Applying GIS in Underwater Cultural Heritage: Case Studies from the Grotta Naxos and the Eunostos

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Abstract. Underwater Cultural Heritage (UCH) is an extremely valuable resource but yet increasingly threatened. The application of Geographic Information Systems (GIS) is significant in the process of monitoring the UCH. This study will involve a comparative examination of two different case studies: Grotta Naxos in Greece and Eunostos in Egypt. The findings indicate that the dynamism of GIS is flexible to different situations. The combination of GIS and modern technologies such as Unmanned Surface Vessels (USV) and a variety of sensors were used at Grotta Naxos which allowed the quantitative and high-precision reconstruction resulting in the creation of detailed 2D and 3D models. In contrast in the case of the Eunostos site, by the constraint of modern harbor facilities and military controls, GIS was a hub site to generate qualitative volumes of valuable datasets, such as old maps and sonar imagery to facilitate strategic planning. The comparison demonstrates that GIS is an indispensable platform for UCH archaeology. The future should be fostered by interdisciplinary collaboration, combining artificial intelligence and big data to improve the accuracy of archaeological site research.

Keywords: Geographic Information Systems; Underwater Cultural Heritage; Side-Scan Sonar; Spatial Analysis

1 Introduction

Underwater Cultural Heritage (UCH), including shipwrecks, submerged settlements, and ancient maritime routes, which represents a unique and irreplaceable part of human history [1]. Underwater Cultural Heritage offers precious insights into human-ocean interactions in the past, and also it helps simultaneously hold significant potential for future tourism and cultural preservation. Nevertheless, UCH sites are vulnerable to be threatened by natural factors, such as the rise of sea level, coastal erosion, as well as anthropogenic pressures. Some unregulated salvage and extensive coastal development show the importance of emphasizing the urgency for effective conservation strategies.

Geographic Information Systems (GIS) have rapidly become a significant way in the monitoring and management of cultural heritage [2,3]. By integrating diverse spatial data—from remote sensing imagery to archaeological survey points—GIS serves as a

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centralized platform for spatial analysis[4,5]. GIS can achieve precise positioning, facilitating dynamic monitoring of the underwater site conditions, and having powerful visualization capabilities as same as what divers see underwater. As a result, under the help of GIS, the scope and accuracy of land can be significantly expanded and enhanced, which promotes underwater archaeological research.

This paper aims to evaluate the application of GIS in Underwater Cultural Heritage management by comparing two distinct case studies: Grotta Naxos in Greece and the Eunostos harbor in Egypt. The study will first outline the principal challenges researchers find during exploration, and then come into a deeper comparative analysis of how GIS technologies were applied in these two cases under different environmental and limitation of human factors. Finally, the paper will discuss the experience learned and concluded, and explore future opportunities, emphasizing how the integration of GIS with existing technologies like AI and 3D modeling can further be deployed in the field of underwater archaeology, or other archaeological researches in the ground.

2 Main Challenges in Underwater Heritage Exploration

2.1 Natural Environmental Factors

Climate change plays the most significant natural threat to the long-term preservation of UCH. The threat such as sea-level rise which is driven by global warming, not only it will risk submerging more coastal sites but also deepens existing underwater sites into an undetectable depth. Climate change will alter the water flow conditions around the site and the decomposition process of the heritage will be accelerated[6]. Furthermore, the increasingly frequent extreme weather, such as typhoons and heavy rainfall will trigger strong currents and storm surges that erode the sediment layers covering the sites. These sediments act as a natural protective shield against corrosion and biological erosion. Once the sedimentary rocks are removed, these cultural relics will be directly exposed to water, thereby subjecting them to physical impacts, displacement or unpredictable complete destruction. Also, the action of tides exerts continuous physical pressure on the foundational structures of underwater relics may lead to material fatigue and potential structural collapse. These unpredictable influences can affect normal lives of surrounding citizens. Even if models can be used to predict the movement of water bodies, such as Computational Fluid Dynamics (CFD) and Residual Relief Modelling (RRM), uncertainty has always been a major challenge for researchers.

2.2 Human Activity Factors

The pressure caused by human activities on UCH are increasing. The government encourages large-scale coastal development. For instance, the port expansion, land reclamation, and installation of submarine tools can directly destroy archaeological sites permanently [7]. Even some protective measures, such as the breakwater construction which can change local current patterns and indirectly cause scour. Moreover, land pollution caused by industrial wastewater, agricultural fertilizers, and domestic sewage can cause seawater eutrophication and acidification. Acidification promotes the corrosion of metallic objects (e.g., hulls, cannons), while eutrophication promotes the proliferation of algae and biofilms. These organisms will attach themselves to the surface of the cultural relics, and cause biological corrosion and also affect the features of the archaeological sites. Although many nations have established laws to protect UCH, still many challenges exist in enforcement.

2.3 Data and Technical Bottlenecks

Compared to terrestrial archaeology, underwater heritage exploration is internally constrained by high costs and low efficiency in data acquisition [8]. Firstly, the cost of operation are substantial, including professional diving operations, high technological sonar systems (e.g., Side-Scan Sonar, Multibeam Echosounders), and Autonomous Underwater Vehicles (AUVs), which restrict large-scale, long-term surveys. The high-tech will have a continuous spend which is always unaffordable during the exploration. Secondly, the rapid decline of radio waves in water renders GPS cannot be used for direct underwater positioning. The position location by surveys should be based on the underwater acoustic systems which are much less precise than GPS and also are affected easily by interference to the signal as a result of the changefulness of the water temperature, gradient of salinity and Seabed topography which causes spatial errors. The poor visibility in the water also greatly affects the implementation of optical photography where it is hard to use to fast track identification and recording of features by the divers or the Remotely Operated Vehicles (ROVs). Together, all these technical bottlenecks lead to major problems in error control, causing ineffective site detection, modeling and monitoring.

3 Case Studies

3.1 Case 1: Grotta Naxos (Greece)

Grotta Naxos is in the northwest of the island of Naxos in the Cyclades archipelago of Greece, which occupies the North coastline of Naxos and part of the region underground. It is covered with modern residential areas and harbor facilities nowadays. The author divided the site into two sectors [9]. Sector A is the current Grotta Beach, its scope covers the entire underwater edge area of the beach. It is also surrounded by the steep slopes of the Apollomata Mountain on the east, connecting with the Paratiya Island by artificial land on the west. Sector B covers almost the entire Beigang Basin. The north wind is the dominant wind direction factor, because the activities of the east wind and west wind are relatively weak. (see Fig.1).

The survey employed a compact side scan sonar (SSS) system. This system operates at high frequencies (455/800 kHz) to achieve high-resolution detection and enables efficient investigation of large areas (up to 90,000 m^2). A broadband chirp Signal Beam Bathymetric Sonar (SBES) was also deployed during the research, which uses broadband linear modulation pulses (83/200 kHz) to collect water depth data at different seabed locations. It has strong flexibility, anti-interference capabilities and high resolution in terms of distance. These measurements provide precise three-dimensional spatial coordinates (X, Y, Z) for locating underwater cultural relics. Data mosaics were created to represent the study area, and all datasets were processed in GIS ArcMap to construct the final underwater map. GIS ArcMap is a powerful tool for integrating and visualizing complex spatial datasets, it enables users to perform detailed digitization.

Fig. 1. Map of the surveyed area.

The research shows that the morphological acoustic data gained from Sector A provides a comprehensive picture of the evolution of the seabed and the distribution of ancient relics above it. The researchers identified six structures with unique architectural characteristics. The sonar data indicated that the spatial distribution of these ruins becomes increasingly scattered when the distance approaches, which presenting a chaotic pattern where architectural features are dispersed throughout the area. It shows a trend of local concentration but lacking overall planning. What's more, after applying the SSS technology in the two areas with distinct color characteristics within sector B, various changes were observed on the seabed. Sector B area was found to be composed of unconsolidated sediments, such as sand was detected, and it contains three main structures apparently arranged artificially. Additionally, researchers recognized a separate stone assemblage, and it presents patterns that are consistent with those of larger-scale archaeological sites. This discovery has been listed as a potential archaeological target for future investigation (see Fig.2).

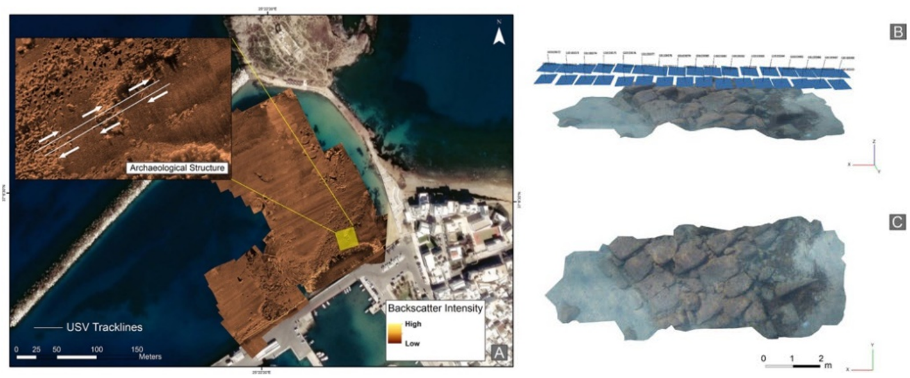

Fig. 2. (A) The positions of measurement structures & the navigation trajectory records of the USV during photogrammetry. (B) Images collected to construct a three-dimensional model. (C) Part of the orthophotography images. Reproduced from [9].

3.2 Case 2: Eunostos (Egypt)

Two sunken cities were discovered in Abukir Bay during the late 20th century: Heracleion-Thonis, which located in a lake connected to the Kaopik River. Canopus, which located along the westernmost branch of the Nile. Both cities were major Egyptian harbors for trading with Greece even before the establishment of Alexandria. An underwater archaeological archaeological field work in an area of about 80 km 2 in the waters of Alexandria was conducted by a team of Russian archaeologists [10]. The most important was the Harbor of Happy Return which is also another element of the complex Eunostos, the center of exploration is found in the vicinity of the cliffs of Anfushi and Al-Silsila sea cliffs.

The first field experiment to be done was to deploy underwater sleds and hovercrafts by use of small motorboats and their movements tracked in real-time on GIS. ArcGIS was used to create a GIS that combines satellite images and 17 th -19 th century historical maps as well as sonar information. The CES RAS together with the Egyptian officials identified a number of locations around Agami where sonar prospecting was to be done later. In this gear the Klein 3000 side-scan sonar (SSS) is installed, and other water depth measurement devices are also included like the Odom dual-frequency single-beam depth sounder which is linked to the global positioning system. It can accurately identify cultural relics at a depth of a range of 20-30 meters.

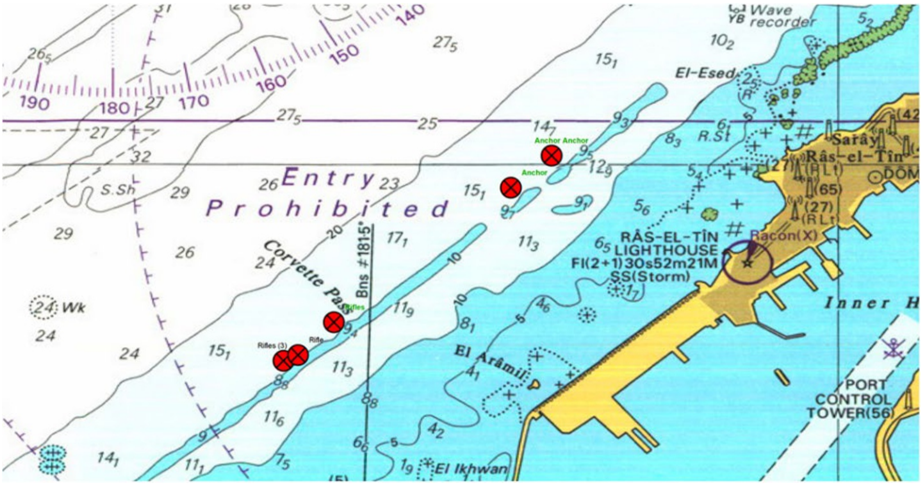

Fig. 3. The location of the anchor found during the underwater reconnaissance dive in the second layer of submerged reefs in the Anfushi area. Reproduced from [10].

The archaeological site of Anfushi uncovered a breakwater ruin which was about 200 meters off the coast. The massive promontory, which was made of roughly hewn blocks of limestone, was in an endless line, stretching parallel to the coast line--a direction which agrees with early historical jottings. There were also high numbers of anchoring devices that were documented such as Greek-type limestone stocks and Roman wooden anchors. Also, there were records of shipwrecks, including: Le Patriote, that went sinking in 1798 and a ship of ancient Greek merchant. In Al-Silsila the traces of some old breakwater and stone anchor fittings were found, showing that there were port facilities here at one time. Nevertheless, the site is located at some distance to the operation base and the capabilities of exploration are limited, which results in a lack of in-depth knowledge of this location (see Fig.3).

The archaeological value of the Eunostos was further confirmed by the fact that there was a great number of anchoring devices of various origins which were discovered mainly on the second line of submerged reefs. An example is the underwater finding of a large limestone inventory of a Greek-type wooden anchor, which is 231 cm long and weighs 320kg, and dates back to some time between the middle of the 4th and 3rd centuries BC. Also, a Roman lead anchor stock, 90 cm long, its relevant lead reinforcement collar, and a Byzantine iron anchor were also recorded in that locality. This discovery of anchors in various historical times attests to the ancient activity along the sea belt and the maritime problems due to the presence of the rocks at the entrance point of the ancient port.

The research proves that in even high-sensitized locations with limited entry. An example is the places that were controlled by Egyptian Navy. At this stage, a specific core exploration technique and the spatial analysis with the help of the GIS is required to reach the important archeological outcomes. This strategy is quite effective as it turns the port of Eunostos that is historically recorded into an archeological reality of intuitive nature.

3.3 Case Comparison

The location where Grotta Naxos will be put is situated in an ancient coastline and this place has not been entirely taken up by the modern urban building processes. It was a place where sophisticated technological equipment could be proliferated because the environmental conditions were relatively simple and the areas occupied by water were quite big to offer space. The methodology of research consisted in the combination of GIS and the unmanned surface vessels (USVs) to create detailed 2D and 3D models. The approach illustrates that high quality and innovative remote sensing technologies could be non-invasive, highly precise and sophisticated to be used as a framework in future archaeological studies. Conversely, the site of Eunostos is much overfilled with a modern harbor and military base and it led to a complicated working environment that raised the complexity of archaeology and prevented the use of innovative technologies. In the case, GIS was used to superimpose and combine various temporal data. The GIS was marginally involved in the archaeological study of the Grotta Naxos, however on the Eunostos site it served to combine a big amount of information in forging a strategy, and it successfully overcame the absence of finer detail. Although both of the cases highlight how GIS is an essential utility in underwater archaeology, it is demonstrated that GIS can unite various types of data, conduct spatial analysis, and even visualize findings. This comparison between the two enables to understand the flexibility of geographic information systems in various cultural heritage settings and gives a useful contribution to the future construction of heritage monitoring systems. A summarized comparison of the two cases is presented in Table 1.

Table 1. Comparative analysis of GIS applications in Grotta Naxos and Eunostos

Comparison	Grotta Naxos(Greece)	Eunostos(Egypt)
Environment	Open sea area, few modern construction	Modern harbor area, military restrictions
Main technologies	USV, SSS (455/800 kHz), SBES	Klein 3000 SSS, single-beam sonar
Data sources	high-resolution sonar data	Historical maps, satellite imagery, sonar surveys
GIS Functions	2D/3D modeling, spatial distribution analysis	Multiple source data integration, strategic planning
Survey Area	0.09 km²	80 km²
Major Discoveries	6 architectural structures, 3 artificially arranged features	Breakwater structures, stone anchors, shipwrecks
Limitations	Limited optical imaging in shallow waters	Military factors

4 Discussion

The comparative study of the Geographic Information Systems (GIS) implementation in the Grotta Naxos and in the Eunostos can show a number of lessons concerning the role of technologies in managing under-water cultural heritage. This section will be addressing how GIS will be integrated with other technologies to deliver areas that each would not access with any of them, and the additional benefits of such integration to underwater cultural heritage research.

4.1 GIS as an Adaptive Platform

These two case studies show that the GIS is not a one-way tool but rather a flexible platform which functions may be tailored to particular research settings. The environment factors such as availability of high-resolution acoustic and optical data have made the GIS the major center of integrating the same data at the Grotta Naxos. The system can perform the quantitative 2-D/3-D reconstructions and elaborate space examination of archaeological features. Indicatively, the capacity to handle 0.01-meter-resolution-side-scan sonar(SSS) mosaics and 0.874-millimeter-per-pixel-accuracy orthophoto mosaics through the GIS to demonstrate the capabilities of the platform in the achievement of accurate documentation of archeological documents.

4.2 The Synergy of Multiple Sensor Integration

The example of the Grotta Naxos shows how synergy of several sensor integration can be achieved through the combination of GIS structure. Three tools were employed in the study on one USV to image a wide area, side-scan sonar (SSS), to detect depth data, and a camera to capture an image, single-beam echo sounder (SBES). The data gathered by each sensor was of different nature and when they were pooled together in GIS they gave the site a full picture that was not possible to produce with individual tools.

This interplay is especially notable in the process of differentiating the artificial and the natural landscapes. The rocky bottom of the area chosen resembled the sonar picture of some ancient ruins. Thus it made the researcher harder to be spotted correctly. But through the intervention of visual data into GIS, the researcher was in a position to directly compare sonar returns with the real pictures, ensuring that only features that were actually archaeological were confirmed. Through this incorporation, scientists were in a position to locate six ancient buildings or structures as well as three artificially positioned stone entities. This demonstrates that, multiple sensor integration cannot be additive only- they deliver superior meaningful interpretations. Yet, numerous problems remain standing in the way of the researches and they include the question of whether the research is worth the high technologies to install such enormous equipment, the location of large facilities and whether it is straightforward to apply high-technologies in various regions or not.

5 Conclusions

This study has systematically examined both the principal challenges in Underwater Cultural Heritage research and the effective application of GIS as a platform. The analysis confirms that UCH faces significant threats from environmental factors such as the rise of sea level and the rate of coastal erosion, as well as human activities including coastal development and unregulated salvage, and technical limitations in data acquisition and processing. In this study, professional comparative analysis of Grotta Naxos and Eunostos case studies is used to indicate that GIS is an adaptive platform, GIS can solve these problems by incorporating into its discussions various source data, ranging between high resolution sonar surveys to historical maps, which can prove useful in identifying sites, environmental monitoring, and risks.

Looking forward to the integration of emerging technologies. As an example, the artificial intelligence, big data analysis, and high-quality 3D modeling, they are capable of increasing the accuracy and intelligence of the UCH monitoring along with its predictability. Besides, interdisciplinary cooperation and creation of shared digital archives are required to move the field of science forward and enhance the long term heritage management practice. The research paper does not only support the use of GIS as a tool that cannot be overlooked in underwater archaeology, but also offers a scalable framework in tackling the multifaceted problems confronting cultural heritage conservation in underwater settings.

References

1. Benjamin, D., Romanowska, I., Harris, K., Crabtree, S.: Combining Geographic Information Systems and Agent-Based Models in Archaeology: Part 2 of 3. Advances in Archaeological Practice 7(2), 185–193 (2019) https://doi.org/10.1017/aap.2019.5

2. Fortin, J., Meacham, S., Rissolo, D., Rosland, A., Dorshow, W.: Bridging Photogrammetry and GIS Through Workflow Automation: A Scalable Approach for Spatially-Linked 3D Data in Underwater Cultural Heritage. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. 48(M-9), 497–502 (2025) https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-497-2025
3. Frigerio, A.: The Underwater Cultural Heritage: a Comparative Analysis of International Perspectives, Laws and Methods of Management. (2013) https://doi.org/10.6092/IMTLUCCA/E-THESES/107
4. Hamouda, A. Z., El-Gendy, N. H., El-Gharabawy, S., Salah, M., Barakat, M. K.: Marine geophysical surveys and interpretations on the ancient Eunostos harbor Area, Mediterranean Coast, Egypt. Egyptian Journal of Petroleum 32(1), 47–55 (2023) https://doi.org/10.1016/j.ejpe.2023.01.003
5. Papageorgiou, M.: Underwater cultural heritage facing maritime spatial planning: Legislative and technical issues. Ocean & Coastal Management 165, 195–202 (2018) https://doi.org/10.1016/j.ocecoaman.2018.08.032
6. Poglajen, S., Poklar, M.: Underwater Mapping in Shallow Coastal Waters Using MBES and Photogrammetry: Applications in Archaeology and Marine Habitat Monitoring. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. 48(2/W10), 223–229 (2025) https://doi.org/10.5194/isprs-archives-XLVIII-2-W10-2025-223-2025
7. Ramachela, T., Bizos, A.: The Protection, Preservation and Repatriation of Marine and Underwater Cultural Heritage: Lessons and Opportunities for Africa. The Strategic Review for Southern Africa 47(1), 52–64 (2025) https://doi.org/10.35293/srsa.v47i1.6182
8. Siddique, I.: Machine learning empowered geographic information systems: Advancing Spatial analysis and decision making. World Journal of Advanced Research and Reviews (2024) https://doi.org/10.30574/wjarr.2024.22.1.1200
9. Merkouris, K., Geraga, M., Dimas, X., Vlachopoulos, A., Papatheodorou, G.: Marine geoarchaeological mapping using Unmanned Surface Vehicle (USV): Case study of the ancient semi-submerged settlement of Grotta, Naxos, Greece. Journal of Archaeological Science Reports 66, 105274 (2025) https://doi.org/10.1016/j.jasrep.2025.105274
10. Ivanov, S., Belov, A., Belova, G., Laemmel, S.: Russian underwater archaeological mission to Alexandria. General report (2003–2015). (2019) https://doi.org/10.24411/2686-9276-2019-00005