Assessing and mapping Vermetid reefs on the coastline around the Paralimni Marina Project

November 2019

On behalf of I.A.CO Environmental & Water Consultants Ltd, environmental consultants of PMV Maritime Holdings Ltd.

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INTRODUCTION

Paralimni Marina is a proposed 300 berth marina and residential development in the village of Pernera. The primary infrastructure works in the sea include a 500 m long wave breaker with a total width of 70 m. The main wave-breaker interconnects with the shore at the protruding edge of the bay across the small harbour of Pernera and ends approximately 130 m off the shore, slightly southeast of the existing port. Other proposed works are the extension of the existing northern wave-breaker at the harbour of Pernera, and the construction of a protective wall at the eastern part of the existing small harbour. The construction will also include dredging operations of the seafloor on the outer sides of the fishing harbour.

During the construction phase, dredging could impose major pressures on the surrounding marine environment, particularly on foundation species and organisms that are sensitive to anthropogenic perturbations and located within the impacted area. Increased resuspended solid concentration and sedimentation that exceeds natural deviations can smother benthic communities downstream dredging operations, however mitigation measures planned can minimise the plume impacts. During the operational phase, nutrient enrichment and the accumulation of toxic compounds within the marina, may be hazardous to the adjacent marine community if these pollutants leach outside the marina, but again mitigation measures are planned that can minimise impacts (e.g. oil spill response plan).

One particular group of organisms that is vulnerable to such stressors and were detected in the EBS and within proximity of the project's area, are the vermetids (Milazzo *et al*. 2017). Vermetids are marine gastropods and are pivotal components within the littoral communities, due to their bioconstruction properties (Cocito 2002). More specifically, Mediterranean vermetids in association with coralline alga (Chemello and Silenzi, 2011), form crusts or reefs in the intertidal or shallow sublittoral zones, acting as bioengineers, reef-builders that protect the coastline from erosion, regulate sediment transportation and accumulation, enhance biodiversity as well as sequester carbon, an essential ecosystem function in respect to climate change mitigation and regulation (Milazzo *et al*. 2017).

The ecosystem functions and services of vermetid reefs in the Mediterranean are significant, however, vermetids are considerably abundant and have well-developed reefs in the easternmost Mediterranean parts (i.e. Israel, Lebanon and Syria) and are restricted to rocky coastlines where water temperatures do not fall below 14 °C (Chemello and Silenzi, 2011).

Anthropogenic disturbance, however, renders many vermetid reefs susceptible to regression (Milazzo *et al*. 2017). Nowadays vermetid reefs are considered to be endangered habitats and have been listed in the Mediterranean Red Data Book (UNEP/IUCN/GIS POSIDONIE, 1990). They are also included in the reference list of priority habitats to guide selection of sites of conservation interest within the purview of the Barcelona Convention (UNEP-MAP-RAC/SPA, 2006). In addition, *Dendropoma petraeum* is listed in Annex II (Endangered or Threatened Species) of the Protocol for Specially Protected Areas (RAC/SPA), and the Biological Diversity in the Mediterranean Revised at the 17th COP meeting (UNEP/MAP, 2012). Lastly but not least, the vermetid reef is further included in Annex I of the European Habitats Directive under ‘reefs’ (code 1170), while the main builder species (calcareous red macroalgae and vermetids) are also included in the annexes of the Berne Convention.

Considering their given conservation/protection status, their significance in ecosystem functioning, and their presence within the marina prospect area, it was judged essential that baseline information on the vermetid reefs is established prior to the initiation of any coastal interventions, so any possible appropriate mitigation measures can be set, and the monitoring approach following the constructional phase is focused and targeted where it matters more.

SCOPE AND OBJECTIVES

The study aims to acquire baseline knowledge on the spatial extension of the vermetid reefs along an approximately 1.5 km stretch of shoreline encompassing the proposed potential impact area. Researchers have snorkelled the entire shoreline to record the vermetid coverage (including dead facies) and estimate densities and ratio of living gastropods. Results are interpreted and displayed in maps. Based on the results acquired, the study further aims to briefly discuss the potential impacts during the constructional and operational phases of the proposed project on the vermetid reefs.

MATERIALS AND METHODS

Sampling

Shallow surveys were conducted by marine biologists to detect vermetid reefs at about 1.5 km stretch of shoreline (Figure 1). Marine biologists snorkelled the entire coastline and thoroughly investigated the upper subtidal (0-1 m depth) for the presence of vermetid gastropod reefs. Surveys took place in November 2019 and lasted several days.

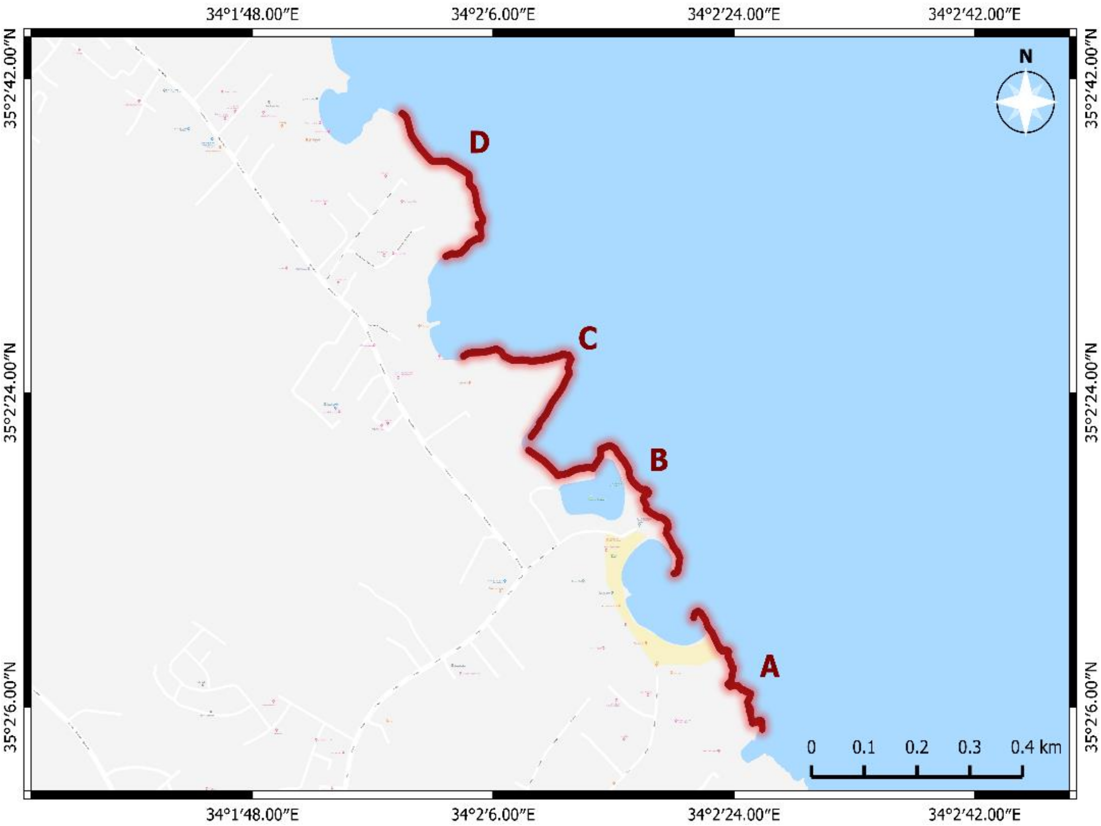


Figure 1. Surveyed area for the presence of vermetid reefs. Letters indicate the distinction of the different examined regions of the study area.

Geographic coordinates were collected with a handheld GPS mounted on a surface buoy every 10 m, acting as sampling points. For every sampling point, a thorough visual investigation extending 5 m from the sampling point on each side, was conducted to estimate the percentage coverage of vermetids on the reef (e.g. vermetids covering the entire reef regardless of density, or exhibit patchy distribution), in order to define how much reef-construction is being attributed by these gastropods. Vermetid densities were further undertaken in each sampling point using stratified random sampling within four replicated quadrats (0.16 m^2) to express the vermetid viability as the percentage of living vermetid individuals (Figure 2). Living individuals were distinguished by the presence of the operculum (an anatomical structure found in the majority of gastropods, which seals the aperture of the shell; Figure 3A) and its retraction response upon gentle touch or light emission via a diving torch. Whereas, dead individuals were identified as empty and degraded shells, inhabited by encrusting biota, such as sponges (Figure 3B), or even occupied by hermit crabs (Figure 3C).

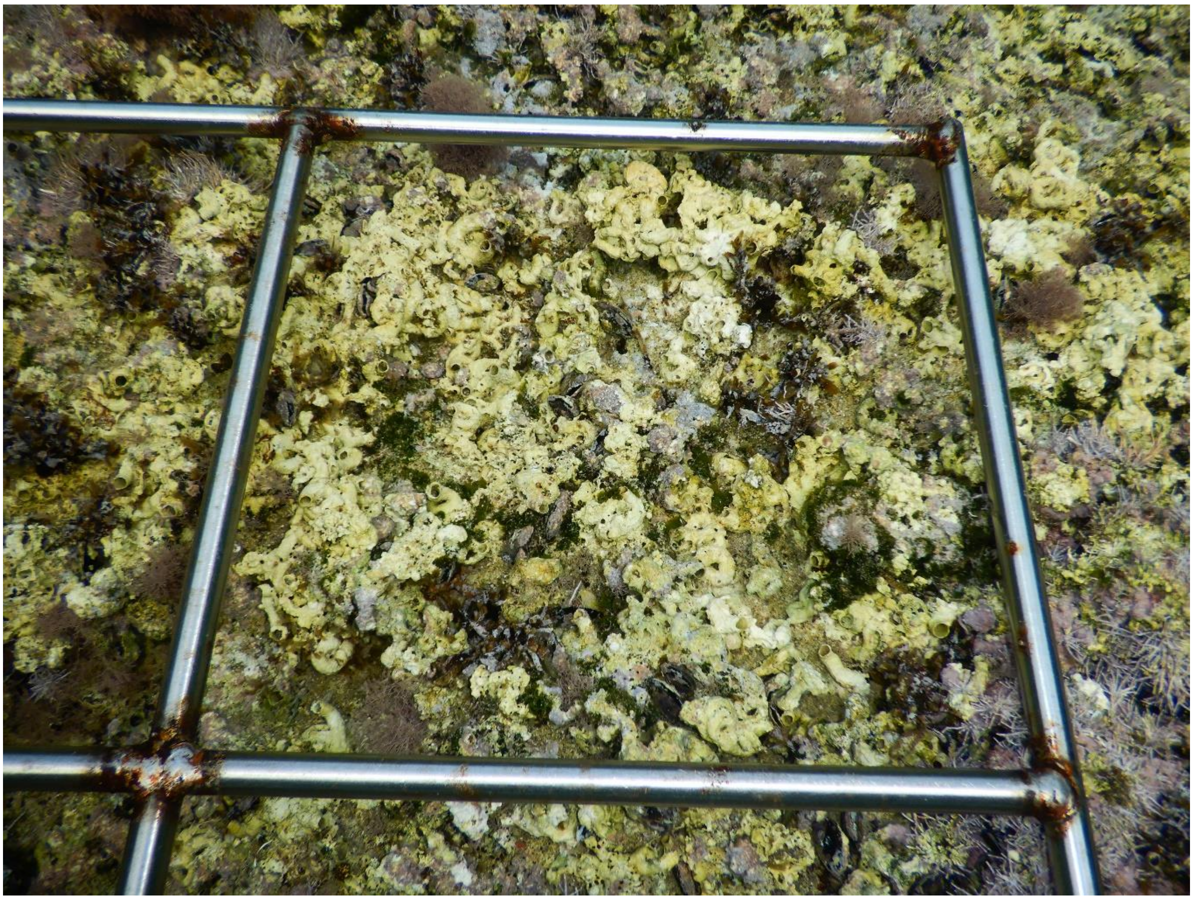


Figure 2. Vermetid density measurements using quadrats.

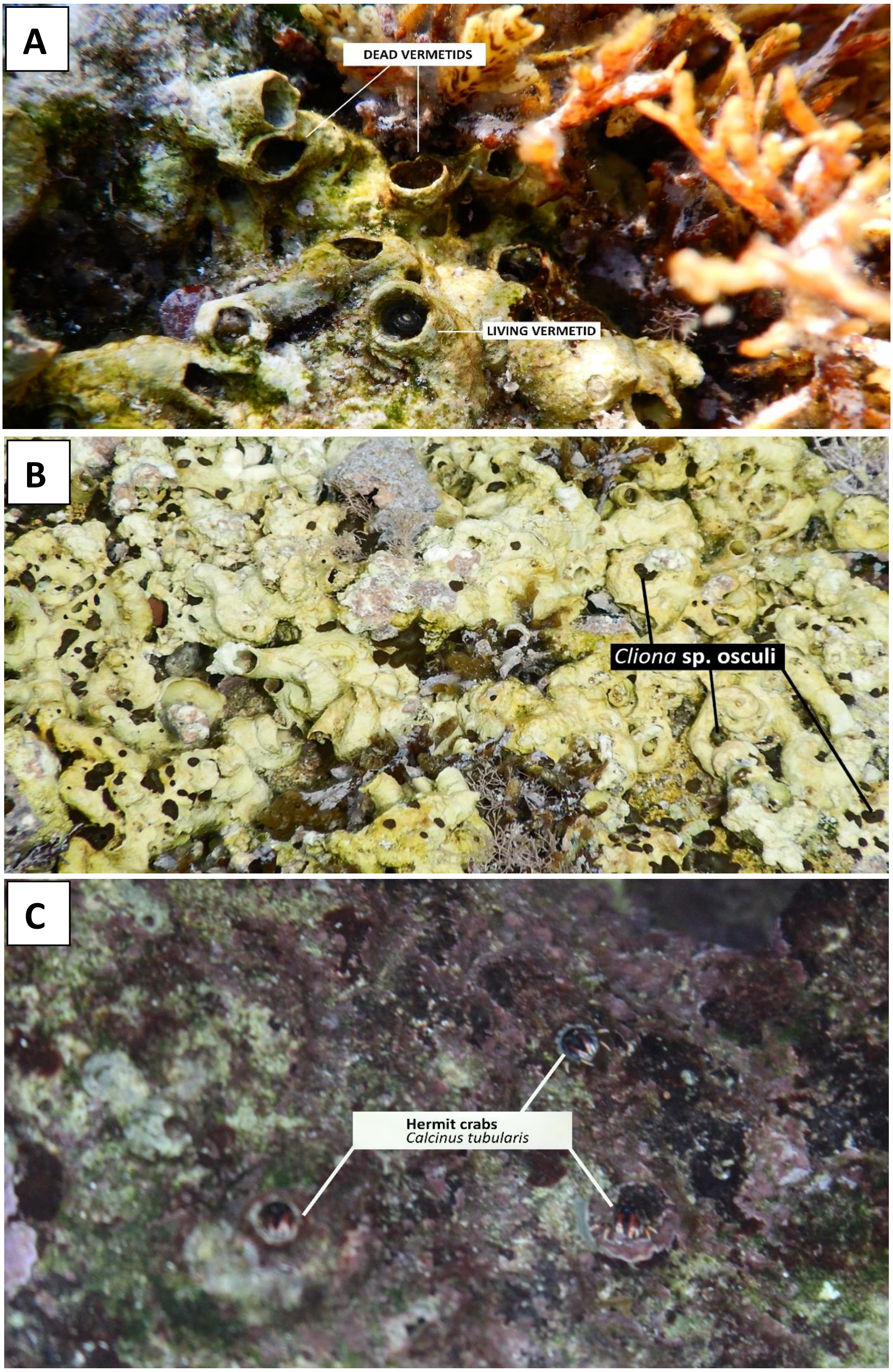


Figure 3. Vermetid shells status: (A) Example of living and dead vermetids with living ones possessing an operculum, (B) Empty degraded vermetid shells with sponge (*Cliona* sp.) growing within, (C) empty vermetid shells occupied by the hermit crab, *Calcinus tubularis*.

Mapping and Data Analysis

Mapping was performed on data collected as total density of vermetids (included both dead and living individuals), percentage of coverage and of living vermetids. Prior to spatial analysis, all quantitative data (e.g. vermetid densities) were inserted as averaged values pooled from replicated quadrats per sampling point. Maps were then constructed as heatmaps using the probability Kernel quartic density function as shown below, in line with the nearest neighbour smoother in QGIS v3.10.0.

$$K(\chi) = \frac{15}{16}(1 - \chi^2)^2$$

$$For\ |\chi| \leq 1$$

where, $K(\chi)$ is the kernel and x is a data sampling point.

Statistical analysis was further performed in R-studio with a Kruskal Wallis non-parametric test, followed by a Dunn's test with a Bonferroni Correction in order to examine which of the geographical regions (A, B, C, D; Figure 1) varied statistically, in terms of vermetid densities (total and living).

RESULTS

The majority of the coastline examined is characterised by high vermetid coverage (Figure 4), indicating that most of the intertidal or upper subtidal reef have been bio-constructed by vermetids (Figure 5A), while some other areas with artificially installed boulders (e.g. shelter's main breakwater; Figure 5B), exhibit lower coverage which, is likely due to slow vermetid settlement and colonization by nearby natural reefs. Some natural reefs that lacked or were less dominated by vermetids, had high coverage of calcareous encrusting rhodophytes, which may have consequently masked the presence of old and eroded vermetid facies in the area (Figure 5C). Without excluding the presence of other vermetid species, the dominant vermetid identified was *Vermetus triquetrus*, native to the Mediterranean Sea.

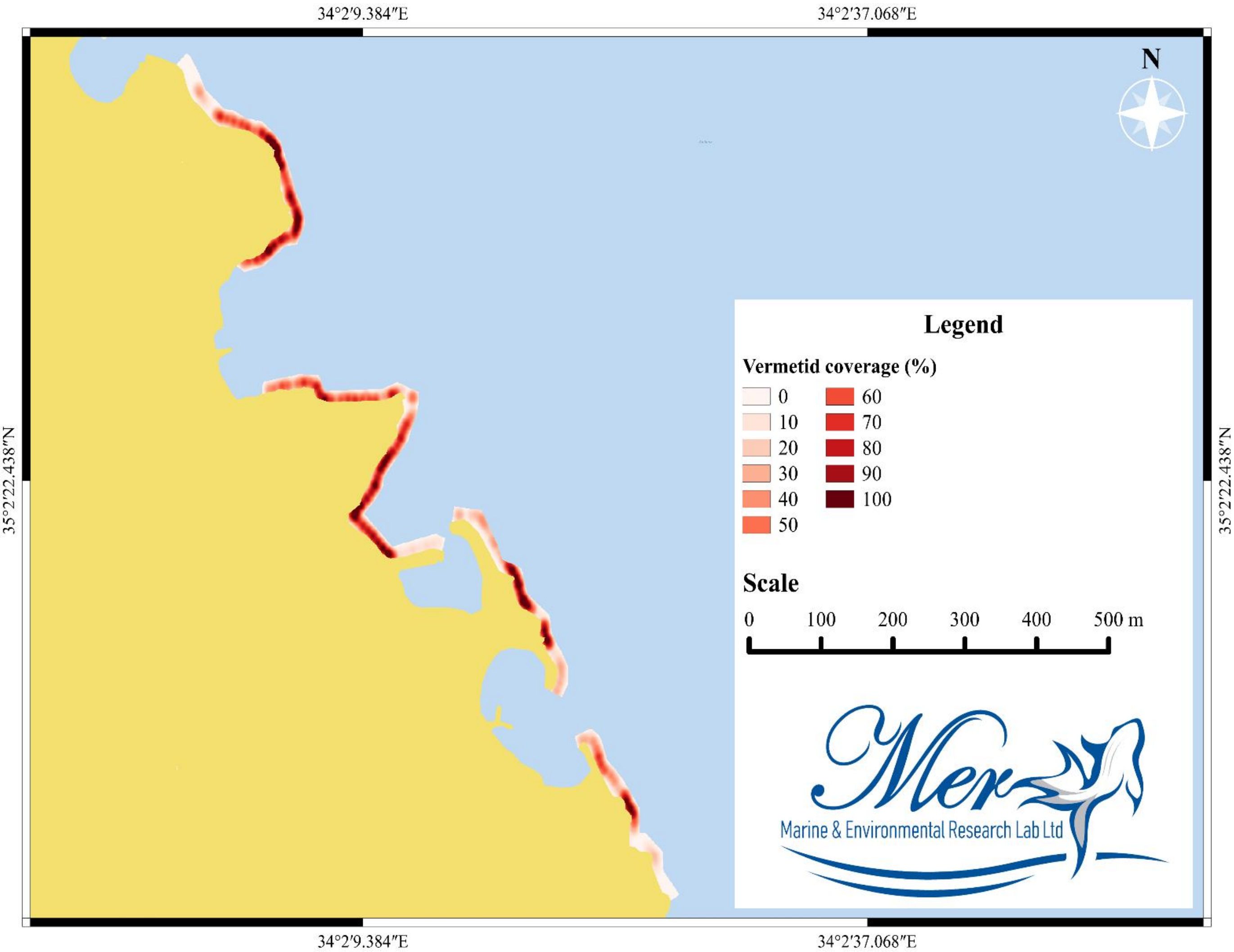


Figure 4. Dead or alive vermetid coverage (%) along the examined shoreline.

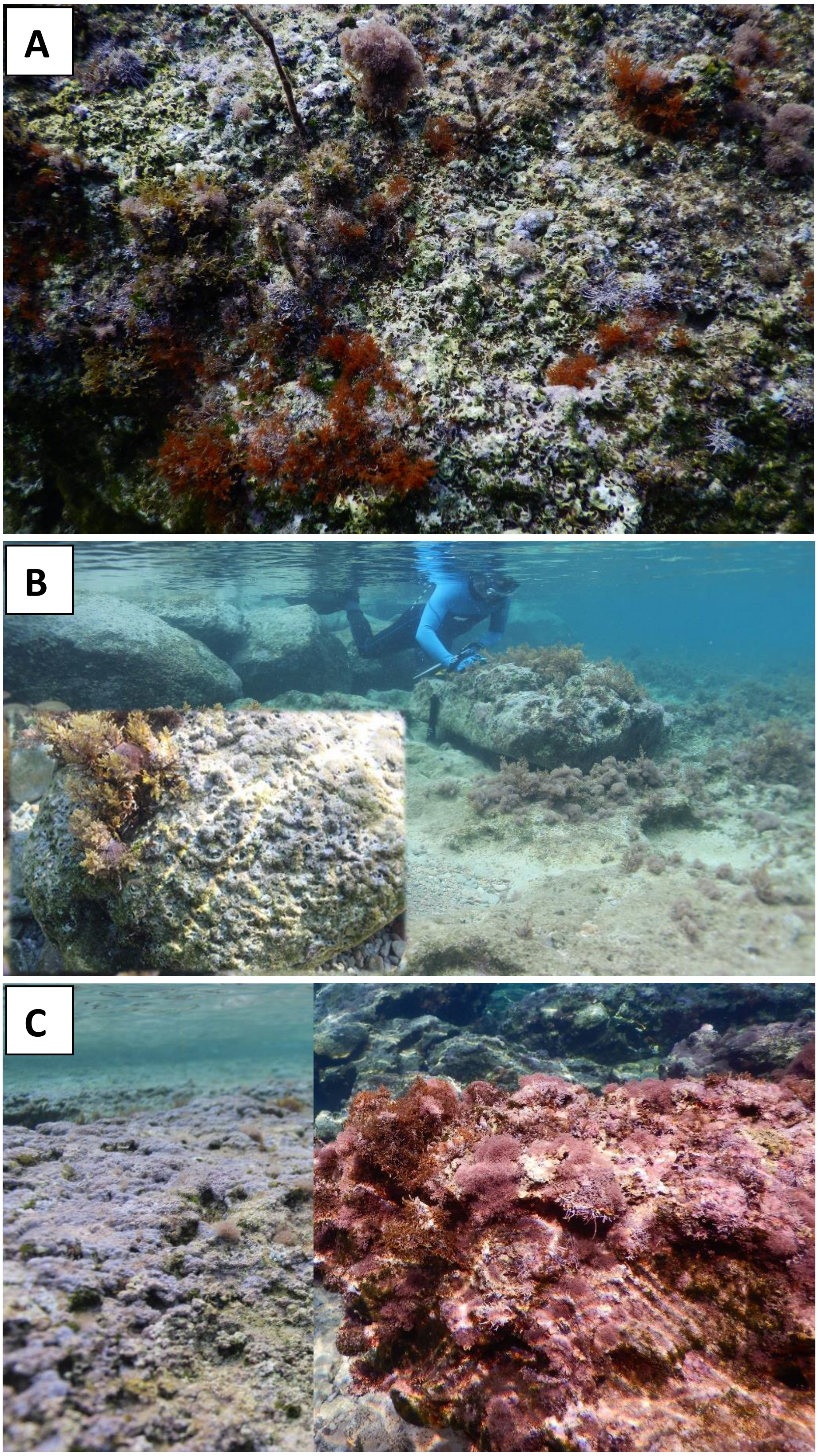


Figure 5. The three type of vermetid facies identified: (A) Natural reefs with high vermetid coverage, (B) Artificially-installed boulders with low vermetid coverage, and (C) Natural reefs with low vermetid abundance and mainly covered/bio-constructed by encrusting calcareous and coralline algae.

In addition to the vermetid coverage, the total density (individuals m^{-2}) was also variable along the examined shoreline, with highest densities observed at the north-western regions, C and D (Figure 6 and 8). Despite the high coverage and total density, all vermetids in these regions were found dead. Regions A and B were characterised by both high and low living vermetid densities (Figure 7 and 8).

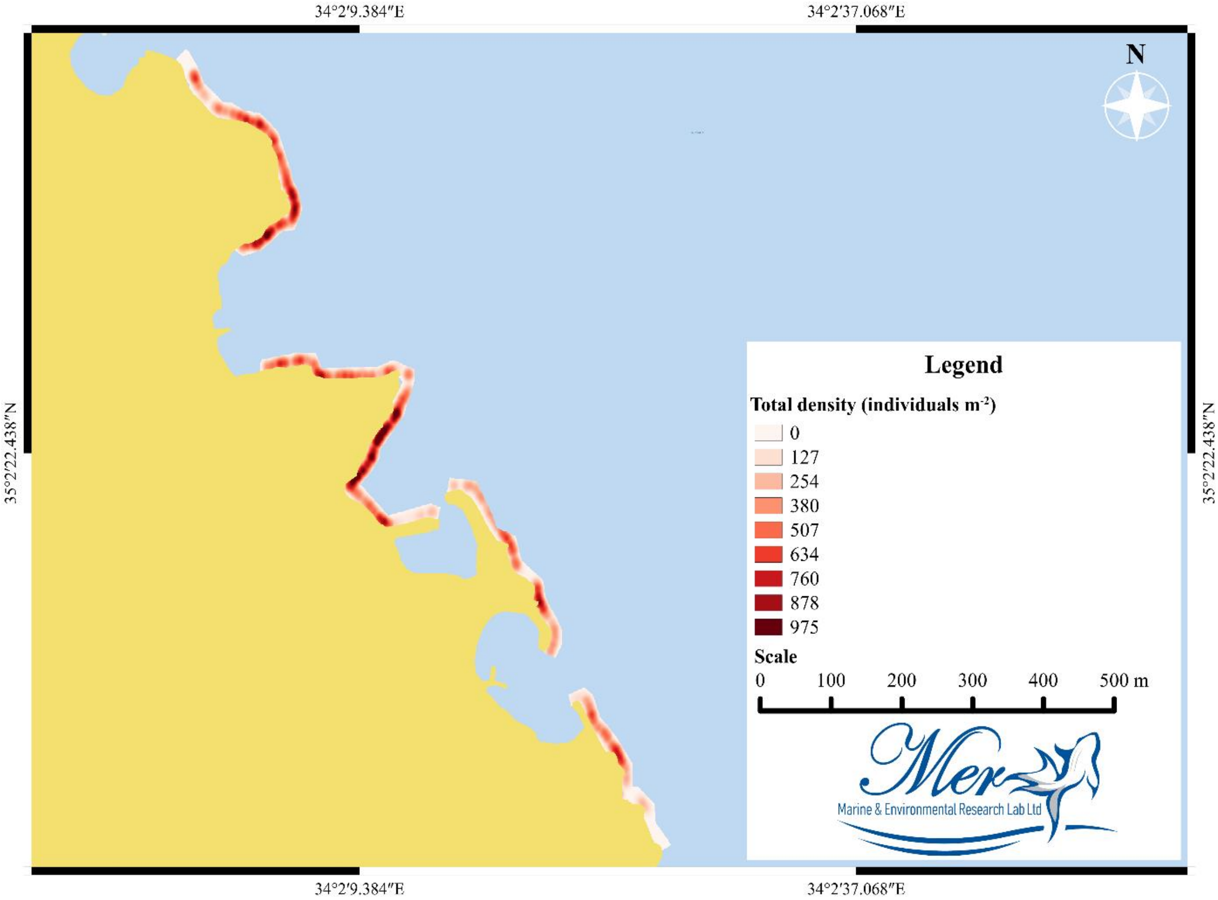


Figure 6. Dead or alive vermetid density (individuals m^{-2}) along the examined shoreline.

Specifically, the highest density of living vermetids was observed at the mid-area of region A and within the semi-enclosed bay outside the existing port in region B (Figure 7). The semi-enclosed bay facing the existing port's entrance and encompassing regions B and C is anticipated to become part of the new proposed marina's basin.

The vermetid facies across the entire investigated coastline were associated with a diverse community of invertebrates and seaweeds (Figure 9).

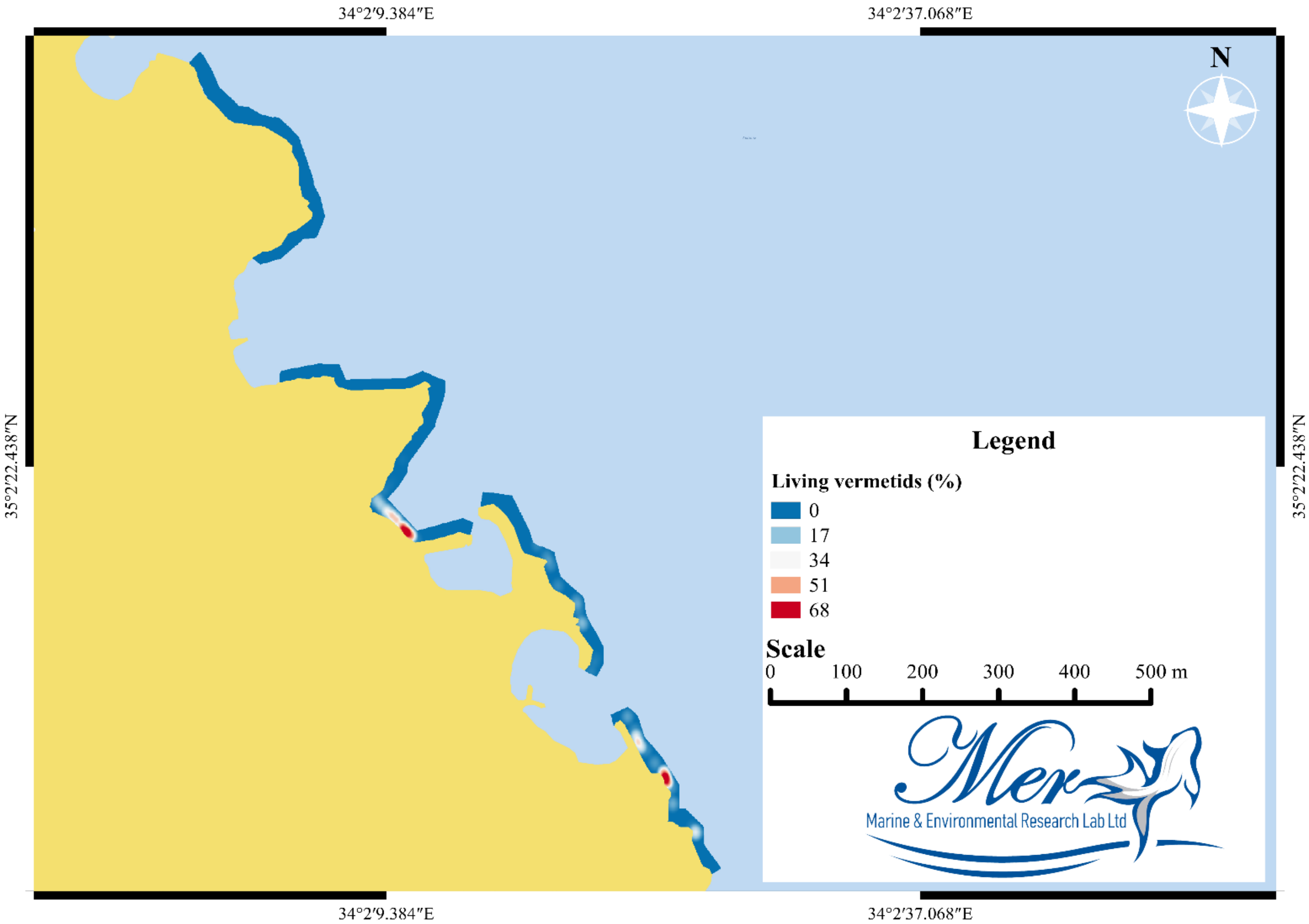


Figure 7. The living vermetids (%) along the examined shoreline.

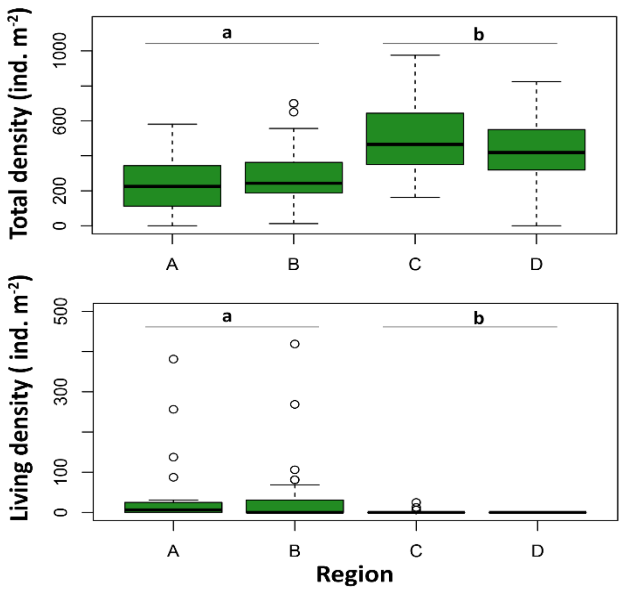
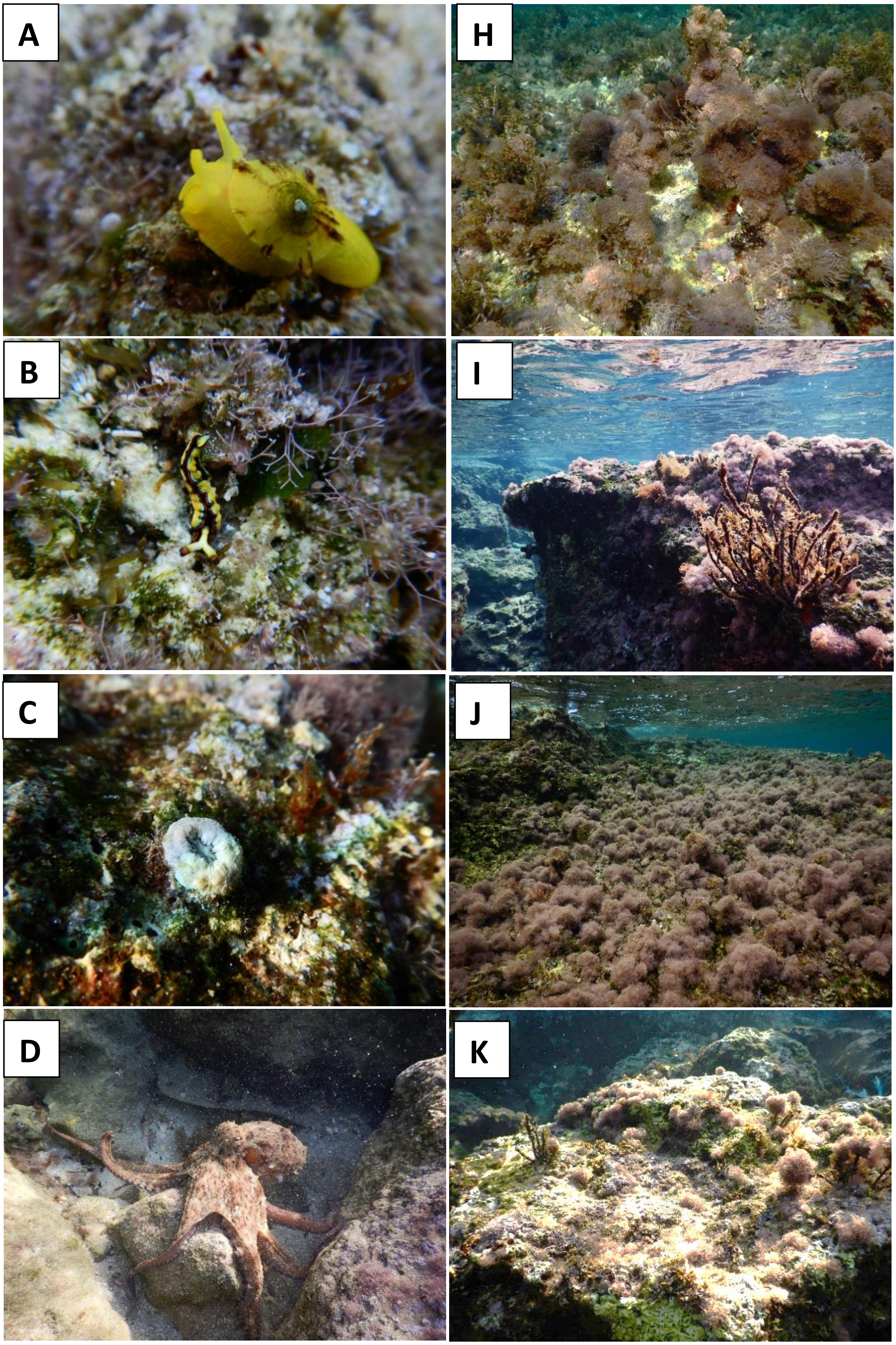


Figure 8. The total vermetid density (individuals m^{-2}) and living vermetid density (individuals m^{-2}) across the four defined regions. **Note**: Regions that do not share the same lowercase letter in each panel, are significantly different at $p < 0.05$ (Dunn's test with Bonferroni correction).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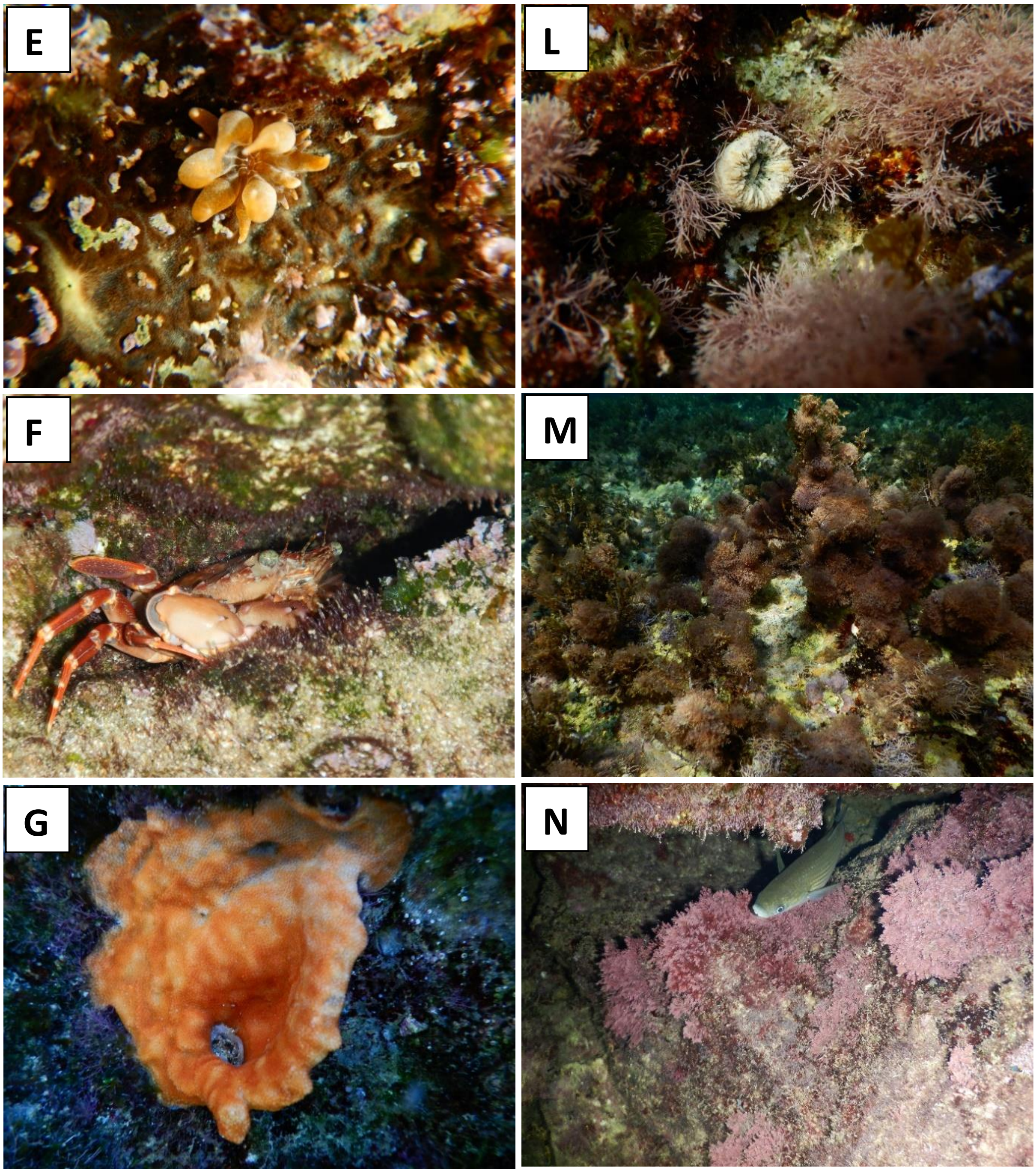

Figure 9. Vermetid reef associated biodiversity of the studied shoreline. A-G demonstrate individual reef species and H-N illustrate macro/micro seascapes.

DISCUSSION

Vermetid reefs in the Mediterranean Sea have been regressing due to natural stressors in synergy with the increasing amount of anthropogenic threats (i.e. chemical/biological pollution, coastal urbanisation, climate change, ocean acidification), particularly in the eastern Mediterranean Sea (Rilov *et al*, 2004; Chemello and Silenzi, 2011; Galil 2013; Rilov 2016; Badreddine *et al*, 2019), a subsequent loss of associated biodiversity is reported (Chemello *et al*, 2000; Goren and Galil, 2001). Their limited biogeographical distribution in the Mediterranean, their ecosystem services including high biodiversity (Milazzo *et al*, 2017) and the recently discovered high genetic divergence between different Mediterranean populations (Calvo *et al*, 2009), calls for a stronger protection interest both at European and Mediterranean level to enhance its conservation status and promote restoration efforts.

Across the approximately 1.5 km of coastline that was investigated, vermetid facies covered much of the hard substrata of the intertidal and upper subtidal (0-0.5 m depth). In most cases (all areas north of the proposed marina), the gastropods were dead. The high mortality of vermetids along the examined shoreline could be induced by natural and/or human stressors. The fossilised remains of shells indicate mortalities at different time scales as some shells were well preserved and easily detected while others were heavily eroded and covered by encrusting calcareous algae e.g. *Lithophyllum* spp., indicating that those individuals died many years ago. Vermetid reefs are particularly vulnerable to petroleum spills, since hydrocarbons float and can affect benthic communities of the vermetid zone if washed ashore.

It is widely reported that ports/marinas accumulate contaminants (e.g. Chapman *et al*, 1987; McGee *et al*, 1995) and are sources of numerous organic and inorganic chemicals (e.g. Callier *et al*, 2009). These, combined with other coastal activities or natural stressors, may have been responsible for the high mortality observed within the studied area. Vermetids inhabit pollution-free zones and with low rates of sedimentation (Calvo *et al*, 1998). Agitation of the water seems another necessary component to its survival (Calvo *et al*, 1998), therefore altering the hydrological regimes via coastal constructions and coastal defences (e.g. sheltered areas which lead to calmer waters) can be a contributing factor to its absence and/or extremely low coverage.

Along the examined shoreline there were only two main areas that are accommodating high densities of living vermetids. A fragmented living population in the northern section of region

B will be lost as that particular area of the study area is marked for land reclamation. However, the future viability of this population if left undisturbed is questionable due to the proximity to the existing port. Living populations of vermetids detected in the south-eastern region (A) may be affected by the constructional and operational phases of the project especially if mitigation measures are not set. Recovery of fragmented populations of vermetids may be a slow process due to their peculiar low dispersal range (Calvo *et al*, 1998; Calvo *et al*. 2009), and their high intolerance levels to marina associated pollutants (Di Franco *et al*, 2011), thus placing this species at risk of local extinction (Calvo *et al*. 2009; Galil 2013).

In conclusion, this study shows that the intertidal and upper subtidal (0-1 m) depth of almost the entire coastline is covered by vermetid facies inhabited mainly by coralline algae and several encrusting calcareous macroalgae (e.g. *Lithophyllum* spp.) animals (e.g. sponges and bryozoans). The vast majority of vermetids detected were dead fossils often inhabited by hermit crabs. During the construction phase of the marina, one of the two main living populations of vermetids detected will be superimposed to direct loss (region B), while the living vermetids on the south-eastern region (A) may be stressed during the constructional (if mitigation measures are not implemented and plume from dredging smothers the benthic habitats of the shoreline south of the proposed marina) and operational (if mitigation measures are not implemented during an accidental oil spill that can reach this side of the coastline i.e. when northerly wind) phases.

However, it should be noted that living vermetids were found very close to the existing port's entrance, indicating that under certain conditions the gastropods can tolerate a certain degree of pollution. The few remaining living vermetid reefs deserve ample consideration for protection and conservation, taking into account their endangered status and their valuable contribution in the provision of ecosystem services. It is highly recommended that the areas with the highest densities of living vermetids in region A are monitored during constructional (to detect whether smothering pressure is imposed) and operational operations.

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