MUSAS: an innovative project for the enhancement of the Underwater Cultural Heritage

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***Abstract*:** Substantial effort is required to effectively monitor Italy's underwater archaeological heritage, in order to protect and conserve submerged sites, and to enhance their importance and value. ISCR is therefore driving an innovative underwater heritage project. The MUSAS project started in 2017. Its aim is to develop an integrated supraregional model to monitor and enhance underwater archaeological heritage, in museums as well as *in situ*, in order to develop best practices that can be extended and deployed at other sites. It has three specific objectives:
1) The creation of a web-portal for the *Museo Virtuale dell'Archeologia Subacquea* where annotated images and 3D models will illustrate artefacts recovered from submerged sites and now housed in museums, and the underwater sites that are the focus of the project.
2) The implementation of an advanced exploration system at the submerged archaeological sites of Baia and Egnazia.
3) The development of a network of innovative sensors that can be deployed flexibly to monitor the environment, the condition of submerged sites and the location of divers.
A number of archaeologically significant locations in Southern Italy have been selected as test sites, in Campania, Puglia (Apulia) and Calabria. In this presentation we will give an update about the activities carried on in Egnazia (Puglia), Kaulonia (Calabria) and in the underwater park of Baiae, in the Gulf of Naples

Keywords: Underwater Cultural Heritage, *Baiae*, submerged sites, 3D reconstruction, virtual museum.

1. THE MUSAS PROJECT

The UNESCO 2001 Convention on the protection of the Underwater Cultural Heritage set new priorities in maritime archaeology, strongly emphasizing the importance of the *in situ* heritage protection and the need for new strategies for its enhancement; innovative projects are nowadays trying to develop shared guidelines and best practices to make easier and safer the enjoyment of cultural heritage in underwater environments, enlarging the public access and including, when it's possible, also people who cannot practice scuba-diving: a vast segment of public, hitherto excluded from the enjoyment of underwater heritage, or limited to a visit to the few dedicated museums or to the still very rare itineraries in coastal sites with transparent bottom boats.

The MUSAS Project (MUsei di Archeologia Subacquea. Tutela, valorizzazione e messa in rete del Patrimonio Archeologico Subacqueo [Campania, Calabria, Puglia]), with a funding of 3,250,000 euros within the PON "Culture and Development" programme, intends to promote the knowledge of the rich underwater archaeological heritage of Southern Italy through new technologies, favouring the fruition of underwater sites and finds, even remotely and in a virtual way, guaranteeing at the same time a constant monitoring.

For the ISCR – the Italian Institute for Conservation and Restoration, it is a new challenge in the field of marine archaeology, after the long experience of the NIAS, the Nucleus for Interventions in Underwater Archaeology established in Rome in 1997 and long directed by R. Petriaggi, that headed an exciting season of works on submerged sites, in Italy and, abroad, in Yemen, Oman, and Libya.

The MUSAS team, led by the current NIAS director, B. Davidde, creator of the project, has been carrying out since 2017 several underwater campaigns, in addition to the implementation of a big web portal (www.progettomusas.eu) and to the execution of a large 3D acquisition campaign, both in the selected sites and in the museums. One of the key-points of MUSAS, actually, is the creation of a Virtual Museum for the Underwater Archaeology, easily accessible by PC and mobile devices, in which the huge amount of data and images acquired in field missions will be shared; the users will be able, using their personal devices, or the *totems* installed in the Museums, to virtually dive in the sites, exploring the submerged ruins of *Baiae*, the port of *Egnatia*, the architectural remains on the seabed of *Kaulonia*; they will have access to accurate 3D models, but also to the reconstructions of spaces and environments in their original aspects; moreover, they will be able to explore a virtual gallery in which they will find the 3D models of a rich selection of underwater findings from the partner Museums: statues and altars, amphorae and anchors, freely scalable and rotatable in order to facilitate their analysis. The archaeologists will enrich the user experience, with detailed charts and explanations of the sites and artefacts, as well as with rich archives of materials for the needs of scholars and researchers. The biologists, on the other hand, will have the task of examining the colonization of ancient structures by marine organisms, in order to provide the tools for an updated assessment of the degradation and for a planning of conservation interventions. Lastly, the aspect of environmental monitoring will be considered with the deployment in the selected sites of a network of submarine sensors, functional to the verification of different parameters, but also to the location of divers: an innovative system that will make possible diving tours with the use of tablets perfectly operating and communicating, online, even underwater.

2. THE SELECTED SITES

2.1. Baiae

Baiae, the luxury thermal Roman resort condemned to submersion by the Phlegraean bradyseism, is a very evocative place for the Italian underwater archaeology: it was the theatre of the first underwater explorations in a submerged structure by N. Lamboglia, just after the pioneering campaigns of Albenga, and quickly became a site of excellence for the experimentation of new excavation strategies, documentation, protection and enhancement of the underwater cultural heritage.

The MUSAS project is operating in two different sites within the complex of the ancient *Baiae*. The first one is the magnificent *nymphaeum/triclinium* decorated with sculptures that was part of the palace of the Emperor Claudius (ZEVI 1983), and which today lies underwater not far from the tufaceous promontory of *Punta dell'Epitaffio* (fig. 1). The archaeologists are at work to document and register the state of conservation of the walls and of the sumptuous coverings, but also to better understand the architectural characteristics of the monument, that was repeatedly subject to works and rearrangements during its long history before the submersion; the detailed 3D

survey of the entire site has already been completed during the first season of the project, and will soon be available on the dedicated portal together with the 3D interpretative reconstruction of its features at the time of Claudius.

Fig. 1: The *Nymphaeum* at Punta dell'Epitaffio, in *Baiae*

The second site in *Baiae* selected for the MUSAS Project is the gigantic *Villa dei Pisoni* (fig. 2) (DI FRAIA, LOMBARDO, SCOGNAMIGLIO 1988, DI FRAIA 1993, LOMBARDO 1993, SCOGNAMIGLIO 1997) and 2002, whose *viridarium* surrounded by a portico marked by niches and half-columns is today one of the favourite destinations for a large number of divers. The villa, which takes its name from the *Calpurnii Pisones*, who were responsible of a conspiracy against Nero and related to the owners of the magnificent *Villa dei Papiri* in Herculaneum, extends over a large area close to the *lacus Baianus*, the ancient port basin today entirely submerged but once surrounded by piers and arches, *villae maritimae* and palaces. In this case too, the archaeological study and the realization of 3D reliefs will allow to offer to the public the use of a complex and stratified site, and to the archaeologists the tools for a new understanding of the articulation of the villa and of its various construction phases.

During the underwater researches, the work of 3D acquisition of a rich selection of artefacts from the Archaeological Museum of the Phlegraean Fields has already been completed: over sixty models, mostly sculptures, discovered in the Gulf of Pozzuoli and rich of stories and connections with the intense life that was led *in amoenis Baiis*, between the villas of the most important figures of republican Rome and the sumptuous palaces of the emperors, from the Julio-Claudian dynasty onwards.

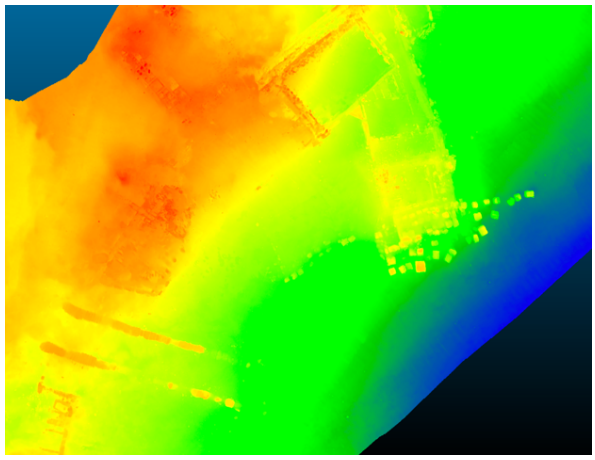

Fig. 2: MBES of the *Villa dei Pisoni*, in *Baiae*

2.2. Egnatia

Before the acropolis of Egnatia, towards the sea, there are important evidence, including rectangular carvings into the rock attributable to burials and underwater remains interpretable as a roman harbor. The first scientific investigation of the Roman port, especially with aerial photos and echosounder, are due to S. Diceglie (1972, 1981, pl. II, 2002). An analysis is also present in Vlora (1975, pp. 56-61, figs. 35-39). Diving and surveys were carried out in 1979 and 1994 by A. Freschi, (FRESCHI, ALLOA 1979-80, pp. 60-65 and p. 134; FRESCHI 1980, pp. 450-455, and 1995, pp. 141-143). A picture of what it was known in the early 1980s is due to Andreassi, Sciarra-Bardaro (1982, pp. 107-118). More recently R. Auriemma (2003, pp. 77-97 and 2004, pp. 15-16) has definitively established the type and the construction techniques.

The northern part of the port has preserved optimally two huge *pilae* (a type of structure that was widespread in the Phlegraean area: GIANFROTTA 1996, p. 71) distant three meters from each other. This work in concrete piers, thrown into water within watertight formwork according to the Vitruvian canonical directions, possessed originally a wall facing in *opus reticulatum* and corners in *opus vittatum*, visible today in the exposed part only in negative.

Along the ideal line of this north side there are also some elements of collapsed *pilae*, always constructed in *opus caementicium* with traces of *cubilia* on the cement mortar.

Compared to these remains, the southern part, probably a pier, is more recognizable. It is a construction made of *opus caementicium* with several superimposed levels, the base of which rests directly on the rock (Auriemma 2003, pp. 81-85).

A series of comparisons suggests a building date for these structures between the end of the Republican and beginning of the Imperial ages. Some experts do not rule out that the construction of the port of Egnazia should be attributed to *M. Agrippa*, *patronus* of the *municipium*, as attested by an inscription, now lost, whose *terminus ante quem* is 38 BC (CIL IX, 262 = EDR026582). All this is framed, in fact, with the strategic position of *Salento* coast as part of the war between *Octavianus* and *Antonius* and the role of *Agrippa*, commander of Octavian's fleet.

Thanks to the MUSAS project a series of discussions could be carried on the Roman port, both at the level of archaeological and historical research. Firstly, following an analysis of the submerged structures with specific SAMAS card (analytical record card for submerged archaeological artifacts, see Petriaggi, Davidde 2005), has been chosen one of the northern side *pilae* to be able to carry out an investigation of the foundation which has allowed to reveal, concealed from the sand, a few rows of *opus reticulatum* perfectly preserved. The excavation yielded ceramic fragments relevant to types and different chronologies, documenting the intense life of the harbor (fig. 3).

Fig. 3: The underwater cleaning of a *pila* in *Egnatia*

Historical research on the port is also directed to the post-classical sources, often bearers of fundamental information. An examination of medieval nautical maps revealed that Egnazia, cited as *Annaso, Anazzo* or *Adanazzo*, often appears near Brindisi as a minor port place since at least the fourteenth century. In fact, in the middle age the ancient city was not completely abandoned: in the acropolis it was built a Byzantine fortress and, later, a fortified town with a tower (CAMPESE, CAGGESE, CUCCOVILLO 2012; CASSANO, CAMPESE, CUCCOVILLO 2015) and it's possible that the old port retained, in some circumstances, a certain functionality.
The archaeological activity was not, of course, just diving. The MUSAS project includes scientific cataloging of finds from the sea of the affected areas. They have been so identified, at the National Archaeological Museum of Egnazia, a number of objects, some of which are of the greatest interest, which have been subjected to 3D relief for exposure within the Virtual Museum.

2.3. Kaulonia

The ancient Achaean colony of *Kaulonìa* (Kaulon) was partly identified with modern town of Monasterace, on the Calabrian Ionian coast between the provinces of Reggio and Catanzaro (Orsi 1891 and 1916). The whole stretch of coast in front of it, from a geomorphological point of view, is changing a lot, due to heavy subsidence and eustatic phenomena that generate an unstable tectonic (GUERRICCHIO 1987, pp. 44-47; D'ARRIGO 1959, p. 60). These have led, over the centuries, to the disappearance of important underwater archaeological evidences related to the Greek colony, identified thanks to thirty years of underwater surveys by the team of Kodros, coordinated by S. Mariottini. Among the Doric temple and the Assi river were found more than 200 stone construction elements with various functions, some of which are clearly not finished (fig. 4). The discovery in the area of two limestone mooring bollards has permitted to hypothesize the presence of a workshop specialized in the processing of building material, presumably located near of a port channel now disappeared (IANNELLI et al. 1993[a]; IANNELLI 1993[b].). According to ancient sources in this area was located the famous *Cocinto* promontory, which *Plinius* the Elder defines as very pronounced (N. h. III, 95): *«Cocynthum, quod esse longissimum ltaliae promunturium aliqui existimant»*. This evidence is now less noticeable precisely because of geological phenomena above described.

Fig. 4: Underwater architectural remains in *Kaulonia*

Underwater it was also found important evidence of more recent times, such as four cast iron cannons dating from the seventeenth century. They may be related to the important phenomenon of Barbaresque ships privateering or to productions of the nearby Stilo furnaces.
The MUSAS project, in addition to detect in three dimensions the underwater artifacts, is handling the cataloging and 3D modeling of many objects recovered from the sea in front of the Greek city and now preserved in the nearby Archaeological Museum of Ancient Kaulon. Among them, many relevant elements of nautical archeology, as anchors of various ages and components of board equipment.

2.4. Kroton

The jagged coastline of Crotone is historically favorable to navigation. Especially Capo Colonna, the old *Lacinium promunturium* (*Strabo, VI, 1:11*), had a considerable importance for the ancient sailors and is quoted by different sources, especially for the presence of the sanctuary dedicated to Hera Lacinia (*Plut. Pomp., XXIV, 6,* describing it as one of the *asyla* of universal fame*; Liv. XXIV, 3. 3*: *sanctum omnibus circa populis*).
The city of Crotone, an Achaean foundation, was a busy port at different times (Severino, 1988).
Despite its fame as fundamental points for sailors, however, the sea in this area is not easy navigable: the coast is characterized by the widespread presence of rocky outcrops, which often have returned evidence of shipwrecks of different times, with a concentration hard to find in other traits of Italian sea (Medaglia 2008, 2010).
Because of these features, the MUSAS project focused primarily on the cataloging and on the 3D survey of the underwater archaeological finds preserved at the National Archaeological Museum of Crotone and those presented in the National Archaeological Museum of Capo Colonna. It was also decided to document, on a preliminary basis, a little-known wreck identified in 2007 in Capo Bianco and characterized by the presence of cast iron cannons (fig. 5).

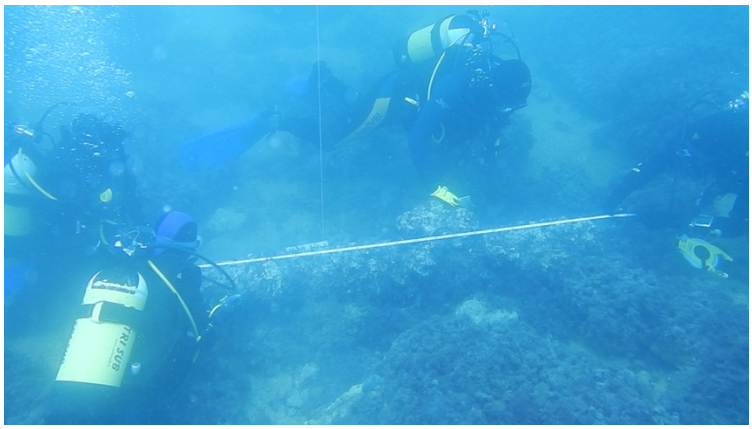

Fig. 5: Underwater documentation of a cannon in Capo Bianco

3. THE TECHNOLOGIES

The activities of the MUSAS project provide advanced operations for documentation and exploitation of submerged archaeological sites and will remain stored up in the various participating museums, with 3D underwater reliefs usable with VR visors and 3D digitization of artefacts. The ISCR has selected the company 3D Research srl, a spin-off of the Department of Engineering Mechanics, Energy and Management (DIMEG) of the University of Calabria, specialized in this type of activities. The 3D surveys use high-resolution data obtained from photogrammetric techniques and the latest acoustic technologies for generating micro-batimetric

maps, in order to obtain a three-dimensional representation of the underwater scene that combines the resolution of the optical sensors with the accuracy of the acoustic type techniques for bathymetric surveys. The methodology allows to have a complete representation of the submerged archaeological site where the artifacts and structures of archaeological interest are accurately georeferenced (BRUNO et al. 2016[a]; BRUNO et al. 2016[b]; LAGUDI, BIANCO, MUZZUPAPPA, BRUNO 2016).

The Sonar Multibeam (MBES), usually used for the generation of bathymetric maps in archaeological contexts, allow to scan large amounts of data over long distances and with low visibility too, but the results are influenced by a low resolution and lack of color information. The optical systems, in contrast, are more suitable for short-range acquisitions and allow to obtain high-resolution 3D data, accurate and textured, but the final product is affected by the underwater visibility. Therefore, the integration of 3D data acquired from these two types of systems turns out to be an excellent technique in underwater applications, since it allows to reconstruct extended and complex scenes in a relatively short time. One of the techniques used for georeferencing provides the positioning, inside the archaeological site, of special optical-acoustic markers, specially made, through which it is possible to unambiguously assign precise spatial coordinates to certain points of interest (position of objects, perimeter of the archaeological site, etc.) according to a local or global reference system.

Downstream of the acquisition process, the optical-acoustic dataset is processed using the most modern techniques, both photogrammetric that computer vision, in order to generate the optical-acoustic georeferenced 3D model of the investigated archaeological site. Independently from the particular technical and technological solution adopted in each stage of the process described, the idea at the basis of the methodology developed for the generation of 3D models of multi-resolution underwater archaeological sites, consists in obtaining a low-resolution polygonal mesh (in the order of tens of centimeters) from the general acoustic bathymetry of the underwater site and surrounding areas, which will be superimposed HD models (at sub-centimeter resolution) of the areas of greatest interest of the underwater site, through a merger that makes imperceptible to user the junction between the two models. The generated 3D model will be finally texturized through HD textures obtained by processing images acquired during the optical survey and appropriately mapped on the model itself (fig. 6).

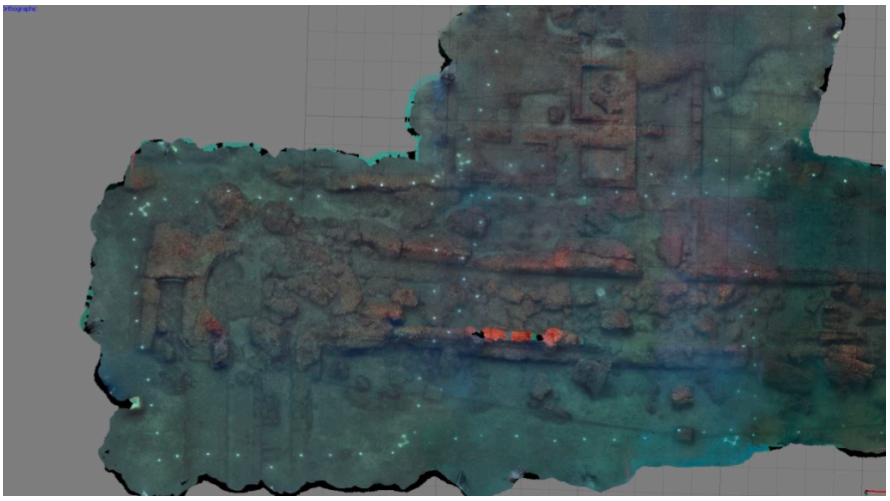

Fig. 6: 3D model, texturized, of a part of *Villa dei Pisoni* in *Baiae*

The 3D digitization of archaeological sites takes place through three-dimensional photogrammetry and laser scanner. The reconstruction method involves two basic steps: the optical acquisition, performed by photography, and the real reconstruction, realized through various software as Agisoft PhotoScan and Blender (Gallo, Muzzupappa, Bruno, 2014, pp. 173-182).

As part of the MUSAS project the enjoyment of these data can take place in two main ways:
- at involved museums, through the use of VR visors and PC. In this case the level of quality of the 3D rendering may be benefited at the top, allowing almost realistic visual experience.
- Remotely, via the website www.progettomusas.eu, to consider the MUSAS project portal a real Virtual Underwater Archeology Museum.
For its implementation it was first launched a worldwide cataloging of all websites developed by various underwater or nautical archeology museums, to understand how new technologies are implemented in this specific field (it was used the DB Symphytum, freeware and open source software, written in C ++ and Qt, for Windows, Linux and MacOS (https://github.com/giowck/symphytum#symphytum). At the same time we have set up a graphics project that could offer to end user a proposal integrated communication at all levels (fonts, logos, project colors, panels, etc.). The MUSAS website uses a CMS (Content Management System) very popular as WordPress, which make WebGL extensive use, a native web technology that doesn't require plugins, completely open source. WebGL takes advantage from graphics chip devices and therefore can offer scalable performance on various hardware typologies, from smartphones to better performing PC. It also allows high performance VR visors to offer virtual augmented reality experience without applications download.
In this mode it will be realized an interactive multimedia exhibition process, able to best describe cultural submerged heritage through surfing the immersive virtual reality sites and through stereoscopic viewing of individual artifacts captured and contextualized, where possible, in the site of origin.
But it will be possible also to enjoy a range of information directly immersed in three archaeological sites involved in the project. This will be through the implementation of an increased exploration system based on the use of special underwater tablets, integrated with inertial navigation systems and acoustic localization. These devices will provide information to enhance the visitor experience. The divers will know, in fact, its position within the site, will receive information about points of interest, depth and dive time. The underwater positioning system, which compensates the absence of the GPS signal underwater, integrates an acoustic communication system based on the installation of four beacons, an inertial platform, a magnetometer and a depth gauge. This is a completely innovative solution and opens up the use of these systems also to non-professional divers.

4. THE BIODETERIORATION OF UNDERWATER ARCHAEOLOGICAL ARTEFACTS

The fulfillment of the Virtual Museum of the Underwater Archeology allows the knowledge of the Underwater Cultural Heritage of the Southern Italy and includes a virtual tour of the marine sites in which the selected remains still lie to explore the underwater archaeological artefacts and to know the biological aspects involving the ancient materials during their underwater life.
The submerged structures can be a growth substrate for countless living forms from the first moment of their permanence on the sea bottom. The marine microorganisms and organisms interact with them temporarily or permanently and establish different relationships connected with their specific ecological needs. The epilithics – that grow on the surface - and the endolithics - are able to produce cavities and tunnels inside the substrata, both microflora and animals, settle on artefacts causing degradation processes, generally defined *bioerosion*.
The substrates with carbonate composition, often used for the construction of ancient statues, mosaic floors, columns and architectural structures, represent the stones most subjected to bioerosion processes in relation to

the ability of the biodeteriogens to solubilize calcium carbonate by acidic metabolites produced by themselves. This deterioration may occur with different levels of dangerousness depending on the degradative capacity of the biodeteriogen, the lithotype, the depth, the microenvironmental features of the site and above all the exposure time. The biological colonization is very heterogeneous, including striking forms that cannot be necessarily harmful for the artworks, and microscopical forms able to exert a considerable damage. The purpose of this biological study is to present to the big public the complexity of the ecosystem artefact/environment and to highlight the biological damage. The Virtual Museum shows the three underwater sites, Baiae, Kaulonia and Egnatia, offering an articulate and exhaustive view of the biological problems linked to the variety of substrates and artefacts and the different laying conditions.

Baiae, with mosaic floors and walls still in place (Figs. 7A-B), preserves a peculiar floristic and faunistic richness. The mosaics, mainly made of calcareous tesserae, sometimes polychrome, are a good example of the high damaging role played by endolithic micro and macroorganisms, such as sponges and bivalves (Fig. 7C).

Kaulonia is a site characterized by alternating phases of coverup and uncovering of the submerged column drums and the semi-finished blocks made of calcarenite (Fig. 7D). This environmental condition represents a limiting factor for the development of majority of biodeteriogens selecting only the organisms able to survive. The artefacts are therefore involved in the degradation processes, mostly due to the bioerosive action of endolithic bivalve molluscs.

Egnatia preserves two long and imposing cement-based piers (Fig. 7E) showing a dense biological colonization with epilithic algal felts and coloured encrustations, not particularly harmful for colonized substrates.

Species descriptions, their ecology and role in degradation processes will be reported in dedicated sections of the web site, guiding the visitor to the discovery of this "invisible" submerged world.

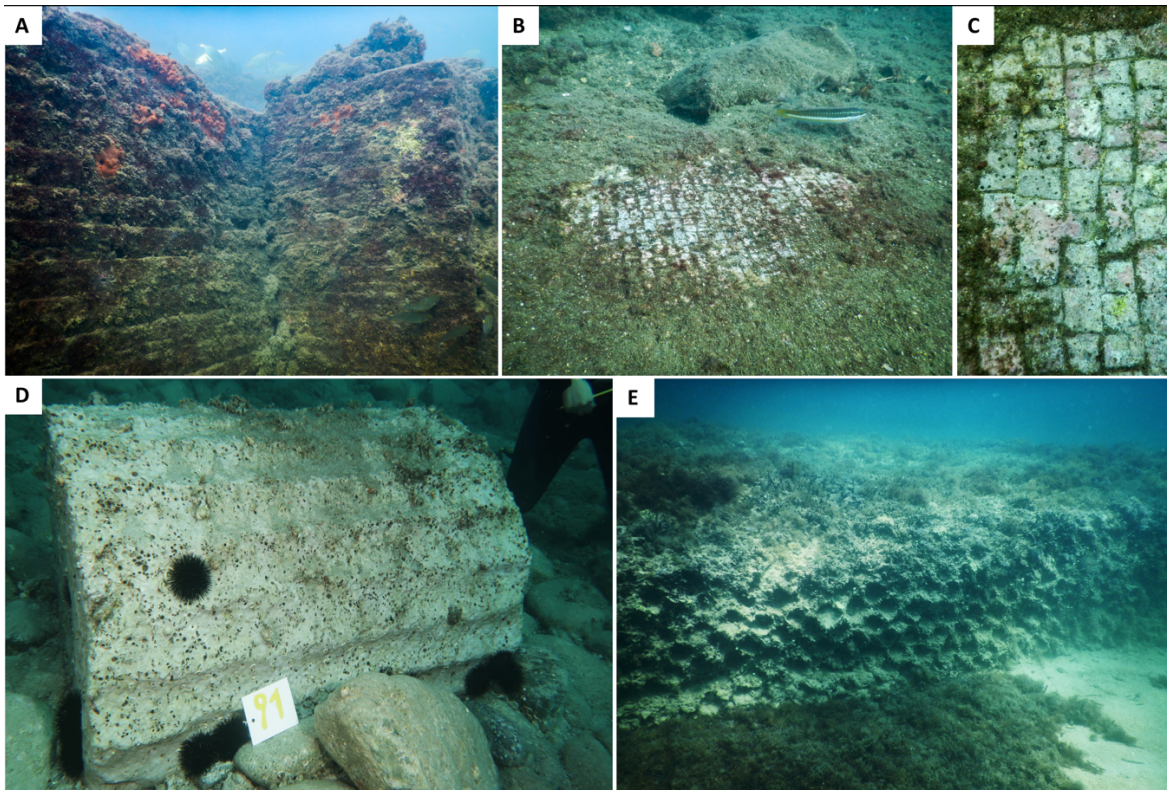

Fig. 7: Biodeterioration in the MUSAS sites

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