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Threatened biogenic formations of the Mediterranean: Current status and assessment of the vermetid reefs along the Lebanese coastline (Levant basin)

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ABSTRACT

Vermetid reefs are a key intertidal habitat in the warm-temperate part of the Mediterranean Sea and in some subtropical and tropical regions in the Atlantic and Pacific oceans. This unique and highly diverse ecosystems is under siege due to both the high anthropogenic pressure and the global climate change, with documented local population declines in the Eastern Mediterranean. This study aims at evaluating the conservation state of vermetid reefs along the Lebanese coast (Eastern Mediterranean), where seawater warming, habitat degradation and coastal urbanization likely threaten their presence. In order to assess the conservation status of vermetid reefs in Lebanon, five sites were randomly selected among those belonging to three impact classes: i) not impacted (i.e. protected), ii) moderately impacted, and iii) impacted. Two different non-destructive methods were applied to assess the presence of living vermetids *Dendropoma anguliferum* (Monterosato, 1878) and *Vermetus triquetrus* (Bivona-Bernardi, 1832) which shape the reef, and the associated communities. Our results highlight that no living vermetid reefs were recorded in the impacted sites where evident signs of bio-physical erosion of the reef are already underway. Living individuals of *Vermetus triquetrus* were found in some not impacted and moderately impacted sites, while living individuals of the endemic reef-builder *Dendropoma anguliferum* were found only at very low densities at the not impacted (protected) site. Such findings corroborate preliminary observations of population decline in the Eastern Mediterranean, and of vermetid reefs vulnerability to human disturbances. This raises concerns about the near future persistence of vermetid reefs in the region, and represents a call for management and conservation actions to preserve this reef-building species in the Mediterranean Sea.

1. Introduction

Vermetid gastropods are important engineers in many coastal regions of the world (Antonioli et al., 1999; Breves et al., 2017; Milazzo et al., 2017). These snails may form biogenic intertidal or shallow subtidal reefs and provide key ecosystem functions and services (Milazzo et al., 2017), by protecting the shoreline from wave erosion (Chemello and Silenzi, 2011 and references therein), acting as carbon sink and being nursery and refuge habitats from predators for many diverse species assemblages (Pandolfo et al., 1992a; Chemello, 2009; Vizzini et al., 2012; Donnarumma et al., 2014), including many invertebrates (Beneliahu, 1975; Pandolfo et al., 1992b; Chemello et al., 1998) and fish also of commercial interest (Goren and Galil, 2001; Consoli et al., 2008).

In the Mediterranean Sea, the formation and persistence of vermetid reefs depend upon the actively rim-building gregarious gastropods of the genus *Dendropoma* (Morch, 1861), often in association with *Vermetus triquetrus* (Bivona-Bernardi, 1832), another solitary vermetid, and the crustose coralline alga *Neogoniolithon brassica-florida* (Harvey) Setchell & L.R.Mason which cements their tubular shells. Restricted to the warmest part of the Mediterranean Sea (Safriel, 1974; Laborel, 1987), vermetid reefs have been reported from several locations along the Mediterranean coasts (Milazzo et al., 2017 and references therein). Molecular analyses have recently revealed that the former *Dendropoma petraeum* (Monterosato, 1884) species actually comprises a complex of four different cryptic species (Calvo et al., 2009; Golding et al., 2014) in the Mediterranean. As a result, it is now accepted that *D. petraeum* is a junior synonym of *D. cristatum* as previously proposed by (Scuderi,

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1995), the westernmost Mediterranean species was named *D. lebeche*, while the easternmost one was ascribed to *D. anguliferum* (Templado et al., 2016).

Dendropoma reefs are widespread along the warm-temperate part of the Mediterranean Sea, representing the most dominant rocky formation along the Lebanese coast (Fevret and Sanlaville, 1966; Sanlaville, 1977; Sanlaville et al., 1997; Kouyoumjian and Hamzé, 2012) that shapes the coastal seascape of many rocky areas. Nevertheless, these unique biogenic reefs are poorly studied, particularly in the Eastern Mediterranean (Galil, 2013), and are rarely object of appropriate management and monitoring activities (Milazzo et al., 2017). Following a precautionary approach, Mediterranean vermetid reefs are now listed as vulnerable habitats in the IUCN Red List (Gubbay et al., 2016), with many experts recognizing *Dendropoma* spp. (as *D. petraeum*) and *Neogoniolithon brassica-florida* as species deserving protection (Relini, 2000; Scotti and Chemello, 2000; Abdulla et al., 2009; Langar et al., 2011; Fine et al., 2017).

Indeed, an example of such lack of information is represented by the significant *Dendropoma anguliferum* (Monterosato, 1878) demise recently documented along the coast of Israel (Usvyatsov and Galil, 2012; Galil, 2013; Rilov, 2013, 2016). Such a rapid vermetid populations decline was hypothesized to be driven by multiple global (e.g. ocean warming, Rilov, 2016) and local impacts (e.g. coastal urbanization, Di Franco et al., 2011 and pollution, Rilov, 2016) occurring in the last few decades in the region.

In a similar way, the Lebanese coastline have suffered severe anthropogenic pressures in the last decades, including over-exploitation and pollution from different origins, making the current uses of coastal areas unsustainable (MOE/UNDP/ECODIT, 2011). These activities include, among others: marine sand and gravel extraction, sewage (Abboud-Abi Saab et al., 2012) and oil dumping, unsustainable and illegal fisheries (Lteif, 2015), habitat degradation, recreational uses, coastal urbanization, invasive species (Bitar et al., 2007, 2017), along with large-scale impacts such as the effects of climate change. Events like the enlargement of the Suez Canal and the deep water activities related to the recent oil and gas drilling, pose further major challenges to plan monitoring and management actions for this unique coastal ecosystem.

The aim of this study is to assess the current conservation status of the vermetid reefs along the Lebanese coastline, where they represent the most dominant rocky formation (Sanlaville, 1977). The vermetid reefs were surveyed along Lebanese coastline in five sites submitted to a different degree of human pressure, in order to correlate their conservation status with eventual impacts. The few existing historical data (Morhange et al., 2006) were also considered in order to better understand the evolution of the reefs in the recent decades.

2. Material and methods

2.1. Study area

Lying at the northeastern tip of the Mediterranean Sea (Fig. 1), Lebanon has about 220 km of coastline, characterized by a narrow continental shelf, perpendicularly crossed by various canyon systems that connect coastal zones to deep-sea habitats. Eighty percent of the Lebanese coast is rocky with the remaining 20% reported to be sandy with some gravel (MOE/UNDP/ECODIT, 2011). A literature survey of studies mentioning “vermetid reefs” (typology, description and ecology) in the sea coastline of Lebanon, has been conducted. These data included scientific papers (including non-peer-reviewed and/or non-indexed articles), books, reports submitted to international organizations (e.g. RAC–SPA and UNEP) and/or Lebanese environmental agencies. Only a few studies investigated the typology and the ecology of vermetid reefs or the associated benthic communities along the Lebanese coastline (Gruvel, 1931; Fevret and Sanlaville, 1965, 1966; Sanlaville, 1977; Bitar and Bitar-Kouli, 1995a, 1995b; Pergent et al., 2007; Bellan-Santini et al., 2015). Most of them consist in general descriptions (Bitar and Bitar-Kouli, 1995a, 1995b) and/or benthic fauna species inventories (Lakkis and Novel-Lakkis, 2000; RAC/SPA - UNEP/MAP, 2012, 2013). The evidence of living vermetid reefs along the Lebanese coastline have only been observed in a recent study (Morhange et al., 2006), reporting living *Dendropoma anguliferum (as D. petraeum)* individuals in the Tyr area.

The study was performed along five sites from the south to the north of Lebanon (Fig. 1). The selection of sites was randomly performed among sites exposed to different levels of human pressure where large vermetid reefs were present, in order to cover the whole Lebanese coastline. Human pressures were assessed on the basis of LUSI index (Land Use Simplified Index (Flo et al., 2011), as reported in Badreddine et al. (2018) (see Table 1). LUSI index integrates several pressures (i.e. urbanization, agricultural and industrial activities, sewage outfalls, commercial harbors, aquaculture or freshwater input). Subsequently, scores were assigned to each type and level of pressure and added up to produce the final LUSI value (Flo et al., 2011; Badreddine et al., 2018). Beirut and Tripoli belong to the impacted category, Tyr and Batroun to the moderately impacted and Nakoura to the not impacted ones (Fig. 1).

2.2. Sampling procedures

The surveys were conducted at low tide and under calm water conditions. At each sites, a quali-quantitative description of the reef was performed, considering the following variables: (i) reef width from the inshore towards the open sea, (ii) presence of the “cuvettes” between edges of each vermetid platform and (iii) height of the inner and the outer margins.

The assessment of living and dead vermetids (*Dendropoma anguliferum* and *Vermetus triquetrus*) and of the whole benthic assemblages was performed by random 10 × 10 cm quadrats and point intercept transects. Since the vermetid distribution can be very patchy particularly when disturbed, and the spatial scale of the different anthropogenic impacts we considered was unknown, these two techniques were employed to avoid underestimation of vermetids presence. At each sampling site, for vermetid density assessment, ten 10 × 10 cm plots were randomly placed both in the inner (i.e. 5 photo - replicates) and the outer edges (5 photo -replicates) of the reefs and photographed with a digital camera (Sony, DSC-W550). In the laboratory, the density of living vermetid individuals was estimated on each photo by counting the shell opercula, which protect the living animal from predation, desiccation and wave impact and get lost in dead individuals. Empty shells were also counted to assess the density of dead vermetid individuals. Density counts were performed using the open access ImageJ software (Schneider et al., 2012) and values were reported as number of individuals/100 cm^2. For the estimation of the associated community, 10 random 5 m long transects, parallel to the coastline were laid along both the inner edge (i.e. 5 transects) and the outer edge (i.e. 5 transects) of the reefs. Species were recorded every 20 cm for each 5 m transect (25 points/transect). The percentage cover of living vermetids (*Dendropoma anguliferum* and *Vermetus triquetrus*), of the calcareous encrusting algae *Neogoniolithon brassica-florida* cementing their shells, and of other algae and invertebrate species were then calculated for each replicated transect. The visual census of the benthic communities allowed us to identify 11 Operational Taxonomic Units (OTUs) of algae and invertebrates for the multivariate analyses (Table 2).

2.3. Data analyses

Statistical differences in the benthic assemblages were tested by permutational multivariate analysis of variance (PERMANOVA) based on Bray-Curtis resemblance matrix of square-root transformed data (Anderson, 2001). A two-ways orthogonal model was used, with both Site (Si, 5 levels: Nakoura, Tyr, Beirut, Batroun and Tripoli) and Edge

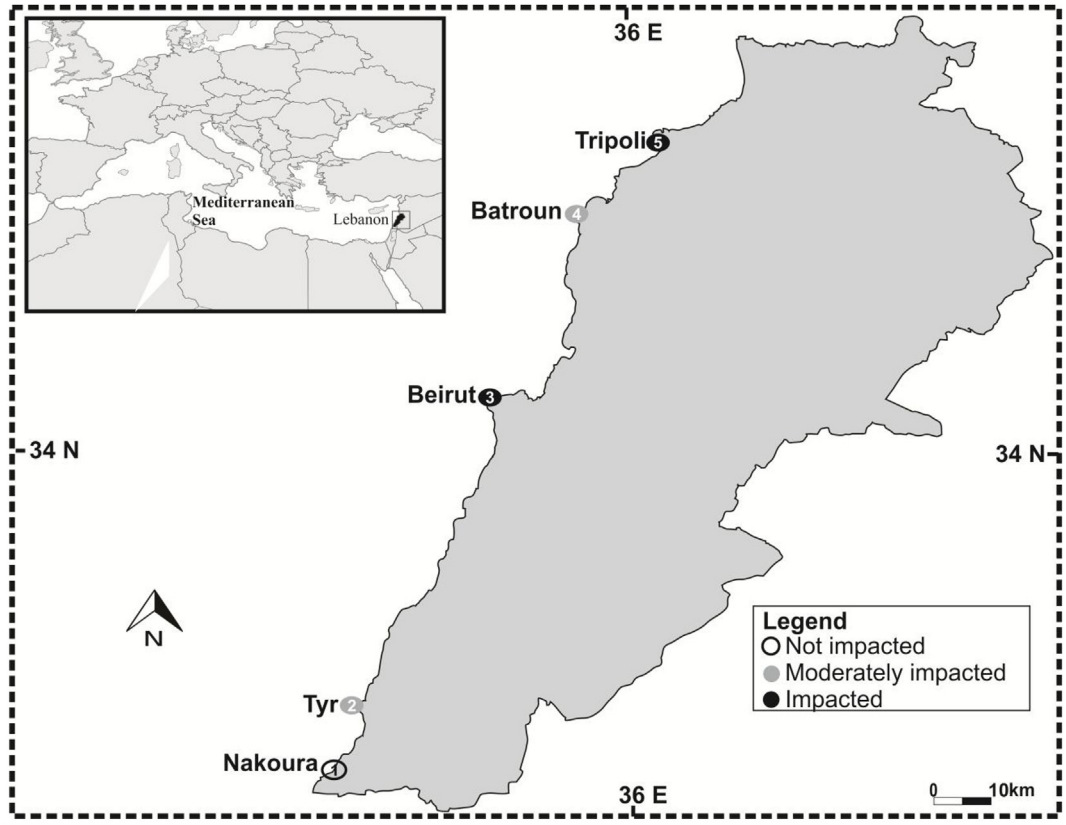

Fig. 1. Map of Lebanon showing the location of the five monitored sites. 1- Nakoura (Not impacted); 2- Tyr (Moderately impacted); 3- Beirut (Impacted); 4- Batroun (Moderately impacted) and 5- Tripoli (Impacted).

Table 1
Sites considered for the assessment of vermetid reefs along Lebanese coast, their coordinates, the corresponding calculated LUSI index and conditions (see Flo et al., 2011 for further details).

Sites	Latitude, longitude	LUSI	Conditions
Nakoura	33° 8′25.15″N, 35° 9′14.82″E	0.00	Not impacted
Tyr	33°16′33.58″N, 35°11′34.64″E	3.00	Moderately impacted
Beirut	33°54′9.15″N, 35°29′2.02″E	26.00	Impacted
Batroun	34°15′1.26″N, 35°39′23.97″E	7.00	Moderately impacted
Tripoli	34°26′15.77″N, 35°48′40.03″E	29.00	Impacted

(Ed, two levels: outer and inner) as a fixed factor. To test the differences between Sites (Si), the density data of both living and dead vermetids (*Dendropoma anguliferum* and *Vermetus triquetrus*) were analyzed by one-way PERMANOVA based on Euclidean distance matrix of untransformed data. For all the PERMANOVAs, P-values were obtained from 9999 permutations. Pair-wise t tests were performed in order to discern eventual differences among levels of significant factors or their interaction. Monte Carlo tests were also considered in case of low numbers of unique permutations.

PERMANOVA results were visualized by non-metric multi-dimensional scaling (nMDS) ordinations performed on the Bray-Curtis similarity matrix applied to square root transformed data. The PRIMER 6, PERMANOVA package was used to perform statistical analyses (Clarke and Gorley, 2006).

3. Results

3.1. General description of the Lebanese vermetid reefs

The vermetid reefs of the Lebanese coast form intertidal platforms, with lengths from 70 m (Tyr) to nearly 170 m (Batroun). A general

Table 2
List of observed species and how they were organized in Operational Taxonomic Units (OTUs) for the community analyses.

OTU designation	Species	Taxonomic group
DEND	*Dendropoma anguliferum* (Monterosato, 1878)	Gastropod
VERM	*Vermetus triquetrus* (Bivona-Bernardi, 1832)	Gastropod
PATE	*Patella* spp. (Linnaeus, 1758)	Gastropod
BRAC	*Brachidontes pharaonis* (P.Fischer, 1870)	Bivalve
CHTH	*Chthamalus* spp. (Ranzani, 1817)	Cirriped
ACOR (Articulated Corallinales)	*Corallina* spp. (Linnaeus), *Ellisolandia* elongata (J.Ellis & Solander), *Jania* spp. (J.V. Lamouroux)	Algae
SARG	*Sargassum vulgare* (C.Agardh)	Algae
UPHO (Ubiquist Photophilic Algae)	*Padina pavonica* (Linnaeus) Thivy, *Dictyota* spp. (J.V.Lamouroux), *Dictyopteris polypodioides* (A.P.De Candolle), *Taonia atomaria* (Woodward), *Palisada perforata* (Bory)	
ULVA	*Ulva* spp. (Linnaeus)	Algae
NEOG	*Neogoniolithon brassica-florida* (Harvey) Setchell & L.R. Mason	Algae
CYAN	*Rivularia* spp. (C.Agardh)	Cyanobacteria

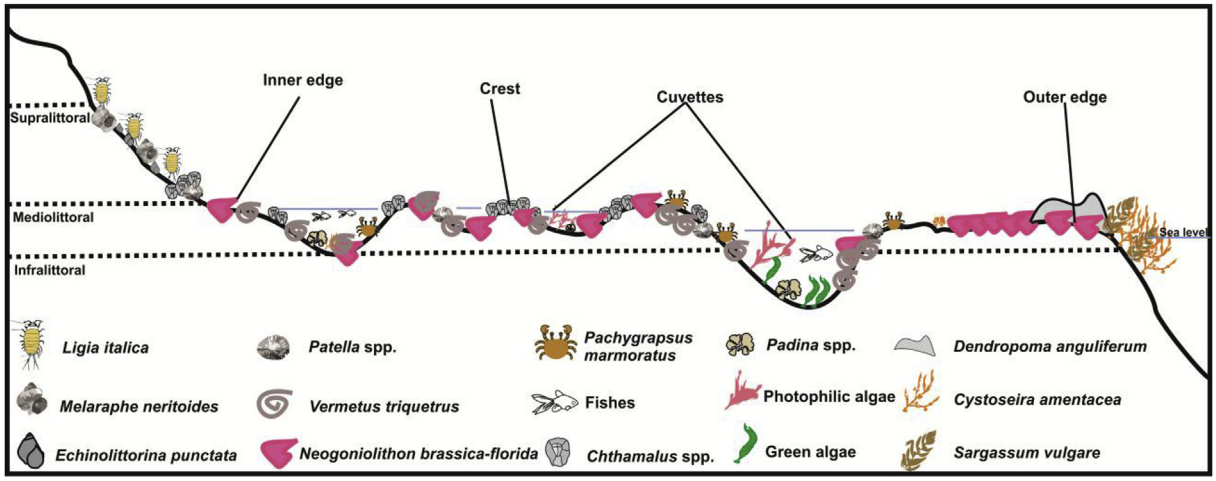

Fig. 2. Schematic illustration of a typical vermetid reef along the Lebanese coast, reporting the relative position of the reef according to the sea level (supralittoral, upper and lower mediolittoral and infralittoral, following the Mediterranean scheme (Pérès and Picard, 1964), and some characteristic species.

scheme of the reef topography is reported in Fig. 2 (according to Molinier, 1955), while a detailed description of the five monitored sites is reported in Fig. 3. Moving seaward, the platforms can be divided into three typical morphological zones (according to Antonioli et al., 1999): the outer edge, the "cuvettes" and the inner edge (Fig. 2). The outer edge is wide, flattened with some crevices in Nakoura (Fig. 3.1), Tyr (Fig. 3.2) and Batroun (Fig. 3.3) reefs, while is thin and sometimes absent in the platform of Beirut (Fig. 3.5) and Tripoli (Fig. 3.4). The inner edge is irregular with many tidal pools in Nakoura, Tyr and Batroun platforms, and is mostly shallow and often lacking "cuvettes" in Tripoli and Beirut. The macrobenthic species identified on the Lebanese vermetid reefs were typically the lichen *Verrucaria amphibia* (Clemente), the littorinids *Melarhaphe neritoides* (Linnaeus, 1758) and *Echinolittorina punctata* (Gmelin, 1791)), and the isopoda *Ligia italica* (Fabricius, 1798) in the supralittoral zone. The sessile fauna was mostly represented by *Chthamalus depressus* (Poli, 1791) and *C. montagui* (southward, 1976), whereas mobile species such as *Patella ulyssiponensis* (Gmelin, 1791) and *P. rustica* (Linnaeus, 1758) and the intertidal crab *Pachygrapsus marmoratus* were found in the upper midlittoral zone. The lower midlittoral rock was characterized by *Vermetus triquetrus* occurring in the inner edge and *Dendropoma anguliferum* only present in the outer edge of the Nakoura reefs; along with other mobile invertebrates like the gastropods *Patella ulyssiponensis* and *Phorcus turbinatus* (Born, 1778), and the crab *Pachygrapsus marmoratus* (Fabricius, 1787). Often vermetid species were in association with the red encrusting alga *Neogoniolithon brassica-florida*. Shallow tidal pools or "cuvettes", considered an infralittoral enclave, were frequent in the Lebanese vermetid reefs and were mostly dominated by macroalgae (e.g., Corallinales, Dictyotales, Sphacelariales and Ulvales) (Fig. 2).

3.2. Assessment of vermetid population densities and benthic assemblages along the Lebanese coast

Photo-sampling to assess the vermetid population density over the five sites spanning the Lebanese coast revealed that the maximum of living vermetid density was on average 11 individuals ± 4.2/100 cm^{-2} (Mean ± S.E.), of *V. triquetrus* in the inner edge of the Nakoura reefs (Fig. 4). On the outer edge of Nakoura reefs (the only site where living *Dendropoma* were observed) mean density of *Dendropoma anguliferum* was 1 individual ± 0.1/100 cm^2 (Mean ± S.E.) was recorded uniquely (Fig. 4). Both vermetid species were absent at the impacted sites of Beirut and Tripoli, and only *V. triquetrus* was recorded in the moderately impacted reefs of Tyr (1 individual ± 2.0/100 cm^2, Mean ± S.E.) and Batroun (3 individuals ± 4.3/100 cm^2, Mean ± S.E., Fig. 4). The statistical analyses (univariate PERMANOVA and pair-wise t tests) provided consistent results for the living individuals of the two considered vermetid species (Table 3), showing significant differences among sites. Tyr was not significantly different from the other sites, showing therefore an intermediate position, meanwhile for Beirut, Tripoli and Batroun the denominator was equal to zero. Densities of dead vermetids peaked in Batroun, Tyr and Nakoura for *Dendropoma anguliferum* and in Tripoli and Batroun for *Vermetus triquetrus,* showing no difference among sites (Table 4).

Historical data on the conservation state of vermetid reefs in the Eastern Mediterranean are very rare, and almost absent in Lebanon. A study performed in 2000/2002 (Morhange et al., 2006) mentioned a living *Dendropoma* rim in Tyr region, where no living *Dendropoma* were found in the present study. Multivariate PERMANOVA on the benthic assemblages (transect method) showed a significant 'Edge x Site' effect (Pseudo-F: 23.873; $p < 0.001$; Table 5) and pair-wise comparisons showed highly significant differences between sites either in the outer or the inner edge (Pair-wise t tests, Table S1). In agreement with PERMANOVA results, the points are separated in the nMDS representation, confirming that composition and structure of the benthic assemblages of both the outer and inner reef edges strongly differed among the five sites (Fig. 5). The three level of human pressures (high, moderate and low) are disposed along a gradient from the right to the left of the graph. Both the inner and the outer edges communities are less homogeneous (more variable) in Tripoli, as proved by the high dispersion of points, compared to the other sites (Fig. 5).

According to results obtained with the photoquadrats method, living individuals of *Dendropoma anguliferum* were only recorded, with the transect method, at the outer edge of Nakoura (with an average 14.5% cover, Fig. 6). Similarly, *Vermetus triquetrus* was recorded in patches in the inner edge of Nakoura, Batroun and Tyr (with average values ranging from 16% to 40%).

In the inner edge, the reef-building encrusting red alga *Neogoniolithon brassica-florida* dominated in the not impacted site of Nakoura and at the moderately impacted sites of Tyr and Batroun (with average values ranging between 40% and 50%). Similar patterns were observed on the outer edge, apart in the Tyr vermetid reefs, where macroalgae represented by ACOR (Articulated Corallinales) and UPHO (Ubiquist Photophilic Algae) were the most dominant group with on average more than 60% cover. Cyanobacteria and *Ulva* spp. mostly characterized the impacted reefs of Beirut and Tripoli, where % cover of bare rock, likely covered by biofilm, was also very high (Fig. 6).

4. Discussion

The present study represents the first assessment of vermetid

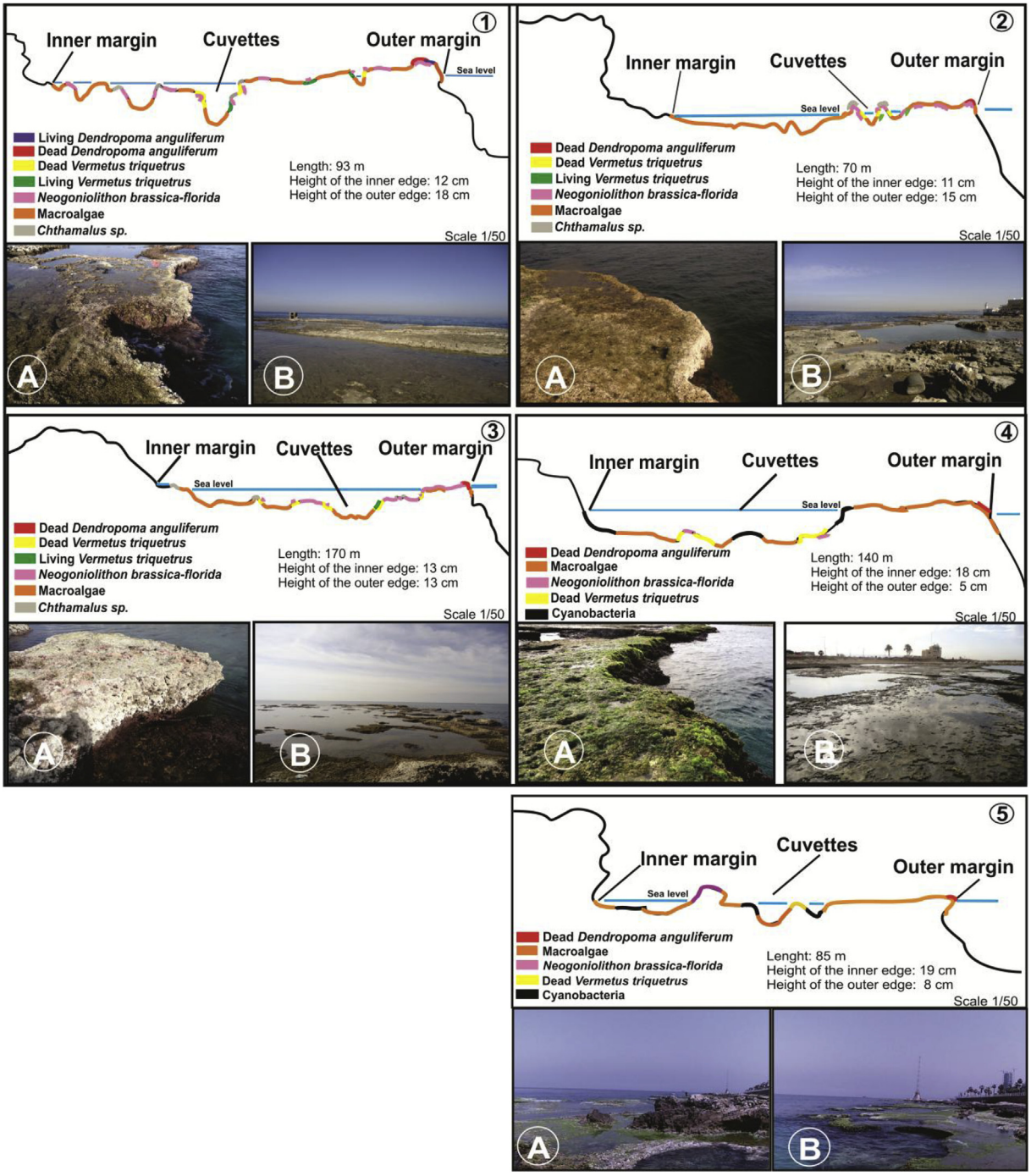

Fig. 3. Reef topography and pictures of the outer/inner edge of the considered vermetid platforms. 1) Nakoura; 2) Tyr; 3) Batroun; 4) T ripoli; 5) Beirut. A) outer edge; B) inner edge.

populations along the Lebanese coast and one of the few for the Levantine Sea (Eastern Mediterranean). It meets the urgent need of addressing the potential impacts of anthropogenic activities on the intertidal reefs built by *Dendropoma anguliferum*, an endemic species of the Levantine Sea, whose local extinction seem to be presently underway (Galil, 2013; Rilov, 2016). The observations performed prove that Lebanese vermetid reefs have a similar general morphology to the one described along Israeli (Lipkin and Safriel, 1971; Safriel, 1974), Syrian (Al-Nimeh and Elassafin, 1996) and Italian (Molinier, 1955; Antonioli et al., 1999) coasts, showing very large intertidal platforms between the reef edges (Fig. 2) (Sanlaville, 1977; Chemello and Silenzi, 2011). Along the Lebanese coast, *Dendropoma anguliferum* individuals in association with the encrusting alga *Neogoniolithon brassica-florida* are found in the seaward outer edge of the reef, exposed to higher wave energy. By contrast, the landward inner edge, exposed to a longer period of emersion during low tide and higher desiccation stress in the warmest months, is mostly characterized by *Vermetus triquetrus*.

Remarkably, the presence of living individuals of *Dendropoma anguliferum*, at very low densities, was observed uniquely at the not impacted reef of Nakoura. Living individuals of *Vermetus triquetrus* were recorded at the not impacted reef of Nakoura and, at lower densities, at the moderately impacted reefs of Tyr and Batroun. The present study also shed light on the distribution of the encrusting calcareous algae *Neogoniolithon brassica-florida,* considered as a significant

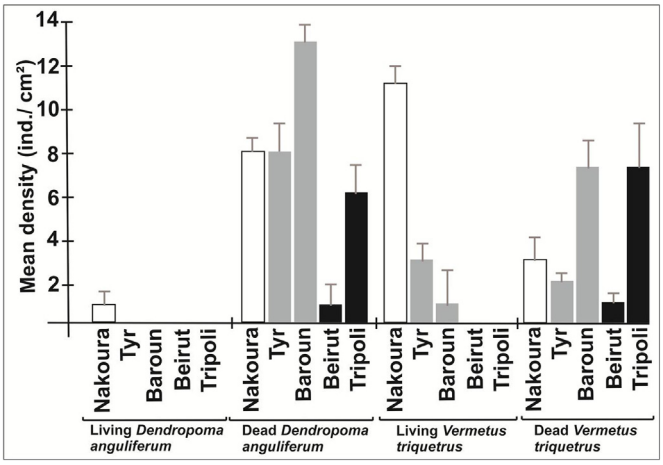

Fig. 4. Mean density (± standard error)/100 cm^2 of living and dead vermetids (*Vermetus triquetrus* and *Dendropoma anguliferum*) at the five monitored sites. White: not impacted; grey: moderately impacted; black: impacted.

Mediterranean reef–builder (Milazzo et al., 2017), along the surveyed Lebanese reefs. As a result, a high percentage coverage of *Neogoniolithon brassica-florida* was recorded in both the inner and outer edges at the not impacted reef of Nakoura and the moderately impacted reefs of Tyr and Batroun, where living individuals of vermetids are still present. At the impacted sites of Beirut and Tripoli, where only dead vermetids were recorded, *N. brassica florida* was nearly absent. The potential decline of *N. brassica florida* along disturbance gradients have also been reported along the Israeli (Fine et al., 2017) and Tunisian coast (Langar et al., 2011), confirming the sensitivity of *N. brassica-florida* to both natural (e.g. acidification, Milazzo et al., 2014; Fine et al., 2017; and sea warming, Rilov, 2016) and human pressures. The observed changes in the composition and structure of benthic assemblages suggested a general decrease in community complexity and species diversity from the not impacted to the impacted sites. More specifically, the canopy–forming *Sargassum vulgare* (Fucales, Phaeophyceae) was only recorded at the not impacted site of Nakoura, whereas less complex algae represented by ACOR and UPHO dominated the moderately impacted reef of Tyr and Batroun. *Ulva* spp. and cyanobacteria characterized the impacted sites of Beirut and Tripoli. These results are in agreement with the general trend of fucoid loss and replacement by turf algae well described along Mediterranean coasts by several studies (Ballesteros et al., 2007; Mangialajo et al., 2008; Airoldi et al., 2014; Connell et al., 2014; Strain et al., 2014; Blanfuné et al., 2017; Mancuso et al., 2017; Badreddine et al., 2018; Orlando-Bonaca and Rotter, 2018).

The comparison with the few existing historical data allowed highlighting that the loss of individuals of *Dendropoma anguliferum* in the Tyr region seems to have happened in a recent past, as the presence of living individuals (as *Dendropoma petraeum*) was reported in 2002 (Morhange et al., 2006). A further evidence of a recent process of loss is represented by the observed high density of dead shells in the not impacted and the moderately impacted sites. The low abundance of dead shells in the high impacted site of Beirut could be the sign of an older loss followed by the erosion of the shells. Studies performed along the Italian coasts showed a range of *Dendropoma cristatum* individuals densities from 31 individuals/100 cm^2 in an impacted site up to more than 650 individuals/100 cm^2 (Di Franco et al., 2011, as *D. petraeum*; Fine et al., 2017), with a mean value of around 300 individuals/100 cm^2. Along the Israeli coast, Usvyatsov and Galil (2012) quantified, in 2003, less than 1 individual per 100 cm^2 densities of *Dendropoma anguliferum* (as *D. petraeum* - complex), while Fine et al. (2017) did not found any living *D. anguliferum* individual in 2012. The density of living *Dendropoma* recorded at the not impacted Lebanese reefs (1 individuals per 100 cm^2) is comparable with values found along Israeli coast in 2003 (Usvyatsov and Galil, 2012), that can be likely considered as representative of a suffering reef (only dead individuals were observed 9 years after by Fine et al., 2017). The densities reported in the Levantine Sea are very low when compared to the densities reported in Sicily, even when considering an impacted site, where around 100 individuals of living *Dendropoma cristatum* (as *Dendropoma petraeum*) were recorded per 100 cm^2 (Di Franco et al., 2011). Nevertheless such comparison has to be taken with care, the pressures in Sicily can be different from the Lebanese ones, with potentially different consequent impacts and it is now know that two different species are present in the two sites. It is worth stressing that the natural recovery of reefs where *Dendropoma* spp. populations are lost is very unlikely, because of the low recruitment of this species, even from adjacent healthy reefs (Milazzo et al., 2017): in fact *Dendropoma* species show a peculiar reproduction characterized by low connectivity and dispersal range (Calvo et al., 1998), as snails brood their young and the hatchlings crawl only a short distance before becoming a sessile individuals (Milazzo et al., 2017). The presence of living *Vermetus triquetrus*, at low densities, in moderately urbanized sites (Tyr and Batroun reefs), is likely due to the fact that *Vermetus triquetrus* is less sensitive to human pressures (Schiaparelli et al., 2003; Calvo and Templado, 2005) and that his dispersal potential is higher (Bieler, 1995; Schiaparelli and Cattaneao-Vietti, 1999; Schiaparelli et al., 2003, 2006; Calvo and Templado, 2005). The causes of the *Dendropoma anguliferum* ongoing loss are still unknown (Milazzo et al., 2017). Several hypotheses have been proposed to explain such large mortality events, which seem to be led by the combined multiple natural and human stressors (Rilov, 2016). The Lebanese coastline, as the entire Eastern Mediterranean Sea, is experiencing major ecosystems-wide changes, due to the multiple and massive anthropogenic and natural pressures, such as climate change (e.g. the rise of the Sea Surface Temperature SST, Abboud-Abi Saab et al., 2013), overfishing (Lteif, 2015), pollution and coastal urbanization: as an example, artificialization of the coastline concern 32% of the Lebanese coastline (Badreddine et al., 2018). A supplementary potential threat is the trampling of tourists and fishermen that may affect vermetid recruits

Table 3
One - way PERMANOVA and pair wise t tests on the densities of *Dendropoma anguliferum* and *Vermetus triquetrus*. Si: Sites. MC: Monte-Carlo. Statistically significant values are in bold.

Living vermetids	*Dendropoma anguliferum*					*Vermetus triquetrus*				
Source	df	SS	MS	Pseudo-F	P(MC)	df	SS	MS	Pseudo-F	P(perm)
Si										
Res	45	2	0.1			45	2047.6	45.502		
Total	49	3.36				49	2798.3			

Pairwise test (Si)	t	P(MC)	Pairwise test (Si)	t	P(MC)
Nakoura vs. Beirut	2.4495	**0.0376**	Nakoura vs. Beirut	2.3313	**0.0308**
Nakoura vs. Tripoli	2.4495	**0.0367**	Nakoura vs. Tripoli	2.3313	**0.0309**
Nakoura vs. Batroun	2.4495	**0.0364**	Nakoura vs. Batroun	2.3313	**0.0325**

Table 4
One - way PERMANOVA on the densities of dead individuals of *Dendropoma anguliferum* and *Vermetus triquetrus*. Si: Sites.

Dead vermetids	*Dendropoma anguliferum*					*Vermetus triquetrus*				
Source	df	SS	MS	Pseudo-F	P(perm)	df	SS	MS	Pseudo-F	P(perm)
Si	4	693.3	173.3	1.563	0.198	4	750.72	72.23	1.383	0.236
Res	45	4991	110.9			45	2047.6	52.229		
Total	49	5684				49	2798.3			

Table 5
PERMANOVA analysis on the benthic assemblages (transect method). Ed: reef Edges; Si: Sites. Statistically significant values are in bold.

Source	Df	SS	MS	Pseudo-F	P(perm)
Edge (Ed)	1	34805	34805	181.39	**0.0001**
Site (Si)	4	45639	11410	59.463	**0.0001**
EdxSi	4	18323	4580,8	23.873	**0.0001**
Res	40	7675,2	191,88		
Total	49				

survival and settlement success (Milazzo et al., 2017) as well as the associated benthic assemblages (Milazzo and Ramos-Esplá, 2000; Milazzo et al., 2004). It is also likely that the prolonged exposure to solar radiation and to higher documented air temperatures, particularly during the warmest summer months and at low tide (Franzitta et al., 2016), could have been lethal for *Dendropoma* recruits. The vermetid platform can also be place of choice for the deliberate or accidental settlement of introduced species, such as the lessepsian bivalve *Brachidontes pharaonis* that replaced *Mytilus galloprovincialis* (Lamarck, 1819) in Lebanese vermetid reefs (Gruvel, 1931; Bitar, 2008). It may

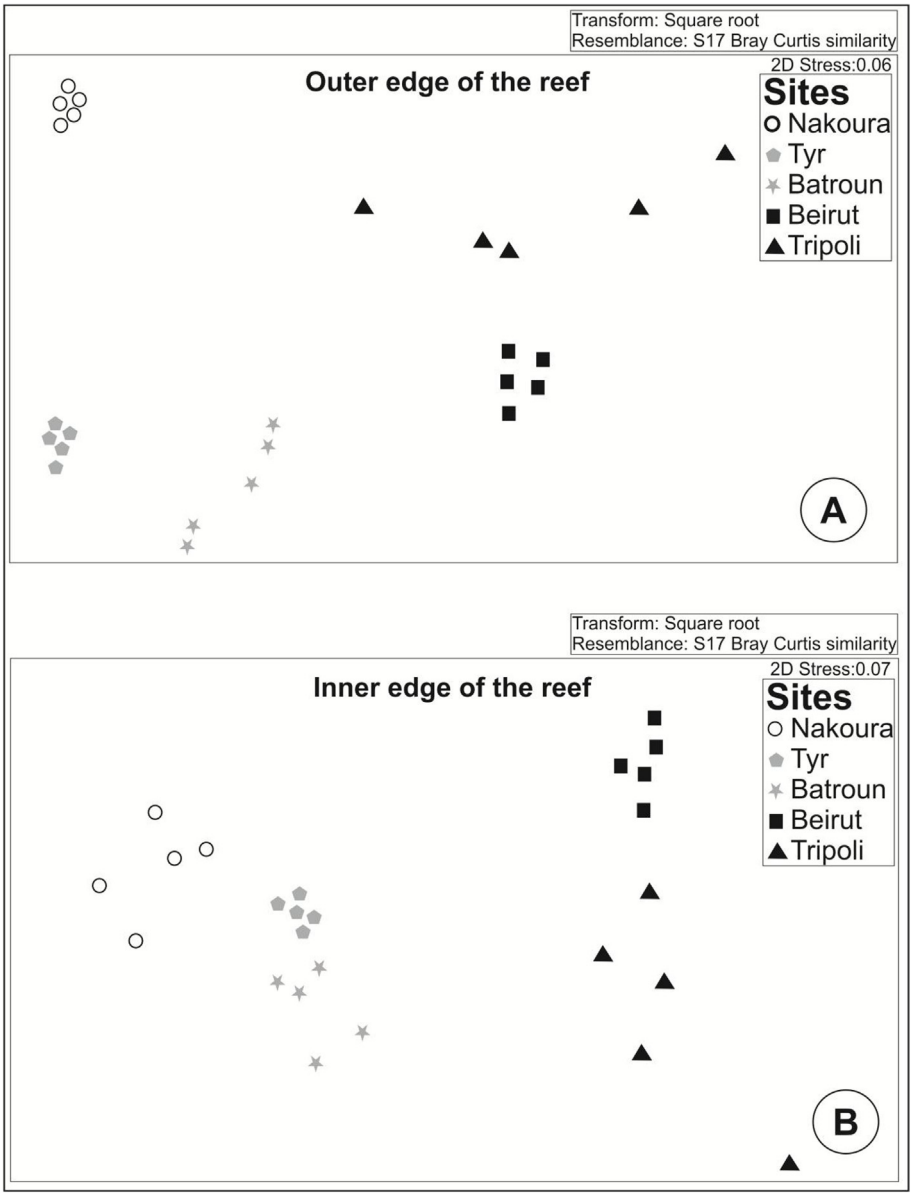

Fig. 5. Non-metric multi-dimensional scaling (nMDS) on benthic assemblages,. A) outer edge and B) inner edge. 1- Nakoura (Not impacted); 2- Tyr (Moderately impacted); 3- Beirut (Impacted); 4- Batroun (Moderately impacted) and 5- Tripoli (Impacted).

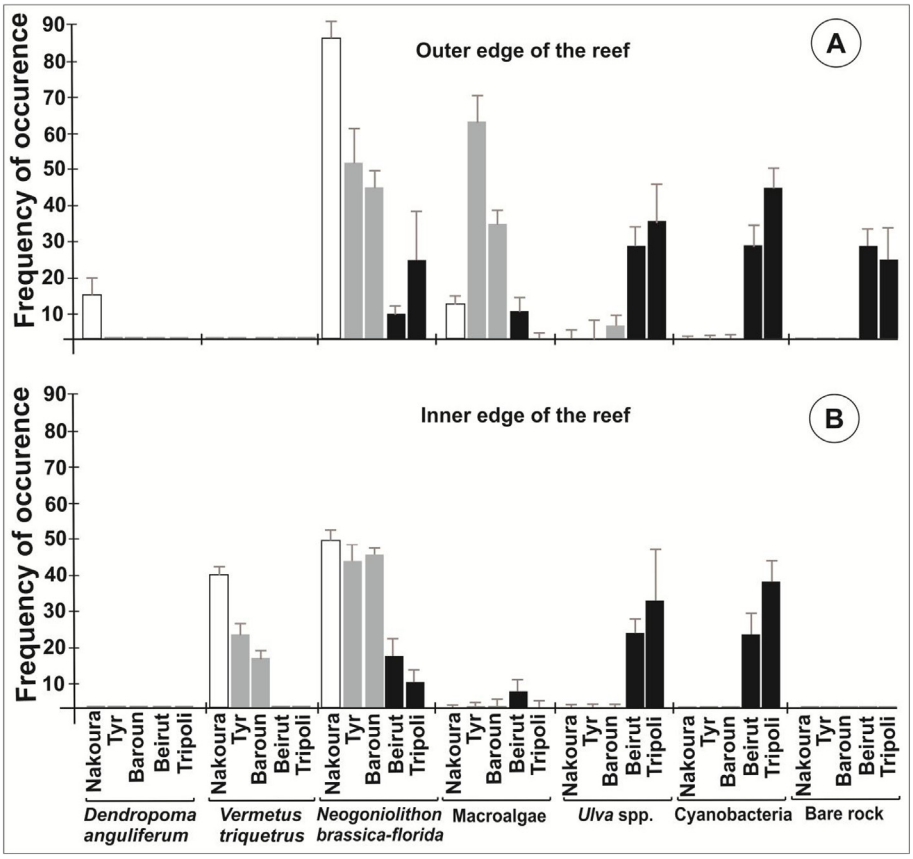

Fig. 6. Frequency of occurrence ± standard error (S.E.), of major benthic species (and bare rock) at A) the outer edge and B) the inner edge of the vermetid reef of the five studied sites. White: not impacted; grey: moderately impacted; black: impacted. For abbreviations, see Table 3.

represent an additional direct threat to the vermetid persistence (Milazzo et al., 2017 and references therein), but such hypothesis still have to be confirmed by experimental evidences (according to Rilov (2016), *D. petraeum* does not have non-indigenous competitors or predators). In summary, the present study corroborates the initial hypothesis that the endemic vermetid *Dendropoma anguliferum* is under local extinction throughout the Eastern Mediterranean Sea (Galil, 2013; Milazzo et al., 2017). The living individuals observed in Nakoura should be the object of regular monitoring surveys (using non-destructive methods) and protection measures should be implemented, such as limiting trampling. Further studies should be performed, especially in remote areas of the Levantine basin (i.e. offshore small islands) in order to better assess the present distribution of living populations of *Dendropoma anguliferum* and investigate their ecology. Replenishment of lost areas in the framework of ecological restoration actions should be planned, once the causes of loss have been identified and removed.

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Appendix A. Supplementary data

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