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Fouling Communities of Two Accidental Artificial Reefs (Modern Shipwrecks) in Cyprus (Levantine Sea)

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Abstract: Artificial reefs are considered one of the alternative methods in fisheries management, used in order to enhance stocks and marine biodiversity in general. A number of biotic and abiotic parameters influence the fouling communities' formation on artificial reefs through complex interactions. In order to understand how epibiotic or fouling communities progress through time, it is important to study these communities in mature artificial reefs, especially those that have been around for many decades, or in some cases, millennia. This study was conducted on the coral and other fouling organisms of two accidental artificial reefs (40 to 70 year-old shipwrecks) in Cyprus (Levantine Sea). The thermal and nutrient annual regime of the study sites were characterized by processing satellite data. The results indicate that the wrecks are normally under warm and oligotrophic conditions. Percentage coverage of corals and other organisms on the wrecks was calculated (image-analysis software) on photos taken in 2010 (two wrecks) and again in 2016 (one wreck) of the fouling communities. Sponges were the organisms with the highest percent cover (~27%) at the two wrecks. Four scleractinian coral species were found (7%–19% total coral cover). The oldest wreck, which has well-developed coral communities, was revisited during fieldwork in a near-by area in 2016. Only two major benthic categories (dead coral and macro algae) changed significantly between sampling periods. Given the actual policies to sink wrecks to create artificial reefs and the diverse environmental conditions in different areas that will inevitably influence fouling, it is important to carry out studies relating to mature artificial reefs/wrecks in order to be able to assess the ecological effectiveness of longstanding artificial reefs.

Keywords: artificial reefs; shipwrecks; fouling communities; benthic cover; corals; Cyprus

1. Introduction

The Mediterranean Sea is an oligotrophic environment with limited primary productivity [1]. In its eastern part, the Levantine Sea's ultra-oligotrophic nature limits productivity even further [2–4]. In such oligotrophic environments, highly diverse fouling communities are of extreme importance in the transfer of energy from primary production to higher biological levels [5]. In that perspective, artificial reefs in the Levantine Sea can play a key role in the transfer of energy in two main ways. Artificial reefs (when intentional) are preferably placed on shallow sandy bottom areas [6]. As a consequence, they alter the currents' strength and direction, affecting the sediment size and enhancing the deposition of organic material in the vicinity of the wreck, with subsequent consequences in, for

example, the current and sedimentation rates up and down-stream inevitably occurring [7]. In addition, artificial reefs can act as a barrier to currents, creating an upwelling that brings nutrient rich waters higher in the water column, thus also increasing phytoplankton productivity [8]. Artificial reefs can also enhance the biomass of fouling communities by providing additional surface for colonization. As soon as the artificial substrate is submerged, it provides free space to be colonized by numerous fouling organisms that would have otherwise been lost during the settlement process [9]. The sessile epifauna (biofouling) growing on shipwrecks around the world has been the subject of various studies since the 1960s [10–14], demonstrating their importance as artificial reefs/stepping stones for the various organisms they harbour, including non-native species [15].

From the relatively few published studies on the abundance of scleractinian corals in the Levantine Sea, for example [16], and despite the oligotrophic nature of the region, diversity is still higher than expected. In Cyprus, recent scientific efforts have identified >13 species of shallow and deep water coral species [17,18], with many of them found on the various shipwrecks lying on the seafloor around the island.

The Levantine Sea—a region with a very long history of maritime traffic—hosts a wealth of shipwrecks from different eras, found at various depths. Despite the abundance of shipwrecks, very few studies have focused on their encrusting communities, let alone on scleractinian corals. Among the goals for the creation of Marine Protected Areas with artificial reefs is to protect marine biodiversity and to assist in the recovery of ecosystems; hence, we need to understand the dynamics and general characteristics of sessile communities associated to artificial substrates.

Even though a number of parameters influence the formation of fouling communities on artificial reefs through numerous complex interactions, the aim of this study is to compare the fouling communities—scleractinian corals in particular—of two artificial reefs (shipwrecks) located off the coast of Cyprus, in the Levantine basin. By comparing the diversity, percent of cover, and species composition of the scleractinian coral communities on each shipwreck, and by contrasting the ecological parameters that dominate each site, results from the study will assist in shedding light on those ecological factors that determine the colonization of scleractinian corals on the shipwrecks.

2. Materials and Methods

2.1. Study Sites

Surveys of the coral and other fouling communities were performed on two steel wrecks located in south-eastern Cyprus—Touba and Cricket. Touba (63 m length, 35 m depth) was sunk during a storm in 1974 while carrying military cargo from the local port cities of Limassol to Larnaca. Cricket (73 m length, 32 m depth) was used as a shooting target for practice by the military and sunk in 1947. Both wrecks have settled on the seabed upside down. Cricket, due to its superstructure and prominent scour is accessible to divers from below, with the deck of the ship now forming a “ceiling” colonized by well-developed encrusting communities. Touba, on the other hand, has its hull exposed, but with no easy access to the deck of the ship, which has sunk into the seafloor. This wreck, unlike the Cricket, is mostly a flat surface exposed to direct sunlight. Incipient scour allows the establishment of fouling organisms on the sheltered sections. Touba is resting on an irregular bottom made up of rocky substrate and patches of the seagrass *Posidonia oceanica*. There are communities of the Mediterranean endemic pen shell *Pinna nobilis* surrounding the wreck. In contrast, Cricket is resting on a sandy bottom with abundant filter feeding communities of sabellid polychaetes and echinoids.

2.2. Environmental Conditions

Two of the main environmental factors affecting benthic marine communities are sea temperature and productivity. To characterize these parameters at the studied sites in south-eastern Cyprus (Figure 1), annual mean sea surface temperature (SST) and chlorophyll-*a* (Chl-*a*) maps were derived according to [19] from MODIS/Aqua satellite data (there are no in situ data on any environmental

parameters at the study sites). These SST and Chl-*a* products provide per-pixel temperature and concentrations, respectively, in a sequence of swath-based to grid-based global products (spatial resolution of 4630 m). The geo-database consists of a 13-year period (2003–2016, 332 images) of SST and Chl-*a* concentrations data obtained from NASA Ocean Color web servers in Network Common Data Format [20].

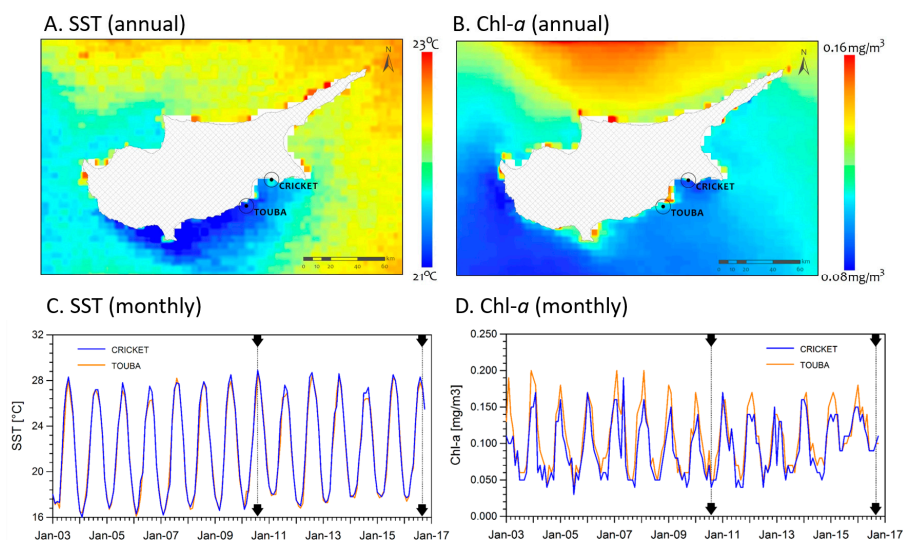


Figure 1. Satellite-derived sea surface temperature (SST) and chlorophyll-*a* (Chl-*a*). (A,B) Annual mean (2003–2016) around Cyprus; (C,D) Monthly mean (2003–2016) at the study sites Touba and Cricket. Date format MMM-YY. Black arrows indicate the months when the shipwrecks were studied.

2.3. Coral Species and Benthic Cover

Benthic cover was determined with the use of photographic material obtained by three divers in August 2010 (Touba, Cricket) and September 2016 (Cricket) at 32–35 m depth. The divers followed a route along the scour, and penetrated the wrecks' structure until confined spaces limited the survey. From the pool of photos ($n = 273$), the ones covering at least an area of approximately $13 \text{ cm} \times 19 \text{ cm}$ and with a perspective perpendicular to the substrate were pre-selected haphazardly using a table of random numbers generated by MS Excel. Based on image quality, the best 20 photos from each wreck (2010) were analysed. Since the Cricket wreck was re-visited in 2016, the selection procedure was repeated, and 20 photos compared to those from 2010, which were taken approximately in the same areas of the structures in the wreck (specific walls, noticeable hatch doors, for example). Analysis was performed using Coral Point Count with Excel extensions [21]; original coral code files were replaced with Mediterranean taxa. A pilot test to determine the frequency of points necessary was made using three point frequencies, 0.25, 1.0 and 2.25 cm^2 , using two point distributions, random and systematic. No significant difference between any combinations of parameters was detected (Kruskal–Wallis, $p > 0.05$). However, the 2.25 cm^2 frequency and random distribution parameters missed some species, while the 0.25 cm^2 was too time consuming and was therefore abandoned. In conclusion, a density of one point per cm^2 ($n = 247$ points) was used. Points that fell in areas of the photos with image distortion or shade were not counted. Sessile taxa ($\geq 1 \text{ mm}$) were identified and classified to the lowest possible level of taxonomic groups according to the organisms (e.g., corals). Percent cover was assigned to main categories, such as live coral and dead coral, macro algae and calcareous algae, sponges, bryozoans, other organisms (e.g., polychaetes, foraminifera, bivalves), and free or uncolonized substrate (steel and corrosion products). Particular attention was given to coral species in order to use the data as baseline to compare with natural substrates. Since benthic cover data did not conform to parametric statistics' assumptions (normality and homogeneity of variances) after square root or $\text{Log}(x + 1)$ transformation was applied, non-parametric tests were used. Mean percent cover for each category between wrecks

was performed using analysis of variances (Kruskal–Wallis), and the differing pairs identified with a post hoc test (Mann–Whitney pairwise comparison).

3. Results

3.1. Environmental Conditions and Study Sites

The wrecks are located in areas where relatively mild environmental conditions exist (no extreme values aside from the seasonal variability), at least on an annual scale. Variations of annual SST and Chl-*a* between sites (Figure 1A,B) are not considered extreme; they are around 1 °C and 0.01 mg/m³, respectively. On average, the water in the area around Cricket is slightly warmer (22.3 °C vs. 21.8 °C) and marginally more oligotrophic (0.09 vs. 0.10 mg/m³) compared to the conditions around Touba.

The two shipwrecks were sampled simultaneously during the seasonal warmest and most nutrient depleted period of 2010. The long-term monthly means (Figure 1C,D) show a clear seasonal variability that is similar at the two study sites. The average conditions during the Summer months (in particular around August) of every year are usually of high sea temperature and low Chl-*a* concentrations. Cricket shipwreck was revisited in September 2016, a month of still-high SST directly after the seasonal maxima (Figure 1C). In contrast, the concentration of Chl-*a* during the month of the survey started to increase after the seasonal minima, which was higher than in 2010 (Figure 1D).

3.2. General Description of the Coral Communities

During the surveys of Summer 2010, the upper sections of both wrecks—which are exposed to direct sunlight—were profusely covered by unusual quantities of mucilage (it was not possible to verify if there was any mortality of organisms associated to this event). The Cricket wreck was also impacted by tangled derelict fishing gear that affected motile (e.g., echinoderms) and encrusting (e.g., sponges) organisms. Sheltered from direct sunlight, the undersides of both wrecks have fouling organisms, such as corals and calcareous algae in particular, depositing a thick layer of carbonate concretion (Figure 2). Foraminifera, serpulid polychaetes, and bryozoa are also important contributors to the carbonate build-up on the wrecks. Several colonies of the solitary coral *Phyllangia mouchezii*—an azooxanthellate colonial species whose distribution covers the Mediterranean and Atlantic regions—were observed only within Touba's communities (Figure 2B). Cricket's fouling communities are more developed than at Touba; expanding all over the undersides exposed by the scour (Figure 2C). The thickness of Cricket's carbonate crust is mainly due to large and numerous communities of sciaphilic species: the Mediterranean endemic facultative azooxanthellate, colonial coral *Madracis pharensis* and also abundant solitary polyps of the azooxanthellate *Caryophyllia inornata*, a species found also in the Atlantic (Figure 2D).

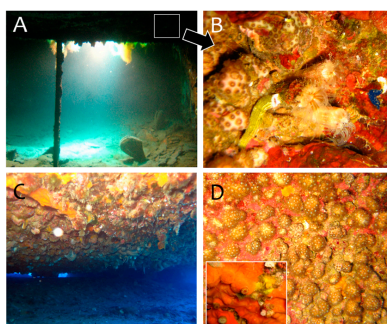


Figure 2. Fouling communities of the studied wrecks. (A) Inner chambers with *Pinna nobilis* in the bottom and coral communities on top; Touba; (B) Carbonate build-up of *Madracis pharensis* and *Phyllangia mouchezii* corals together with serpulids and calcareous algae; Touba; (C) Well developed coral communities and deep scour; Cricket; (D) *M. pharensis*-dominated sections and *Caryophyllia inornata* individuals partly overgrown by *Crambe crambe* sponges (insert); Cricket.

3.3. Benthic Cover 2010 Surveys

Percent epifaunal cover in 2010 was significantly different ($p < 0.05$) between wrecks only for live and dead corals (Figure 3A), found higher at the Cricket (mean \pm SD, 19.3 ± 13 and 7.1 ± 6 , respectively) than Touba (8.6 ± 9 and 3.6 ± 5 , respectively). On average, sponges had the highest percent benthic cover at both Cricket (26.9%) and Touba (27.6%). Other organisms were slightly higher at Touba (18.1%) than Cricket (14.6%), as was also the case for bryozoans (13.1 ± 18.5 and 7 ± 4.1 , respectively). Macro algae and calcareous algae contribution to benthic cover was similar, between 8% and 11.7% at both wrecks. Free substrate—devoid of fouling organisms—was between 7.8% and 8.9% at both wrecks.

In total, four scleractinian coral species were found in the fouling communities of the wrecks, three species in each. No significant differences were detected on the individual species' contribution to coral cover between wrecks. However, from all coral species, *M. pharensis* contributed the most (64% to 80.8%, $p < 0.0001$) at both wrecks (Figure 3B). Individuals of *C. inornata* contributed 4.2% to 6% of coral cover on the wrecks. *Phyllangia mouchezii* was found only at Touba, and *Polycyathus muelleriae*—a colonial azooxanthellate species whose distribution covers also the Atlantic and Mediterranean—only at Cricket, each of them contributing to about 5% of coral cover.

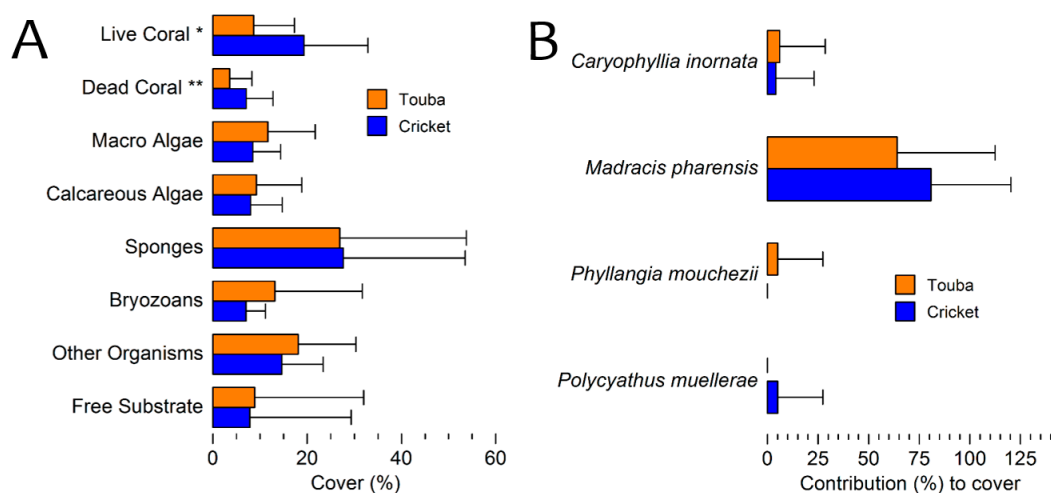


Figure 3. Percent benthic cover in 2010 at the Touba and Cricket wrecks according to (A) categories and (B) contribution (%) to coral cover of four species. * $p = 0.01078$; ** $p = 0.01859$.

3.4. Benthic Cover 2016 Survey

Six years after the initial survey in 2010, benthic cover at Cricket—the only wreck revisited in 2016—changed slightly. Only dead coral and macroalgae cover showed significant changes ($p < 0.05$; Figure 4A); while the former decreased from 7.1% to 3.6%, the latter increased almost double from 8.5% to 16.8%. The other six benthic categories remained within similar values to those reported in 2010.

The contribution of the three coral species found in Cricket to the total coral cover varied significantly only for *C. inornata* (Figure 4B). This species contribution increased since 2010 from 4.2% to 12%. Still, *M. pharensis* continue to be the coral with the highest influence on coral cover (73% to 80.8%) and the fouling community in general.

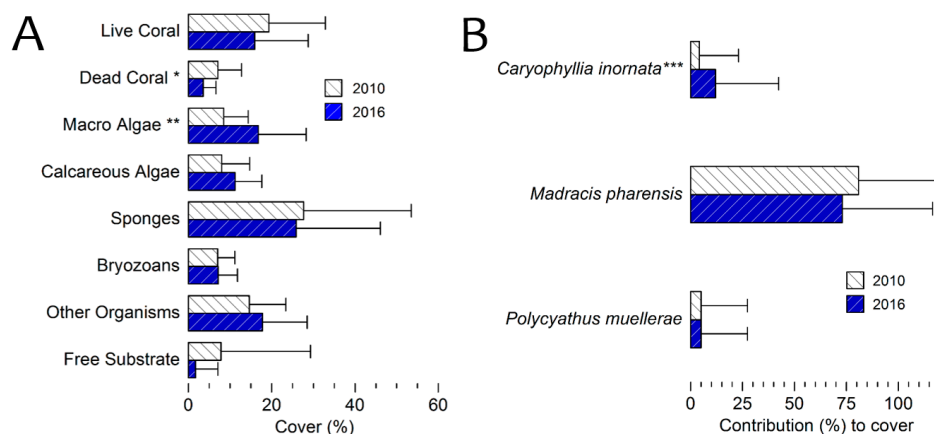


Figure 4. Percent benthic cover in 2010 and 2016 at the Cricket wreck according to (A) categories and (B) contribution (%) to coral cover of four species. * $p = 0.03341$; ** $p = 0.007709$; *** $p = 0.04758$.

4. Discussion

The conditions prevailing at the study sites compared with the conditions of the Levantine Basin present significant differences. Regarding annual SST, the areas around both wrecks present higher annual values than the mean annual temperature of the Levantine basin, which is 21.3 °C. As for the concentrations of Chl-*a*, it is clear that both study sites harbour more intense oligotrophic conditions, evident from the high annual values found at the south and eastern coastal margins of the basin exceeding 2 mg/m³ (highest value of the basin is 9.9 mg/m³ in areas close to the Nile Delta). Furthermore, the absence of major influxes of freshwater and nutrients to the studied sites make this study an important and interesting comparison to other wrecks found in more eutrophic conditions, such as in the Central or Western Mediterranean.

Cyprus was affected in 2010 by prolonged seawater temperature increases during a period of several weeks [22]. Coral bleaching and mortality was documented around the island, and mucilage was also observed in unusual quantities and depths. In 2010, both wrecks were covered by profuse mucilage, though coral mortality was not widespread as in other shallow areas, where extensive partial mortality of coral colonies was recorded [22]. Cricket was also impacted by tangled derelict fishing gear, affecting motile and encrusting communities. Fouling communities under the wrecks—sheltered from direct sunlight—were less affected than those at exposed surfaces. Interestingly, shaded areas and temperature act synergistically, and have been associated with increases in non-indigenous fouling species [23].

Even though the wrecks differ in age by 27 years (1974 Touba, 1947 Cricket), once the communities have been established and stabilised, changes occur very slowly unless there is a major disturbance event; hence, time seems not to be a major factor influencing the development and extent of the fouling communities on the steel structures. Studies elsewhere have found that time is a factor that interacts in complex ways with nature and composition of the founding fouling assemblages [24]. Other more recent wrecks—such as the Zenobia in Cyprus (sunk in 1980)—have diverse fouling communities comparable to Cricket [25]. It is perhaps the thickness of the carbonate crust that may have a better indication of the maturity of the wreck. Corals and other fouling organisms found at Cricket appear to be more developed, but this comes probably as an artefact of greater availability (larger surface area) of substrate in this wreck for the larvae to settle. In Touba, substrate similar to what is available in Cricket is mostly buried underneath the seafloor. The inaccessibility to divers, and hence limited sampling of sections of this wreck is also another factor to take into consideration. Nevertheless, the settlement process is a result of a number of physical, biological, and ecological interactions. In general, the age of an artificial reef determines the percent cover and species composition of coral communities [26]. Coral communities are affected by the surface orientation of a reef, favoring vertical surfaces—the reason probably related to the degree of exposure to various other parameters such as light and

currents [27]. Depth has also been demonstrated to affect the fouling processes, with a decreasing gradient towards deeper parts of the reef again in relation to exposure to physical parameters such as light penetration and temperature [28]. Another determining factor for the fouling community formation are the associated organisms present in the area, which can act as the source of larvae to the artificial reef [29]. Nearby fouling communities release larvae in the water column. The distance covered by larvae is species specific and depends on the duration of larvae stage of each species and the governing currents in the area. Assuming that existing fouling communities of natural reefs in close proximity are exposed to similar environmental characteristics and positioned within the “pathway” of currents that run towards the artificial substrate, then there is higher possibility for them to be part of the suppliers of larvae, which will colonize free space in the adjacent area.

The small temporal change in the coral and other fouling organisms on the communities of Cricket is noteworthy. Another significant seawater temperature warming event occurred within the six year interval between surveys. A widespread mortality of corals and other organisms was recorded in 2012, which affected most parts of the island [22]. A localised mortality event in *Cladocora caespitosa* coral communities was also documented in the summer of 2015, when prolonged high SST occurred [30]. If there were any effects on the fouling communities of Cricket during the warming events, our survey failed to detect it, or it may have never occurred. For example, a significant decrease of benthic cover of slow growing organisms (such as corals) would have been an indication of a widespread mortality. Alternatively, an increase of dead coral cover would have suggested a recent coral mortality event. The slight and non-significant decrease in live coral cover (Figure 4A) can be attributed to competition and overgrowing by other organisms, such as the aggressive sponge species *Crambe crambe* that smother corals and other fouling taxa on the wrecks (Figure 2D). These are fast growing species in comparison to scleractinian corals in the wreck. Since several of the photos in 2016 were taken close to the original 2010 position, it was noted how sponges overgrown coral colonies and solitary polyps (Figure 2D). One coral species, *C. inornata*, contributed more to coral cover in 2016 than in 2010. This apparent increase is mainly due to the inclusion in the analysis of photos from a section of the wreck with a large community of this species. Interestingly, other biological processes, such as predation, seem not to significantly affect *C. inornata* cover in the wreck. The bearded fireworm *Hermodice carunculata*—a common corallivore in Cyprus—could potentially wipe out small populations of this coral species. Numerous individuals of *H. carunculata* have been observed preying intensively on corals of Cricket and elsewhere in Cyprus. This corallivore can consume coral tissue from up to 100 cm² in a colony within a few hours [31]. Lastly, different environmental conditions during the two survey periods (e.g., Chl-*a* concentration) may have played a role that we are not able to further discuss due to our sampling method and lack of in situ environmental data.

5. Conclusions

The findings of this study showed the potential of artificial substrates—in this case steel wrecks—to attract complex fouling communities. Interestingly, Touba communities are not more developed than Cricket, despite being surrounded by and resting on natural hard substrate. It is typically assumed that the closer the artificial substrates are to natural ones, the more diverse communities they will develop [29]. Wrecks’ location, position, depth, orientation, material, and structural complexity are important controlling factors that need to be considered when planning and managing artificial reefs [32,33]. Long-term ecological studies on diverse wrecks and monitoring of permanent plots for benthic cover and composition of taxa would increase our understanding on the fouling communities’ development and functioning under oligotrophic conditions such as those in Cypriot waters. Moreover, if positioned properly, hard substrata supporting a high diversity of encrusting communities will in turn support higher ichthyofaunal diversity, therefore enhancing the abundance of commercially, economically, and ecologically important species [34].

Additional forthcoming research should include the potential role of these artificial reefs as substrate and refugia for opportunistic and invasive species [15,35], both for encrusting and nektonic

species. To investigate how these species will interact and respond to factors such as wrecks' age and size, and maturity of the fouling community, human activities on the wreck will undoubtedly assist in the management and removal of invasive species.

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Author Contributions: Carlos Jimenez conceived and designed the study. All authors collected the field data. Carlos Jimenez analysed the benthic cover data and wrote the first draft. Andreas Georgiou processed and analysed the satellite data for Section 3.1. All authors contributed to expanding and improving the first draft and writing of the manuscript. Carlos Jimenez and Louis Hadjioannou were responsible for the revised and final version of the manuscript.

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