

Geophysical techniques for non-intrusive documentation of UCH: Comparative analysis of the methodology developed in three study areas in Spain.

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ABSTRACT

Generally, the combined use of different geophysical instruments and archaeological fieldwork provides enough information for the classification and preliminary study of sites. However, the application of these techniques in detailed analysis of specific archaeological sites is still in its early stages. In this paper, we present the results of the geophysical survey work carried out in three different underwater contexts, as part of three research projects, in three areas of Spain: Algeciras (Cádiz), Cartagena (Murcia) and Palma de Mallorca (Balearic Islands).

Geophysical survey allows for the application of non-intrusive techniques to achieve the documentation of UCH, as recommended by the 2001 UNESCO *Convention on the Protection of the Underwater Heritage*, without altering the archaeological material in any way. Therefore, we have used the Sub Bottom Profiler in several archaeological works, with varying depths and conservation conditions, to address our research questions of how much information can we obtain non-intrusively on the UCH and how can we best use the equipment to innovate in the development of non-intrusive methodology. Based on the results obtained in each area, we can draw several methodological conclusions that lay the groundwork for a method that can be applied to other case studies.

Keywords: non-intrusive techniques, geophysical survey, Sub Bottom Profiler, monitoring UCH.

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1. INTRODUCTION

We present an innovative and non-intrusive method of monitoring and documenting Underwater Cultural Heritage (UCH), in which we have taken advantage of the opportunities offered by the development of new technologies. We analyse the methodology implemented in three case studies, in which we have surveyed the UCH in different areas using a Sub Bottom Profiler (SBP). This is an equipment that emits acoustic pulses that penetrate the sediment, resulting in the image of a stratigraphic profile of the seabed and the artefacts or anomalies that may be buried beneath it. In this way, without disturbing the seabed, we can see what is buried, what is anomalous and how deep it is. This research has been the result of a collaborative effort of the University of Cádiz (Spain), through three different projects, with the universities of Murcia, Cartagena, Barcelona, Balearic Islands and the Consell de Mallorca.

2. CASE STUDIES

This methodological study took into consideration three case studies (see figure 1), each with different characteristics related to the archaeological heritage to be studied and the geological conditions of the environment in which it is located. Furthermore, although the research goals of each project were distinct, they all shared the methodological questions that we aim to address in this paper.

2.1. HERAKLES Project (Algeciras, Cádiz)

As a pioneering project for this research, the HERAKLES Project (FEDER-UCA18-107327)⁷ was the first scenario to test the SBP techniques. We undertook the geophysical survey in a specific zone of the Bay of Algeciras: the harbour area (see figure 1.1). As the main objectives of the HERAKLES project were to document the UCH of Algeciras Bay and to assess the impact of port and industrial constructions on it, the goals of this survey were two:

1. To determine the existence of anomalies buried under the sediment.
2. To understand the stratigraphy of the area and how successive dredging and harbour works have modified the natural sedimentation processes.

2.2. ALADROQUE Project (Cartagena, Murcia)

The second scenario was the harbour area of Cartagena, which differed significantly from the previous case study. The zone of intervention covers the mouth of the Benipila Rambla (stream) and the Algameca Chica, up to a depth of approximately -50 m, an area of detrital and rocky seabed with plenty of archaeological materials (see figure 1.2). The ALADROQUE project⁸ arises after the high impact weather event known as cold drop (Depresión aislada en niveles altos – DANA) that affected the Region of Murcia in September 2019. One of the most serious consequences of this episode was the overflowing of the streams, such as the Benipila, causing a large amount of sediment and rubbish to be dragged into the sea. Thus, the ALADROQUE project aimed to assess the impact of this event on the seabed and on the UCH. The objectives of the geophysical survey were therefore two:

1. To identify possible anomalies that might correspond either to UCH or to objects dragged by the floods.
2. To evaluate the rate of sedimentation caused by floods and sea currents by monitoring the burial process in two known archaeological sites.

2.3. ARQUEOMALLORNAUTA Project (Palma de Mallorca, Balearic Islands)

The third case study involved the Ses Fontanelles shipwreck (Munar et al., 2022; Soler et al. 2021), located in shallow waters, with sandy seabed, offering ideal conditions for studying its state of preservation and the probable dispersion of its materials. The ARQUEOMALLORNAUTA project⁹ aimed to document and excavate this unique Late Roman shipwreck, and a geophysical survey was conducted as a preliminary activity before archaeological fieldwork (see figure 1.3). Therefore, our objectives were threefold:

1. To obtain a three-dimensional visualization of the shipwreck that would allow the evaluation of its state of preservation.

⁷ “Entre las Columnas de Hércules, Arqueología Subacuática de un espacio privilegiado. La bahía de Algeciras” (FEDER-UCA18-107327 HERAKLES)

⁸ “ALADROQUE: El impacto de los eventos climáticos tipo DANA en la conservación de los entornos subacuáticos de los accesos al puerto de Cartagena (España)”, an initiative of the Cartagena Oceanographic Research Institute (CORI), in collaboration with the University of Murcia (UM), the University of Cadiz (UCA) and the Navy Diving Centre (CBA),

⁹ Joint project of the Consell de Mallorca and the universities of Barcelona, the Balearic Islands and Cádiz.

2. To provide stratigraphic details especially about the characteristics of marine sedimentary levels.
3. To detect the existence of anomalies that can be analysed in the interpretation phase of the results of the archaeological fieldwork.

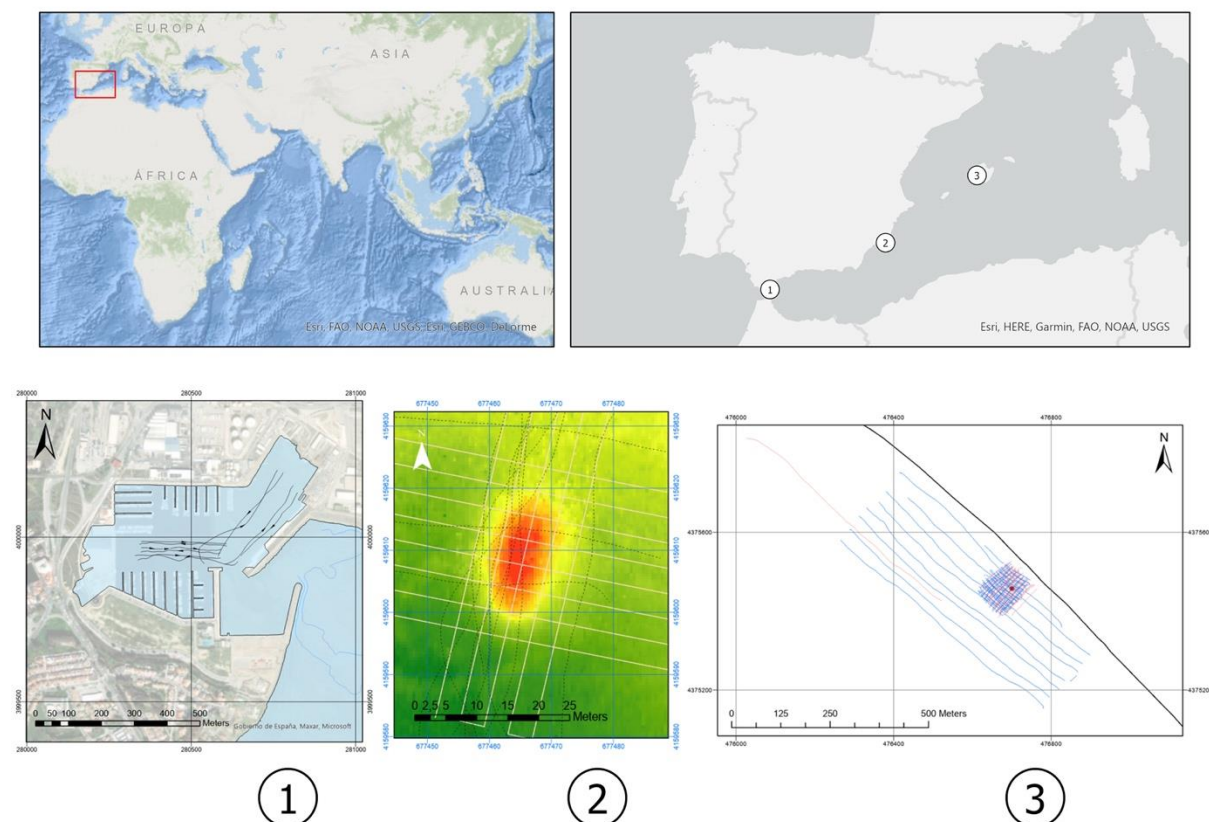


Figure 1 – Location of the case studies and surveyed areas: 1. Bay of Algeciras; 2. Harbour of Cartagena; 3. Palma de Mallorca.

3. RESOURCES

The resources available to conduct the work include the equipment used (see figure 2), property of the Laboratory of Archaeology and Prehistory (LABAP) of the University of Cádiz (UCA), consists of:

- Sub Bottom Profiler (SBP) model SES-2000 standard, manufactured by the German company INNOMAR. It is parametric in nature, which allows a high resolution in the detection of strata and layers of sediments. The signal penetrates, on average, twice the depth at which it probes.
- Motion correction sensor (MRU) to correct and improve precision of the spatial location of the signal.
- Mobile RTK GNSS Leica GS18 Antenna, which ensures the positioning of the data readings with a millimetre error margin.

Besides, different boats were used in each case study. For the survey in Algeciras, we used the *Tarpán*, a fiberglass rigid boat with inboard motor, and a draft of 0.5 m. Secondly, in Cartagena we had two fiberglass vessels from the University of Murcia, the *Betsaida*, with 0.3 m draught, and the *Universitas*, with 0.6 m draught. In the third case study, a semi-rigid inflatable boat with an outboard motor was used, with a draft of 0.4 m, named *Mustelus*. A very important variable for the reliability of the results in geophysical surveying with SBP is the expertise of the boat captain. In the three case studies, they

were very skilled, showing great ability, not only in handling each boat, but also in understanding what the team needed.

Regarding the human team, the works were performed by two archaeologists from the University of Cádiz, trained in the use of geophysical techniques thanks to the activities coordinated by the Nautical and Underwater Archaeology Line.



Figure 2 – Equipment used on board the vessel for fieldwork.

4. FRAMEWORK

Given the three case studies presented, the methodological inquiries of this research aim to determine the limitations of the SBP technique. Furthermore, we have identified various types of anomalies in all three geophysical surveys, which have been subsequently cross-checked with other techniques such as historical information, magnetic anomalies, test pits, and visual surveys. This has allowed us to create a comprehensive catalogue of anomalies that can be utilized in future SBP surveys (Cerezo Andreo *et al*, 2022; Higuera-Milena and Cerezo Andreo, 2021).

Following the principles established by UNESCO in the 2001 Convention (Maarleveld, Guérin and Egger, 2013; VVAA., 2010), surveying with SBP allows prioritising *in situ* conservation of UCH, exploration over recovery and non-destructive techniques.

The precision of the transects over the area to be studied is fundamental for the interpretation of the data, so once the working areas have been defined, the density level of each survey grid must be planned, considering the objectives proposed for each survey.

In the framework of the HERAKLES project, given the large extension of the Bay of Algeciras, we have focused on understanding the general stratigraphy and the degree of preservation of original sediments in “El Saladillo”, one of the ancient harbour spaces.

Before conducting the survey in the port of Cartagena, we had access to valuable information that aided in our planning process. Specifically, we were aware of certain anomalies that had been detected during a previous survey conducted in 2008 by the National Museum of Underwater Archaeology (ARQVA). During our SBP surveys, undertaken in 2021 and 2022, we detected new anomalies and checked the levels of burying or unearthing in sites. Some of the anomalies were documented by diving or using a ROV. We also verified their archaeological potential and established a protocol for the periodic monitoring of their state of preservation.

For the ARQUEOMALLORNAUTA project, two work areas were surveyed: the one where the Ses Fontanelles shipwreck is preserved and a larger one to document its general sedimentation dynamics and to detect anomalies that could be related to the site. The seabed in the study area is generally sandy but with a strong muddy matrix that allowed the signal to penetrate several metres below, reaching - 5.5 m in some profiles. The Ses Fontanelles shipwreck was protected by sandbags, resulting in a 2.5 m deep tumulus. That makes the water column between the transducer and the shipwreck very small.

After the data analysis and processing (see figure 3), we obtained a series of anomalies that we classified according to their archaeological interest and their accessibility. Subsequently, a fieldwork season to check the most significant anomalies was planned.

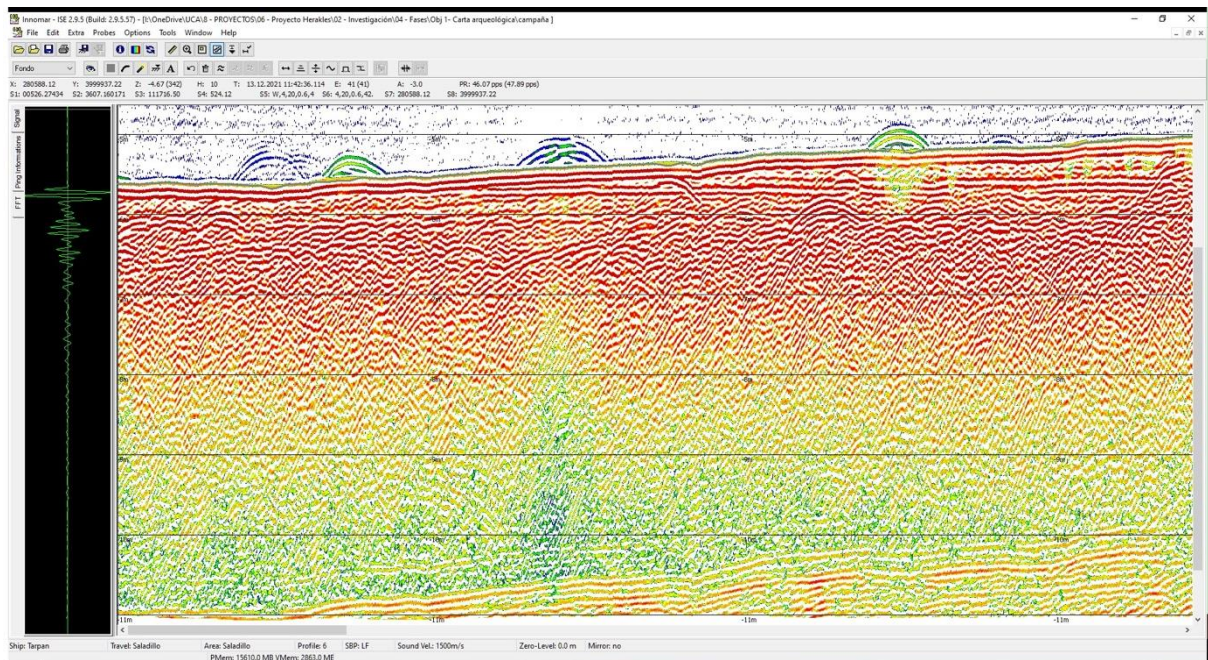


Figure 3 – Signal processing example using ISE 2.9 INNOMAR software.

5. RESULTS

5.1. HERAKLES Project (Algeciras, Cádiz)

On the El Saladillo research area we have successfully identified the paleochannel from the Last Glacial Maximum period (see figure 4.A). This unknown geological feature was not easily silted by sediments, so it kept its depth for a long time, which explains why this area was used as an anchorage throughout history.

Our surveys led to notable discoveries, including the identification of the basement levels of Isla Verde Island. This now-destroyed island was once one of the main landmarks on the maritime landscape in the ancient Bay and provided a reliable source of fresh water.

5.2. ALADROQUE Project (Cartagena, Murcia)

The intensive use of the SBP in the port of Cartagena has yielded high-resolution stratigraphic profiles, enabling the documentation of the impact of the flooding caused by the 2019 DANA. The resulting data about the impact of the flood on the UCH holds potential for advancing monitoring and conservation efforts. In addition, we have assessed the burial or erosion factor that some archaeological sites are suffering, especially the Cartagena 1 shipwreck, located at 63 m depth, one of the best-preserved shipwrecks from the 2nd century BC in the Iberian Mediterranean. Cross-checking data between 2008-2021-2022, we have been able to verify that the shipwreck has been unearthed between 70 and 80 cm. The cargo is now scattered over a space twice the size it was in 2008, which means that the tumulus is falling apart (see figure 4.B). On the contrary, there are areas that have been significantly buried, hiding known elements since the 2008 surveys. This process is partly positive because burial offers good guarantees for the conservation of the heritage, but also it makes access to it impossible.

Finally, dives to verify the selected anomalies have revealed the presence of rubbish and other debris which are altering the structural integrity of some objects.

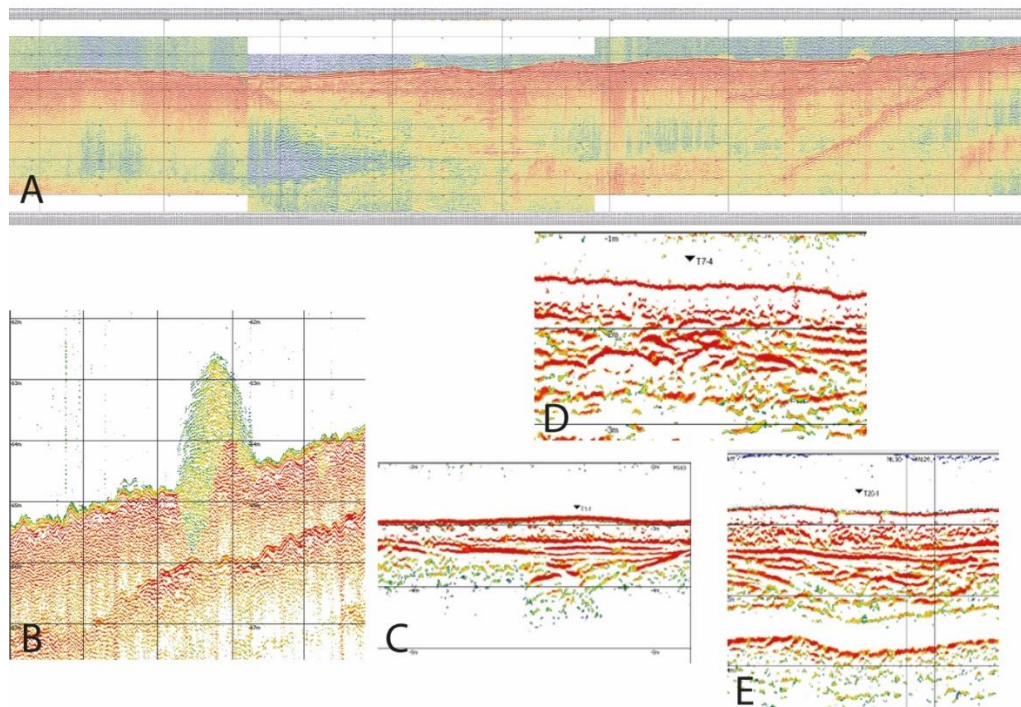


Figure 4 – Types of anomalies recorded. A) Paleochannel with continental sedimentation; B) Shipwreck C) Pipeline D) Buried object (in this case an amphora) E) Natural anomaly corresponding to the bottom of a paleochannel.

5.3. ARQUEOMALLORNAUTA Project (Palma de Mallorca, Balearic Islands)

The results have been very positive, as we have achieved a stratigraphic visualisation of both the Ses Fontanelles shipwreck and its surroundings. Among the 31 significant anomalies detected, those of special archaeological or stratigraphic interest were selected. Thus, we configured three categories of priority for intervention according to their accessibility: size, morphology, and depth below the seabed.

After the second processing of the signals and the comparative analysis of the anomalies, three of them were identified with paleochannels, one with the Ses Fontanelles shipwreck, five provided relevant information on the stratigraphy and six were considered to be a pipeline (see figure 4.C). Therefore, we made eight archaeological test pits to verify this interpretation. Only one test pit was positive as far as the presence of archaeological material was concerned, finding a fragment of ancient pottery. The artefact was found under a layer of shells and coarse gravel, covered by another layer of dead seagrass.

The hyperboles shown by the acoustic signal corresponded to points where the archaeological material was buried (see figure 4.D).

The anomalies of natural origin correspond to a layer of rubble, coarse gravel, and pebble rocks that we consider to be the seabed of a paleochannel, with continental sedimentation phases (see figure 4.E). This provides interesting information about the palaeolandscape in the pre-Holocene period.

With respect to the anomaly identified as the Ses Fontanelles shipwreck, collected in 53 stratigraphic profiles, we could document the different levels that comprised the shipwreck's protective tumulus.

5.4. Conclusions

The results achieved in the three case studies demonstrate that the use of the SBP has been proven effective for UCH surveying, providing high-resolution stratigraphic profiles and detailed information on the morphology of the seafloor and any anomalies present. Overall, the use of the SBP is a useful tool in the field of UCH research, allowing for non-intrusive and precise surveying of underwater archaeological sites.

To conclude, here are some generalities regarding the use of the SBP for the UCH surveying, although each site and its characteristics, the equipment used and the objectives of each research will determine the configuration and final results.

- Regarding the type of seabed, the signal penetrates better in mud than in sand, where there is usually more noise.
- The boat used for the survey should be small, to ensure manoeuvrability, but stable and with rigid gunwale, as vertical as possible to the water surface. The most important thing is to prevent engine vibrations from being transmitted to the SBP.
- The recommended speed for conducting SBP surveys is typically less than 4 knots. We have achieved optimal results at speeds between 2 and 2.5 knots. It should be noted that slower survey speeds can result in longer survey durations and increased vulnerability to wave interference, ship vibration, and reduced ability to correct heading.
- It is important to note that obtaining accurate and reliable results with the SBP is highly dependent on the sea state. It has been observed that waves exceeding 30-40 cm significantly impact the quality of the data collected, rendering them unreliable.
- In theory, the penetration distance of the SBP signal is twice the water column below the transducer. Nevertheless, at greater depths, the number of pulses emitted must be increased due to the prolonged time it takes for the signal to return. From our experience, optimal results are obtained at depths ranging between 10 to 20 meters.
- Regarding frequency, increasing it will yield higher resolution, but at the expense of losing penetration depth. Conversely, lowering the frequency will increase penetration depth, but reduce resolution. Finding the optimal frequency setting requires thorough testing and experimentation on a case-by-case basis.
- As for the research objectives, this technique is highly recommended for anomaly detection or for monitoring known sites. It is very useful for surveying UCH at different times and for analysing, by comparing the signals, the rate of sedimentation. It is also very useful for the study of the paleolandscape or to check the impact of dredging on the seabed, but for stratigraphic studies it must be combined with geotechnical cores (Torres et al, 2022).

In the future we have planned more surveys to test this methodology in new and different case studies, therefore we will add more conclusions to this research. A methodology based on the results obtained here will undoubtedly contribute not only to a better knowledge of the UCH, but also to a greater awareness and impact of the research at the international level.

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