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Study of the influence of physical, chemical and biological conditions that influence the deterioration and protection of Underwater Cultural Heritage

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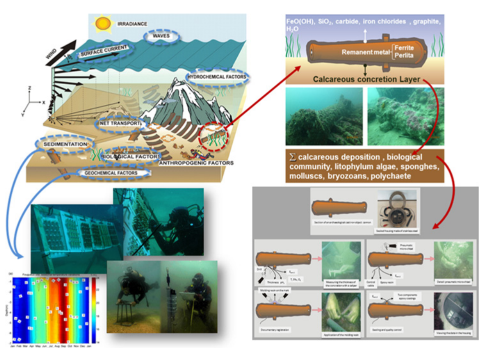
HIGHLIGHTS

- A multidisciplinary approach is necessary to understand how the main marine environmental variables can influence the formation, conservation or degradation of Underwater Cultural Heritage.
- Following the guidelines of the UNESCO 2001 Convention, a holistic and interdisciplinary approach based on the development of four of its thirty-six Rules Rules was applied.
- After monitoring these variables, we have established correlations between the environmental conditions and the degradation suffered by archaeological artifacts.
- A non-destructive technique was developed to obtain information from marine archaeological iron artefacts in historical shipwrecks.
- The effectiveness of cathodic protection as a temporary measure for *in situ* conservation was evaluated.

GRAPHICAL ABSTRACT



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ABSTRACT

Two wrecks related to the Battle of Trafalgar (1805) were studied. Following the guidelines of the UNESCO-2001 Convention for the Protection of the Underwater Cultural Heritage, a holistic and interdisciplinary approach based on the development of four of the thirty-six Rules of this international agreement was applied. A non-destructive survey technique was developed to obtain information from the scattered cannons and anchors without altering their condition (Rule 4). The work performed provided information about the origin of both wrecks, the *Fougueux* and the *Bucentaure*, two ships of the line of the French Navy, and allowed to characterize the state of

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conservation at each site without jeopardizing their future conservation in the marine environment. In addition, measurements of the main physical, chemical and biological variables allowed correlating the conservation status at each site with the marine environmental conditions (Rule 15). Thus, in *Fougueux* shipwreck large iron objects are corroding at a higher rate (between 0.180 and 0.246 mmpy) due to high sediment remobilization and transport induced by waves at this site, causing damage by direct mechanical effect on metallic material and by removing the layer of corrosion products developed on the artefacts. Meanwhile artillery on *Bucentaure* site, covered with thick layers of biological concretion, is well preserved, with lower corrosion rates (0.073 to 0.126 mmpy), and archaeological information is guaranteed. Finally, the effectiveness of the cathodic protection as a temporary measure for *in situ* conservation (Rule 1) was evaluated on a cannon. The use of a sacrificial anode after 9 months reduced the average corrosion rate (from 0.103 to 0.064 mmpy) and the percent of corrosion rate in 37.9%. These results are very useful for developing a decision making system of the Site Management Program, based on predictive models of artefacts permanence and risk factors in the marine environment (Rule 25).

1. Introduction

The increasing rate of discoveries of shipwrecks and other submerged structures poses the challenge of developing alternative methods of storage and stabilization of these archaeological findings. But the problem that arises is threefold: firstly, the initial storage, stabilization and conservation of these findings are very expensive; secondly, full and proper conservation depends largely on the availability of human and material resources; thirdly, it is not always convenient or necessary to excavate an underwater archaeological site, since a part of cultural resources can be managed and stabilized *in situ* (Bergstrand and Godfrey, 2007). The excavation is a destructive and expensive process and therefore should be chosen as the final solution only when objects or obtained information are unique or at risk of disappearing. This *in situ conservation* approach has been endorsed in Rule 1 of the Guidelines to the Annex of the UNESCO 2001 Convention for the Protection of the Underwater Cultural Heritage (UCH) (UNESCO, n.d.), which considers the protection of UCH through *in situ* preservation as the first option.

The *in situ* conservation involves several scientific areas such as materials science, marine chemistry, physical oceanography and meteorology, marine biology, archaeology and conservation. This plurality implies an added difficulty to consolidate research groups working on different problems related to the study and conservation of UCH. However, there are international groups that have made contributions from any of these fields. Some of these groups have been temporally associated in multidisciplinary projects, performing the most recent and relevant contributions in the treated subject.

So, between 2001 and 2004, The MoSS Project (Monitoring, Safeguarding and Visualizing North-European Shipwreck Sites) (MoSS Project, 2004), brought together the efforts of research groups from six European countries. In this project, for the first time, a scientific methodology was applied to the study of the environmental variables in four underwater archaeological sites. The important outcomes of such enormous effort have been published on a website and in several research papers highlighting the problems of working with four wrecks located in marine and inland waters of very different types and temporality: the wreck of Darss Cog (between 1277 and 1293) in the German Baltic, the flotsam Burgzand Noord-10 (1553) in waters near Amsterdam, the merchant Vrouw Maria (1771) on the Finnish Baltic, and the steam E. Nordevall (1856) in the Swedish lake Vättern.

It is remarkable also the work carried out between 2002 and 2005 within the RAAR Project (Reburial and Analyses of Archaeological Remains) (RAAR Project, 2005) whose main objective was to assess the re-burial as an alternative method for long-term storage and preservation of underwater archaeological objects. The researchers involved in this project covered wider areas of knowledge than in MoSS. Studies with modern and archaeological materials were carried out in the port location of Marstrand, north of Sweden, taking advantage of the presence in the area of the remains of the frigate Fredricus (1719).

Similarly it is necessary to highlight the efforts made within the MACHU Project (Managing Cultural Heritage Underwater) (MACHU Project, 2009). It was a three-year project (2007–2009) with 7 partner countries, like MoSS sponsored by the Culture 2000 Program of the European Union. The main goal of the MACHU project was to find new and better ways for effective management of UCH and to improve the access to information for academic purposes, for policy makers and the public in general.

On the other hand, Rule 4 of the Guidelines states that activities should not affect a site more than necessary, and that the overarching aim is to preserve and protect a site as much and as best as possible. Furthermore, this Rule emphasizes the need to use non-destructive techniques and survey methods rather than traditional digging and the recovery of objects and samples.

Currently there are no standardized methods for conservation, in the marine environment, of materials according to their nature (organic, metal, silica, *etc.*), although there have been some experiences both in laboratory (Björdal and Nilsson, 1998) as in the archaeological site (Stewart et al., 1994; Pournou et al., 1998; Gregory, 1999). The two most widely used techniques for long-term conservation of underwater archaeological sites in its natural environment are the preservation *in situ* and burial or "reburial" (MoSS Project, 2004). By *in situ* conservation, the archaeological site or a portion thereof is protected in the marine environment such is located (Bergstrand and Godfrey, 2007). At the burial, the archaeological site is excavated in its location, to be later buried in the same or another environment, either in one piece or dismantled. Both methods mainly used marine sediments or burial material as cover. These in turn are coated by layers composed by sandbags, concrete, or plastic geotextile (Oxley, 1996). However, the results that show a reduction in degradation depending on the nature of these materials are inconclusive, and even warn about the danger of extend these methods to different materials since the analysis have been mainly conducted on wood materials (Palma, 2005; Curci, 2006; Björdal and Nilsson, 2008), leaving out many of the archaeological materials of different nature.

The burial of the deposits as a measure of preservation is also criticized on the basis that the different methods proposed have been assessed inadequately and during excessively short periods of time. As an example, some authors have shown that microbial degradation is also present in protected wood buried in the sediment (Kim et al., 1996; Riess and Daniel, 1997; Björdal et al., 2000), although this method avoids the impact of boring organisms such as bivalve molluscs of the *Teredinidae* family or isopods from genus *Limnoria*. These studies showed that archaeological woods from marine sediments might have bacterial soft rot, and especially erosion forming bacteria, which are the predominant degrading microorganisms in the anaerobic environment nearby sediments. Little is known, therefore, on the relationship between the processes of colonization and degradation rate in relation to the depth of burial or sediment used for this purpose.