Operated Vehicles (ROV) as means for high accuracy target extraction from the marine environment.
3. Materials and Methods

3.1 Equipment

During the offshore survey a variety of technological means were implemented for the vessel's basic functions, geophysical data acquisition (Figure 2) and ground-truthing survey (Figure 3).

The positioning of the survey vessel was determined using the LEICA GS14 GNSS system, which is a Differential Global Positioning System (DGPS) that provided a reliable reference point for the various instruments on board with a typical positional deviation of 25 cm. The system operated in RTK mode and received corrections from the METRICANET/PART OF SMARTNET EUROPE network, incorporating GPS, GLONASS, BEIDOU, and RTK corrections.

The vessel's navigation was facilitated by the HYPACK 2014 navigation software package, which offered a continuous graphical representation of the vessel's movements (tracks), along with the monitoring of across track error limits and the logging of depth data with corresponding geographical coordinates. To record the vessel's movements, a Motion Sensor (FOG) and a heading sensor were utilized. The SMC IMU-108 motion sensor compensated for pitch, roll, and heave, while the hemisphere Vector VS101 GPS Compass with two multipath-resistant antennas compensated for yaw.

Swathe bathymetry was carried out using the ELAC Seabeam SB1185 equiangular multi-beam echosounder, which had a maximum depth rate of 300m. The swath coverage sector varied between 130° and 150° depending on depth, with an along-and across-ship beam of 1.5°. 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. A high-performance computer running on Windows was responsible for data acquisition and system control.
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 was used for data acquisition, and the resulting data was post-processed and mosaicked using the SeaView software (Version 3.7). The resolution of the 4200SP system was 2cm across track and 0.1m along track at a slant range of 100m and a speed of 3 knots.

For magnetic mapping of the survey area, the SeaSPY2 marine magnetometer (Marine Magnetics) was used. The magnetometer was towed in line with the side scan sonar and employed an overhauser sensor, offering accuracy down to 0.1nT. This ensured successful detection of all man-made objects, whether buried or located on the seafloor. The data acquisition was performed using the Sealink software, while the post-processing and production of magnetic maps utilized the MagPick software (Geometrics). Additionally, customized software tools developed by the LMGPO team were employed to correct the data and generate fully corrected and consistent magnetic maps.

For the positioning of the ROV and tow camera systems, an Ultra Short Base Line (USBL) Sub Surface positioning system called Blueprint Seatrac X010 was employed. This system had a tracking range of 1km and a positional accuracy of 1 m.
Figure 3: Ground-truthing Equipment. A) SeaViewer, towed camera (TUC) extension, B) BlueROV2, C) GoPro in waterproof case.

3.2 Survey Area

The targeted area is located in the vicinity of Axagia, the lower part of Achaia, situated in the inner parts of the Gulf of Patras (Figure 4). Covering an area of ~1 km² along the shoreline.

Figure 4: Sattelite image of the gulf of Patras with the targeted area marked.
The Gulf, situated in western Greece, is a graben of Pliocene-Quaternary origin that runs transversely to the strike of the external Hellenide orogen (Ferentinos et al., 1985). It extends westward, opening into the Kefallinia Basin of the Ionian Sea, and is connected at its eastern end to the graben of the Gulf of Corinth via the narrow Rion Straits. Currently, the substantial Acheloos River discharges into the Ionian Sea to the west of the Gulf of Patras. However, during the earlier Holocene, it flowed into the western Gulf of Patras through the present-day Limnothalassa Mesolongiou (Chronis et al., 1991; Piper & Panagos, 1981). Additionally, the smaller Evinos and Peiros rivers directly discharge into the Gulf of Patras. The Acheloos River has an estimated annual sediment yield of 3-4 million tonnes, while the Evinos River yields approximately 0.5 million tonnes (Piper & Panagos, 1981). The Gulf of Patras can be divided physiographically into two segments: an outer segment that trends WNW-ESE, and an inner segment that trends NESW and extends towards the Narrows at the entrance of the Gulf of Corinth. The outer segment comprises a linear trough measuring approximately 22 km in length and 8 km in width. Along the trough's axis, water depths reach 135 m and gradually decrease towards the northeast in the direction of the narrow passage of Rio–Antirrio. The total area covered by the Gulf is approximately 350–400 km².

The investigation area (Figure 5) is located on the southern coastline of the Gulf of Patras (Western Greece) and extends to a total length of more than 40 km. It is a shallow embayment with a maximum water depth of about 120 m leading into the Ionian Sea on the west and the Gulf of Corinth on the east and its southern coastline receives deltaic sediment from the Peiros river (Depountis et al., 2023).
The exact area of study occupies 1.2 km of shoreline and an estimated 0.99 km² of seafloor at the central-northwestern part of the Gulf, reaching a maximum depth of 32 m. The highly populated southern coastline of the Patras Gulf faces significant erosion, exacerbated by climate change, urban development, and human activities. It can be categorized into three sections: the densely populated northeastern part affected by coastal constructions, the central section influenced by the Peiros river accretions, and the western part dominated by the Pappas lagoon.

According to the currently available bibliography the researched area along with a multitude of potential targets are situated within the large expanse of a *Posidonia oceanica* meadow as it has been characterized in Panayotidis et al., 2022 (Figure 6) where the reconstruction of the distribution across the Greek shorelines of *P. oceanica* from multiple data sources took place. The exact nature of the seafloor habitat was confirmed during the ground-truthing stage along with the confirmation of the targets.
3.3 Survey Design

The main objective was to effectively cover the specified area through the use of geophysical means with the prime goal of locating targets of possible archeological significance in the wider vicinity of Patra’s Gulf, while ensuring maximum coverage along with 75-80 % overlapping of the acquired datasets across the predetermined routes. Based on the outline of the area, the vessel's course was divided into 48 sub-courses (Figure 7), evenly space out at approximately 15-25 m apart, which are characterized by the concurrent use of the multi-beam echosounder and magnetometer.
Out of those 48, 16 lines were also accompanied by the use of the SSS, operating at 100 kHz and 400 kHz simultaneously, tracking every 60m with a scan width of 2×75 m both port and starboard side. The multi-beam echosounder was set to operate at a frequency of 128 kHz, producing 128 beams, while the sub-bottom profiler utilized a type Ricker at 3.6 kHz and a pulse duration of 650 μs at a shooting rate of 100 ms. The magnetometer was present throughout the tracks, utilizing 1 kHz for the magnetic survey, with the insertion of 4 additional track lines for error correction/calibration of the results.

During this process potential targets are flagged in real time for later inspection, through the main interface of the observed data stream. These points of interest are catalogued along with the ones from fully revised dataset, given a name tag and its basic discerned features combined with its known location.

After the location of possible targets has been confirmed through a combination of the attained data, the ones being more prominent in the acoustic and magnetic profiles of the area will be selected with regard to their current position and accessibly of that area with the available vessel. The objects will then be prioritized as sites of importance during
the ground-truthing survey, which aims in the recognition of the targeted areas habitat and the object’s potential identity that might also suggest its origin, along with what led to their relocation in the ocean floor.

The ROV system will be utilized for a close target inspection with the possibility of high-quality data acquisition for photogrammetric reconstruction with the assistance of the towed underwater camera (TUC) for the habitat confirmation in support of the initial geophysical information.

3.4 Ground Truthing
3.4.1 ROV&TUC

After the initial acquisition of the basic dataset, either during the operation or afterwards, points of interest are selected for further research and identification. The BlueROV2, a portable, stable and highly maneuverable ROV system, provides full HD video footage down to a maximum depth of 100m, while it can be combined with a specially designed GoPro camera, suited in a case with two parallel scaling lasers. The towed camera (TUC) extension SeaViewer equipped with a GoPro was additionally utilized to cover long tracks along the seafloor. Its ease of use and maneuverability makes it ideal for a targeted video survey of the seafloor across predetermined lines to confirm early assessments. Both devices’ data were viewed live and recorded by the open-source software for ROV, ArduSub.

3.5 3D Model Data

After the confirmation of the target’s location, additional dives were performed with the ROV system equipped with a GoPro, providing video data for its 3D reconstruction. A series of maneuvers were pre-determined for the vehicle to follow to assure maximum coverage and overlap of the video frames. Before incorporating the visual data into a 3D object every single video is split apart into individual frames through the scene video filter command of the VLC player, a free and open-source cross-platform multimedia player and framework, with an extraction ratio of 15, recording around 1-2 frames per video’s
second. The extracted files are saved into a unique folder. Subsequently, a processing step is performed to remove blurry images or images not containing direct visual contact with the targeted feature to assure the highest degree of data utilization, while also facilitating the full use of the software’s capabilities. The final cut of images is ready to be loaded into the photogrammetry software Agisoft Metashape Professional to begin the synthesis of the three-dimensional item.

3.6 Model Creation

The extracted frames are imported into the Agisoft Metashape Professional (Version 1.8.4, build 14493). In this software, a manual color correction is performed using the inner control panel to reduce the offsets caused by the light’s diffraction underwater. After this correction, the frames are prepared for the reconstruction operation.

The basic process (Figure 8) initializes with the alignment of the photos according to the camera’s orientation and relative position of the targeted object through the Align Photos workflow command.

![Flow diagram of the model creation process.](image)

**Figure 8:** Flow diagram of the model creation process.
The aligned photos are then implemented in the next process Build Dense Cloud, which analyzes the various unique characteristics located in every image to find common points (Tie Points) correlating the data. The key point limit has been reduced to zero to essentially take advantage of the high resolution of the extracted frames to achieve maximum coverage in areas where they may be lacking. Additionally, in this early stage of the workflow, the majority of located points not related to the target are being deleted as a part of an initial pre-process to ensure the quality of the data. This operation sets the foundation for the most demanding step of the model’s creation, generating the depth maps and computing the dense cloud by using the Build Dense Cloud command. During this action the software attempts to extract the target’s surface geometric data information, to be replicated into 3D space. Due to the abundance of fine details on the cannon’s surface and the high quality of the source images, Mild depth filtering was enabled to preserve those features for the duration of the extraction procedure. The final stage of the creation process involves the conversion of the point data generated through the previous functions into a solid object, an initial Mesh upon which the calculated texture will be applied. For the 3D object to be generated (Figure 9), the Dense Cloud is used as the data source for the acquired geometry to be solidified, with the surface type being set to Arbitrary for closed three-dimensional objects. Afterwards the produced feature is edited to remove any unnecessary geometry generated as a byproduct of non-calibrated data which were not spotted during the pre-processing. The finalized 3D object is then texturized by the Build Texture command. The surface of the cannon is mapped through the software’s algorithm set to Generic mode which allows parametrizing texture atlas for arbitrary geometry, where the program tries to create as uniform texture as possible. Blending mode was set to Mosaic, which does the blending of low-frequency components for overlapping images to avoid seamline problems, while the high-frequency component, which is in charge of picture details, is taken from a single image, the one that presents a good resolution for the area of interest while the camera view is almost along the normal to the reconstructed surface in that point. Texture size/count was left to default set by the program 8192×8192, multiplied by a factor of 2, to create a pair of texture images with the aforementioned resolution.
Following the model’s completion, it is then scaled using images acquired at a later date by divers, offering an XDive Ribbon 19cm diving knife as the means for the cannon’s size estimation.

The produced geometry is singularly extracted and then imported into the open-source software CloudCompare Version 2.12.4 for further analysis. The model is being put under a smoothing process to potentially reach a certain level of surface morphology, resembling the cannon’s original dimensions, before its century-old exposure to the underwater conditions of Patra’s Gulf. The tool applied to achieve this result is referred to as Laplacian smoothing, which enables after a series of applications of 50 iterations with a smoothing factor of 1.2, the removal of every extreme geometry on the model’s surface. The resulting 3D object is sampled with an average of 5 million points and matched against the original’s, to calculate the absolute distance between corresponding points, and therefore compute the degree of change.
4. Results
4.1 Multiplatform Seafloor Mapping

The area appears to have seemingly mild bathymetry spanning from ~2.50 m in the shallowest part recorded by the multi-beam echosounder (Figure 10) and ~31 m at its deepest. The seafloor presents stable inclination of 1-1.5° on average which is abruptly cut off in certain areas from hole-like structures, semi-circular to oval in shape, displaying a depth anomaly of ~1-1.5m. These anomalies appear parallel to the shoreline appearing at what seems to be two separate increments located at a depth of 9-10 m and 14-15 m parallel to each other.

![Figure 10: MBES swath bathymetry map.](image)

The mosaic occurring from the SSS cover an area of ~1 km² spanning between 150 m to 1 km following the shoreline, towards the inner parts of the gulf. By observing and comparing the resulting mosaics at both frequencies, it was possible to divide the survey area into 5 distinct acoustic types, which comprise the majority of the acquired...
seismic data. This distinction was made through thorough analysis of the intensity and visual representation of the data from both frequencies of 100 kHz (Figure 11) and 400 kHz (Figure) in the environment of SeaView software during and after the completion of the mosaics. Certain features of the seafloor stood out during the processing of the seismic mosaics and were marked as targets for further research.

![SSS Mosaic Map, 100 kHz.](image)

**Figure 11:** SSS Mosaic Map, 100 kHz.

The magnetic survey (Figure 12) was performed in consistence with the SSS survey for the confirmation and potentially further identification of metallic targets on the sea floor and/or within the Posidonia meadows. The area displays overall low values of magnetic anomalies with a major increase being spotted parallel to the shore at a depth of approximately 12.3-14.8 m marking an area of ~200 m in width. Notably, what seems to stand out the most from what appears to be the ambient magnetic profile of the seafloor, are certain high-intensity targets, located throughout the survey area. Some of these targets were selected afterwards based on proximity and ease of access to their
particular location, relative to the pre-scheduled routes of the vessel for further exploration at the ground-truthing stage of the operation.

**Figure 12:** Magnetic Anomaly Map of the targeted area.

### 4.2 Ground-Truthing

During the data acquisition from the ROV and the TUC, consisting of 6 ROV targets (Figure 13), one central line and 11 TUC tracks (Figure), it was confirmed that the entirety of the survey area is located within a *Posidonia oceanica* meadow, comprising of dense, healthy *Posidonia* shoots and *Cymodocea nodosa* in the swallow sandy regions.
Figure 13: Ground-truthing lines using the ROV for targets and TUC for habitat confirmation.
For the most part, the *Posidonia* matte is consistent, with sparse sand gaps scattered across the field. Some of the locations scouted by the aforementioned methods were ground-truthed through the use of ROV, with the results varying between locations. In some of the cases, objects were indeed found in the vicinity of the marked locations, but Posidonia made it impossible in several sites for any kind of article to come into view. Out of the 21 logged contacts (Figure 14), contacts 5, 9, 14, 16, 21, 22 were selected for confirmation, out of which only 14, 16, 21 provided results in the form of fishing tools, anchors, etc. (Figure 15).

![Figure 14: Total of logged targets from both magnetic and geophysical survey on the SSS mosaic, with the explored targets highlighted.](image)

*Figure 14:* Total of logged targets from both magnetic and geophysical survey on the SSS mosaic, with the explored targets highlighted.
Figure 15: Targets located in the ground truthing survey and its corresponding signature in the SSS.

The main target located by the survey, contact 16, the sunken cannon (Figure 16) was located standing up and plunged through the matte. The cannon itself seemed to be covered by marine organisms, mainly sponges and solidified sediment, altering its original shape. Its surface appears to be incrusted in concretions, offering a substrate for the colonizing taxa. The base of the cannon was wrapped by ghost nets with the surrounding Posidonia oceanica over a radius of 30-60cm to appear seemingly damaged and bearing track-like marks moving away or towards the base of the target.
Figure 16: Close up views of the cannon with *Chondrosia reniformis* sponges and coralligenous formations.

Its counterpart, the second cannon (Figure 17), was discovered during the initial exploration of the first, laying on top of the Posidonia, bearing a similar degree of concretion on its surface with the sighting of seashells buried in the solidified sediment. Neither the base nor the trunnion is visible in this case. Moreover, the *Posidonia oceanica*
matte seems to be overtaking it, slowly incorporating it into the meadow. Its visible length has been estimated to be 59.24 cm with a barrel of 20 cm and a bore of 5.38 cm in diameter.

![Secondary Sunken Cannon](image)

**Figure 17**: Secondary Sunken Cannon.

Both appear to have been colonized by similar groups of organisms with the consensus being made up of *Chondrosia reniformis* sponges and coralligenous formations, to an extended degree, which appears to have distort their original appearance.

### 4.3 3D Model

The completion of the model creation process for the main cannon has resulted in the construction of a high-resolution three-dimensional object (Figure 18), comprised of 207,536 points out of the original 249,348 and 298 individual depth maps making up its surface, for a generated dense cloud of 11,249,580 points, which resulted in a 3D model consisting of 5,020,113 faces and 2,510,645 vertices. The texture was finalized using the
original photos as a reference to create a set of imaginés of 8,192×8,192 pixels in order to achieve a whole of 16,384×16,384 pixels comprising the cannon’s surface for a detailed RGB reconstruction of the object’s natural color scheme as it has been affected by the environmental conditions during the time of acquisition. The point confidence was later calculated within the model creation software, attributing for the majority of the object’s volume, moderate to high confidence, which in turn solidifies the legitimacy of the produced geometry. The cannon was brought up to scale with the original, measuring approximately 98.5cm in length down to the trunnion, 29.55cm barrel, and a bore of ~8.4-7.38cm in diameter.

Figure 18: Multiple view of the 3D model produced by Agisoft Metashape Professional.

These data were later applied in the CloudCompare software to produce in 3D space, a comparative image that attempts to assess the distortion of the cannons’ original form, mostly attributed to colonization by marine organisms (Figure 19). On average the occurring cross-shape distances between the 3D artifact and its smoothed counterpart...
are calculated at approximately 1.13cm including the majority of the exposed section. The more profound distortions seem to be concentrated near the muzzle and base of the cannon whereas the main length of the barrel displays rather uniform distribution across its length.

Figure 19: CloudCompare cloud distance results.

4.4 Habitat Mapping

During the course of the ground truthing survey, carried out by the ROV and TUC systems, it was possible to combine the information gathered from the SSS and perform an initial habitat mapping (Figure 20) of the targeted area, with high accuracy, aiming at the integration of the data from both sources, as a valuable byproduct of the initial research goal.
The survey resulted in the delineation of the two major habitat types present on site, meaning the extensive presence of *Posidonia oceanica* in the entirety of the area and *Cymodocea nodosa* near the shoreline.

The appearance of *Posidonia oceanica* in this specific area seems to be visible approximately 75-80m from the shore with its major part being located 230m away, covering an area in width between 500-740m. *Cymodocea nodosa* has been identified as the second species of marine plant inhabiting the area alongside *P.oceanica*, resulting into a seagrass field extending approximately 1km into the Patra’s Gulf. More specifically within the confines of the study area it was possible to calculate the extent of *P.oceanica* to approximately 0.61 km². In certain locations such as Axagia, the high accumulation of sediments across the seafloor near the beach, creates a marine environment of high grain sand in which, the main body of the *C.nodosa* meadows is situated. The shoreline sediments seem to have developed into a thriving environment for this specific type of
seagrass, resulting in the establishment of a large meadow parallel to the shore spanning approximately 130-140m in width and at least 800m in apparent length, covering an apparent area of at least 0.091 km², according to our interpretation of the acoustic mosaic.

Through the shared analysis of both video and SSS mosaics, several acoustic types have been identified, at least for the majority of this current study area, among which the acoustic reflection for *P.oceanica*, Sandy Seafloor, Muddy Seafloor, Dead Matte, Dead Matte-Alive Posidonia and Seafloor with *Cymodocea nodosa* (Figure 21).

By utilizing these data, it is feasible to locate/map the majority of the aforementioned formations with relative accuracy via seismic means alone (Figure 22).
Additionally, by utilizing parts of the footage which did not correspond to the main study area, it was made possible to map a previously unknown coral habitat in the vicinity of Axagia. The first sighting of this alien looking presence on the ocean floor was made approximately 1km away from the shore and about 40m after the last part of the acoustic data provided by the SSS. Thanks to these supplementary visual data, it became possible to map a piece of the unexplored seabed in detail, uncovering foreign aspects of the Patra’s Gulf marine life. The discovery was made at a depth of around 33 to 49m according to the available information, defining an area of at least 420m in width and unknown length. Potentially spreading in a much larger area than what the research has initially uncovered.

The majority of the spotted targets has been identified as the coral species *Spinimuricea klavereni* (Figure 23), making up 95% of our observations over an area of 0.031 km², with some still unknown entities remaining unidentified.
Figure 23: *Spinimuricea klavereni* spotted at a depth of 47-49 m.
5. Discussion

The accumulated information from the available methods has led to a variety of different aspects of the studied area to come to light in an unprecedent way. The majority of the central part of the survey area is comprised of a continues field of *Posidonia oceanica* with its main mass being located between 12-15m, while the *Cymodocea nodosa* is being placed at the outskirts of the formation, near the edge of the Posidonia meadow, both at its deepest and shallowest parts, appearing mostly in depths of around 2-8m and scarcely at approximately 20-23m. These facts are also supported by the SSS data, as it can be derived from the transitions between the different recognized acoustic types. The associated targets are also located within the meadows, making their identification through seismic methods alone highly challenging, whereas the magnetic anomaly map offers a distinct picture of clearly alien targets in the marine environment, calling for their immediate documentation. Although, in a number of confirmation dives with the ROV there were no apparent targets on site, despite the high magnetic anomaly recorded by the instruments on board, leaving the possibility of additional targets from the ones confirmed through optical means to still exist hidden within the dense foliage of the *P.oceanica* meadow or even for them to be incorporated in the matte to a degree similar or potentially even higher than the discovered sunken cannons.

As a part of the full utilization of the acquired footage from the TUC, the detailed mapping of additional features of the seafloor was encourage beyond the boundaries of the SSS and magnetic datasets, resulting as previously mentioned in the discovery of a previously unknown for the Patra’s Gulf community of corals at relatively shallow depths spanning between 33-49 m, where they were initially spotted, mainly comprised by what appears to be the Mediterranean endemic gorgonian *Spinimuricea klavereni* in an undocumented site in the vicinity of Axagia. These, along with the still unidentified elements at the deepest parts of the recorded footage can possibly serve as a stepping stone for the further exploration of coral communities and coralligenus formations of the Mediterranean with potential research interest in the study and environmental management.
The main objective of this survey, the study of the located cannons (Figure 24) was carried out through visual means acquired by the ROV. The same dataset was also utilized for the generation of the 3D model, which in turn was used for the extraction of morphometric data of both spotted antiquities. Out of the two findings, the most effort was focused on the cannon spotted sitting vertically on the seafloor. Its current metrics have been severely affected by its century long stay, exposed to the marine environment. Concretions and biological colonization appear to be the main factors affecting its surface.

![Diver acquired images of the located antiquities.](image)

**Figure 24:** Diver acquired images of the located antiquities.

This also provided the opportunity for the additional use of the CloudCompare software which provided a computer simulated estimation of the organic and sedimentary buildup on to the cannon’s surface over its stay, plunged within the Posidonia matte. The calculation of its original shape was carried out by applying smoothing algorithms, already existing in the software’s toolkit, until the resulting shape displayed almost linear features without deviating from its intended design. As a result, a high accuracy distortion map between the original 3D model and the smoothed-out version was generated, portraying changes in the class of 0.0004-2.5483 cm. The highest amount seems to be focused around the cannon’s base around the area of the trunnion, slowly reaching the middle of the exposed part of the barrel. The rest of the barrel extends above the maximum foliage height of *P. oceanica* in its vicinity, being subjected to slightly harsher conditions in terms of water flow and currents, possibly justifying the lowest observable numbers of distortion.
being gathered upwards as the object rises from the seafloor. In comparison the second cannon was located laying on top the matte, assimilated in the rhizomes of the meadow. It bears similar morphological features to the first with the main difference being its consistency in shape while referring to the amount of build up across its exposed surface. Additionally, in both cases the presence of organisms having colonized their volume is apparent. That combined with the fact that both objects have a magnetic signature, which is what made them visible to the magnetometer can potentially lead to the assumption that the material used in their manufacture was primarily iron.

Through the process of ground-truthing, several anchor marks and fishing tools have been pinpointed scattered throughout the *P.oceanica* meadow, some of which seem to cross paths with the cannon, scrapping its surface at the bottom near the trunnion as it occurs from the video frames and continuing on leaving a trail on top the Posidonia matte, lining on perfectly with the potential damage (Figure 25).

![Figure 25: Potential damage to the cannon parallel to the anchor marks.](image)

A mass of ghost nets is also situated in the area, entangled in its base, slowly chipping away at the excess volume of the cannon, potentially reaching its original surface. The presence of all these factors intertwined within the confines of a, for all intents and purposes protected by European law marine area, gives the impression of a highly active environment, clearly effected in certain areas by human ventures, endangering the functionality and well-being of the field, while at the same time posing a continues source of harm for the archeological artifacts known and still unknown. These two cannons serve as a paradigm for marine archeological research in Patra’s Gulf with the potential to uncover many more, as a result of meticulous and extensive study.
6. Conclusions

This research’s main area of focus, was to demonstrate the application of geophysical methods in maritime surveys, with regards to sunken antiquities, utilizing the part of the shoreline near Kato Axagia, in the vicinity of Patra’s Gulf, an area key to many historical events, as experimental grounds for the implementation of said methodology. Based on the findings of this endeavor it was possible to confirm the legitimacy of geophysical studies in the field of marine archeology in a cost efficient and productive way, opening a variety of additional opportunities.

The main findings located during this survey, namely the two sunken cannons, were located within a *P. oceanica* matte at a depth of approximately 15 m provide further confirmation of the areas historic activity and its importance in scientific studies. The morphometric data extracted from the targets 3D reconstruction will inevitably offer valuable data contributing to its future identification and tracking of origin. Their discovery and later ground-truthing process has served as additional evidence of the accuracy and consistency of this particular lineup of equipment and methodology, setting a paradigm for underwater archeologic research.

During the course of this endeavor, it was possible to gather data about the area’s underwater layout and magnetic characteristics, as well as acoustic data collected by the SSS system, adding its profile and potentially providing insight by letting the researcher view the bigger picture as well as the smallest of details. By incorporating the sum of all those sources into a singular space, it can be made clear where potential anomalies might be located in the underwater world as it might be perceived through a multi-data lens. In addition, it was also made possible to demonstrate the validity of use of the ROV system, not only for the exploration of potential targets of importance, but the extraction of high accuracy morphometric data as well, as it is demonstrated by the 3D model created as a result.

Moreover, the visual and acoustic data collected as part of the quest for lost antiquities, were also utilized as a part of a habitat mapping effort of the research area, generating highly detailed maps of the seafloor features, organic or not, depicting a dense
seagrass field, supporting and confirming the previously mentioned habitat mapping project, while adding valuable input to an otherwise plank canvas.

Additionally, the supplementary visual data collected outside of the specified area led to the discovery of a previously unknown for the area, coral habitat, with potentially far greater reach than the documented sightings would suggest, with great prospective in enriching our current knowledge regarding coral communities in Greek waters and the Mediterranean as a whole.

Future archeological research in the area would certainly benefit from the addition of a Sub-bottom profiler in the equipment array to further increase the system’s ability to uncover targets hidden underneath the dense *Posidonia* matte or layers of sediment currently hindering a major part of the investigation. Furthermore, the existence of undocumented habitats in a highly active environment, affected to a significant degree by marine means of transportation might present a unique opportunity to expand our scope of study onto greater depths, implementing the full force of the scientific processes into a variety of underwater fields of study.

The progress in today’s technology has enabled researchers to have an unprecedented point of view in the underwater world, uncovering hidden secrets with remarkable detail, propelling this field of exploration ever so forward, leaving it up to the researcher to decide the most ideal course of action to achieve their desired outcome.
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8. Bibliography


