Anthropic pressure due to lost fishing gears and marine litter on different rhodolith beds off the Campania Coast (Tyrrhenian Sea, Italy)

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Abstract. Impact of fishing gears and marine litter is a recognized global socio-ecological issue. Little is known about the extent of the problem in the Mediterranean seabed; even less information is available regarding litter distribution and its effects on deep rhodolith beds. Indeed, Mediterranean rhodolith beds are often remote and not yet sufficiently explored habitats, despite being internationally protected and recognized among the most important benthic communities for biodiversity maintenance. In this study, a quantitative assessment of marine litter and lost fishing gears, observed using a remotely operated vehicle, was carried out in 6 sites off the Campania Coast (Tyrrhenian Sea) characterized by different rhodolith covers. A negative correlation between abundance and richness of both marine litter and abandoned fishing gears with respect to the rhodolith cover was detected, suggesting that indirect human pressure along the coasts and direct effect of fishing activities might negatively damage these habitats. In fact, a lot of abandoned fishing gears and litter were recorded in all the 4 sites of the Gulf of Naples, confirming the high impact of maritime activities in this overcrowded area. Particularly, the Secchitiello site showed a very low mean cover of rhodoliths (<5%) in concurrence with the highest abundance of lost fishing gears and litter. On the contrary, the lowest abundance of fishing gears and litter was recorded in the 2 sites along the Cilento coast, possibly due to the relatively low maritime activities in this poorly inhabited area. In conclusion, this work gives new insights into the anthropic pressure due to marine litter and fishing on deep Mediterranean rhodolith beds, and provides useful data for their management and conservation.

Keywords: deep biogenic habitats, coralline red algae, ROV, habitat degradation, human impacts, marine debris, Mediterranean Sea

1. Introduction

Rhodolith beds (RBs) are biogenic calcareous habitats formed by the aggregation of unattached, non-geniculate coralline algae (Corallinophycidae, Rhodophyta). In the Mediterranean Sea, together with *Posidonia* meadows, coralligenous and vermetid bioconstructions, they are considered as extremely biodiverse benthic habitats of high conservation and economic value (Ballesteros E., 2006; Basso

et al., 2016; Franzese et al., 2017; Vassallo et al., 2017; Donnarumma et al., 2018; Buonocore et al., 2018, 2019, 2020a, 2020b), supporting a high diversity of associated species, some of which are commercially important (Soto, 1990; Mannino et al., 2002; Castriota et al., 2003, 2005; Templado et al., 2002; Hall-Spencer et al., 2003). These habitats are often affected by degradation and loss of structural heterogeneity due to anthropogenic disturbances, at both global scale, such as climate change, which will likely

impact coralline algae in the near future (Ragazzola et al., 2012, 2016; Donnarumma et al., 2014; Rendina et al., 2019; Rindi et al., 2019), and local one, such as fishing activities, that causes mechanical impact and sediment accumulation (Marrack, 1999; Bordehore et al., 2000, 2003; Kamenos et al., 2003; Foster et al., 2013). In fact, despite their hard carbonate thallus, rhodoliths are often fragile (particularly mäerl forming species), and with low growth rates, of the order of just 1 mm year^{-1} (also depending on the coralline alga species, and the light intensity and temperature; Blake and Maggs, 2003; Martin and Gattuso, 2009; Foster et al., 2013). For this reason, RBs are particularly affected by mechanical damages due to bottom fisheries (i.e. dredging, fishing gears, bottom trawling), which can result in a reduction of the rhodolith cover, size and structure, loss of living thalli, and eventually transition into sand flats, characterized by a lower diversity and abundance of associated flora and fauna (Kaiser et al., 2001; Hall-Spencer and Moore, 2000; Bordehore et al., 2000, 2003; Hall-Spencer et al., 2002, 2003; Fosså et al., 2002; Steller et al., 2003; Blanchard et al., 2004). Moreover, sediment re-suspension due to fishing causes habitat degradation with burial and anoxia phenomena (Watling and Norse, 1998; Hall-Spencer and Moore, 2000; Foster et al., 2013; Bo et al., 2014). Fishing may also cause severe modifications of structure and functioning of deep ecosystems, leading to a shift in species composition towards opportunistic species with faster growth rates (Harris and Poiner, 1991; MacDonald et al., 1996; Schiaparelli et al., 2001; Clark and Koslow, 2007; Daskalov et al., 2007; Gilman et al., 2012). Additionally, fishing gears and marine litter produce an impact when they are abandoned in the environment, with a large variety of marine organisms damaged by entanglement and ingestion (Carr, 1987; Matsuoka et al., 2005; Brown and Macfadyen, 2007; Gall and Thompson, 2015; Vieira et al., 2015). Hence, the accumulation of abandoned fishing gears and litter is considered as one of the major causes of degradation of the marine environment at global scale, and several studies are trying to estimate their distribution, composition and abundance, and to evaluate their impacts on marine ecosystems (Watters et al., 2010; Galgani et al., 2015; Gall and Thompson, 2015; Vieira et al., 2015).

Only in the last decades, the importance of RBs and their high vulnerability to human pressures have been recognized, and several legal instruments have been adopted for the protection of RBs in European Seas. The first European initiative to protect these habitats was the Habitats Directive 92/43/EEC, which included the two fragile mäerl species, *Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin *ex* Woelkering & L.M. Irvine (1986) and *Lithothamnion corallioides* (P. Crouan & H. Crouan) P. Crouan & H. Crouan (1867), among those species affected by exploitation of marine resources and for which Member States have to ensure effective conservation measures (Basso et al., 2016). In 2006, the Council Regulation 1967/2006 banished some specific bottom fishing gears on coralligenous and RBs (Council of the European Union, 2006). However, the lack of information available on RB spatial distribution makes difficult the effective application of this Regulation (Basso et al., 2016). Finally, Mediterranean RBs have been recently included among the habitats of special interest within the Marine Strategy Framework Directive (MSFD-2008/56/EC), aiming at achieving the 'Good Environmental Status' (GES) of all marine waters by 2020 (European Parliament and Council of the European Union, 2008; European Commission, 2010; Basso et al., 2016). Thus, the assessment of coralline algae distribution and biodiversity has been included within the monitoring protocol as descriptor to evaluate the GES (Basso et al., 2016). Moreover, among the eleven qualitative descriptors of GES (listed in Annex I of the MSFD), one of them concerns marine litter.

Despite the RBs vulnerability and value, both ecological and economic, there are very few studies about their distribution and characterization in the Mediterranean Sea (Basso et al., 2017), and even less information is available on the anthropic disturbances affecting these fragile habitats. This information gap is probably due to the remoteness of these habitats and the difficulties in observing and sampling organisms by scuba diving, compared to extra-Mediterranean shallower beds (Basso et al., 2014, 2016). Recent technological advances in Remotely Operated Vehicles (ROVs) allow to monitor deep sea habitats (e.g. coralligenous bioconstructions and RBs) on a wide area, with non-destructive and standardized protocols, based on computerized analysis of high resolution videos and photos (Aguilar et al., 2009; Bo et al., 2014; Ferrigno et al., 2017, 2018, 2020). ROV investigations have also been successfully performed to obtain quantitative data on benthic marine litter (Bergmann and Klages, 2012; Angiolillo et al., 2015) and to evaluate the impact of fishing activities, through lost gears, in coastal ecosystems (Bo et al., 2014; Cattaneo-Vietti et al., 2016; Ferrigno et al., 2017, 2018).

Despite Campania Coast (Italy, Tyrrhenian Sea) is known to be characterized by a high level of coastal urban population, tourism, and commercial fishing, there are no data available on the abundance of marine litter and fishing pressure on its RBs. The aim of this study is to fill this lack of information by ROV imaging technique and to assess the entity of the anthropic pressure produced by marine litter and fishing gears on deep RBs (40–80 m depth) recorded off the Campania Coast.

2. Materials and methods

Study area

Surveys have been carried out in 2017 and 2018, in a depth range between 42 and 78 m, in six sites off the Campania Coast. The investigation sites were chosen both from the previous records of coralline algal deposits along the Campania Coast (Babbini et al., 2006; Toscano et al., 2006; Gambi et al., 2009; Savini et al., 2012), and from the empirical knowledge of fishermen. In detail, four sites were selected within the overcrowded Gulf of Naples (Fig. 1A): Capri (40°32'20.545''N, 14°13'17.653''E), Punta Campanella (40°32'20.545''N, 14°13'17.653''E), Secchitiello (40°34'45.538''N, 14°17'15.261''E), Ischia (40°46'34.774''N, 13°53'49.401''E); and two sites off the poorly inhabited Cilento Coast (Fig. 1B): Acciaroli A (40°8'9.582''N, 15°3'46.011''E) and Acciaroli B (40°6'37.685''N, 15°3'39.149''E).

ROV data acquisition and analysis

Following the MSFD protocols for RBs monitoring, data were collected by a Remotely Operated Vehicle (ROV

"Perseus" of Ageotec) equipped with a high definition video camera (DVS-3000 high definition), 2 lights, 2 parallel laser beams at the fixed distance of 14.5 cm for the evaluation of the dimensions. The ROV also hosted a further camera with displayed navigation data, obtained by the underwater positioning system USBL (Ultra Short Base Line System), interfaced with the on-board navigation system. This equipment allows to determine the real time geographical position and depth of the ROV videos.

At each site, 3 video-transects were carried out, with a length of 200 m each (covering an area of 1800 m²) and a distance of at least 50 m from each other. HD videos by ROV were analysed using the software VisualSoft®. A visual assessment of the sea bottom, characterized by rhodolith presence, was carried out on 60 images for site (20 images for video-transect), for a total of 360 analysed video frames. The video frames were obtained extrapolating images from the video tracks using the software DVD-VideoSoft®. Videos and photos analysis were carried out according to the standardized monitoring protocol for deep Mediterranean RBs, developed within the MSFD.

Video frames were analysed in order to define the percentage cover of red calcareous algae and the ratio of total live *vs* dead rhodoliths (as indicator of the RB vital-
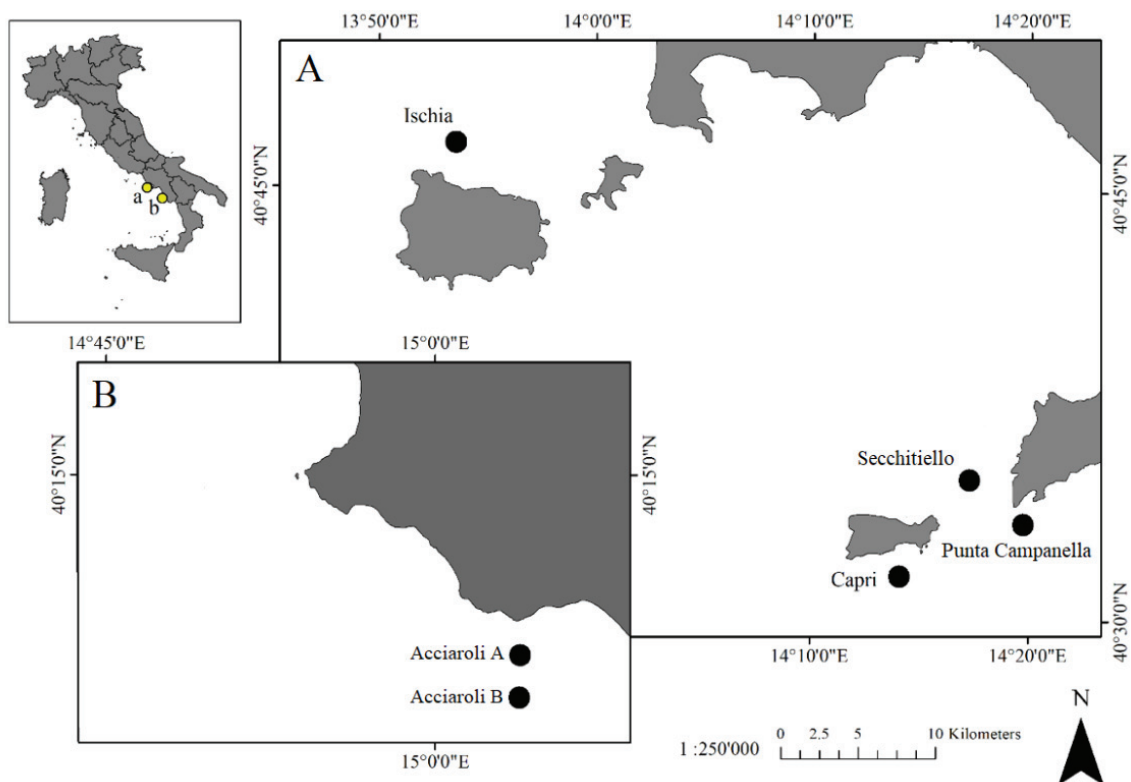

Fig. 1. Map of the sampling sites along the Campania Coast (Tyrrhenian Sea, Italy). (**A**) Gulf of Naples: Capri, Punta Campanella, Secchitiello and Ischia sites. (**B**) Cilento Coast: Acciaroli A and B sites

ity; Peña and Barbara, 2010). Rhodoliths were considered dead when thalli were totally white. Fishing gears and litter abundances within each video-transect were calculated as proxy of the anthropic pressure. A total of 8 items were analysed. Fishing gears were divided into 4 items: nets, longlines, ropes, and other gears (such as anchors, traps, moorings, etc.). Litter was divided into 4 more items: plastic, glass, wood, and metal objects.

Data on rhodolith percentage cover and on live/dead rhodolith ratio, checked with the Shapiro-Wilk's test, were not normally distributed; thus non-parametric tests were applied. Specifically, univariate PERMANOVAs based on similarity matrixes, computed using Euclidean distances (Anderson, 2001; Terlizzi, et al. 2007; Guidetti et al., 2014), were performed in order to assess differences among sites. Pairwise tests were run in order to estimate the degree of similarity between pairs of sites.

Data on fishing gears and litter abundance met ANOVA requirements of normal distribution (Shapiro-Wilk's test) and equality of variance (Levene test); hence, a one-way ANOVA was performed to detect differences among sites. ANOVA was followed by Tukey's test to identify the statistically different groups of sites. Finally, to evaluate the effects of fishing gears and litter on the rhodolith cover and on live/dead rhodolith ratio, linear regressions were calculated. Analyses were performed using PAST software for Windows, version 3.16 (Hammer et al., 2001). Results are expressed as mean ± standard deviation (DS), and p is the significance.

3. Results

The sites were characterized by different rhodolith cover [PERMANOVA, $p < 0.001$]. In particular, the examined video frames showed that Capri and Acciaroli A sites were characterized by a higher mean rhodolith cover (66±14 and 60±4 %, respectively). Punta Campanella and Secchitiello showed by far a lower rhodolith cover (5±28 and 2±21 %, respectively). Intermediate cover values were recorded at Ischia and Acciaroli B (47±27 and 40±10 %, respectively). Sites were significantly different from each other also in terms of live/dead rhodolith ratio [PERMANOVA, $p < 0.001$]. The lowest values of dead thalli compared to the live ones were observed in Capri, Punta Campanella, Secchitiello, and Acciaroli B, with dead thalli ranging from 12 to 17 %; while the highest percentages of dead thalli were detected at Ischia and Acciaroli A (26 and 76 %, respectively).

The quantitative analysis of fishing gears and marine litter items (Fig. 2A) showed significant differences among the investigated sites [ANOVA, $p = 0.002$]. From the examined video-transects arise that Secchitiello was the site characterized by the highest abundance of both fishing gears and litter (0.122±0.010 items per 100 m^2). Intermediate values of items abundance were recorded in Capri, Punta Campanella, and Ischia (0.071±0.040, 0.076±0.012, and 0.053±0.006 items per 100 m^2, respectively). The lowest abundances of items were observed in Acciaroli A and B (0.012±0.006 and 0.015±0.004 items per 100 m^2, respectively).

The qualitative analysis of fishing gears and marine litter items (Fig. 2B) showed that Secchitiello was the site characterized by the highest richness, with 63% of fishing items (i.e. nets, longlines, ropes, and other gears; Fig. 3A-D) and 37% of litter items (i.e. plastic, glass, and metal objects; Fig. 3E-F). In the Capri, Punta Campanella and Ischia sites the relation fishing gears *vs* litter items was 53% *vs* 47%, 35% *vs* 65%, and 83% *vs* 17%, respectively. Finally, both sites off the Cilento coast, Acciaroli A and B, showed the lowest richness of items, with 100% of fishing items (i.e. longlines and ropes).
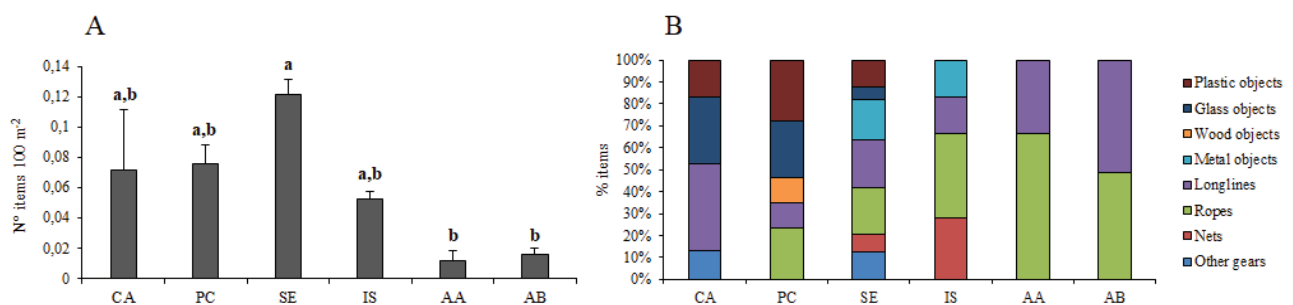

Fig. 2. (**A**) Number of total items per 100 m^2 (± SD) in the different sites. (**B**) Percent abundances of items categories in each site. CA, Capri; PC, Punta Campanella; SE, Secchitiello; IS, Ischia; AA, Acciaroli A; AB, Acciaroli B. Different letters (a, b, and c) indicate significant differences between sites
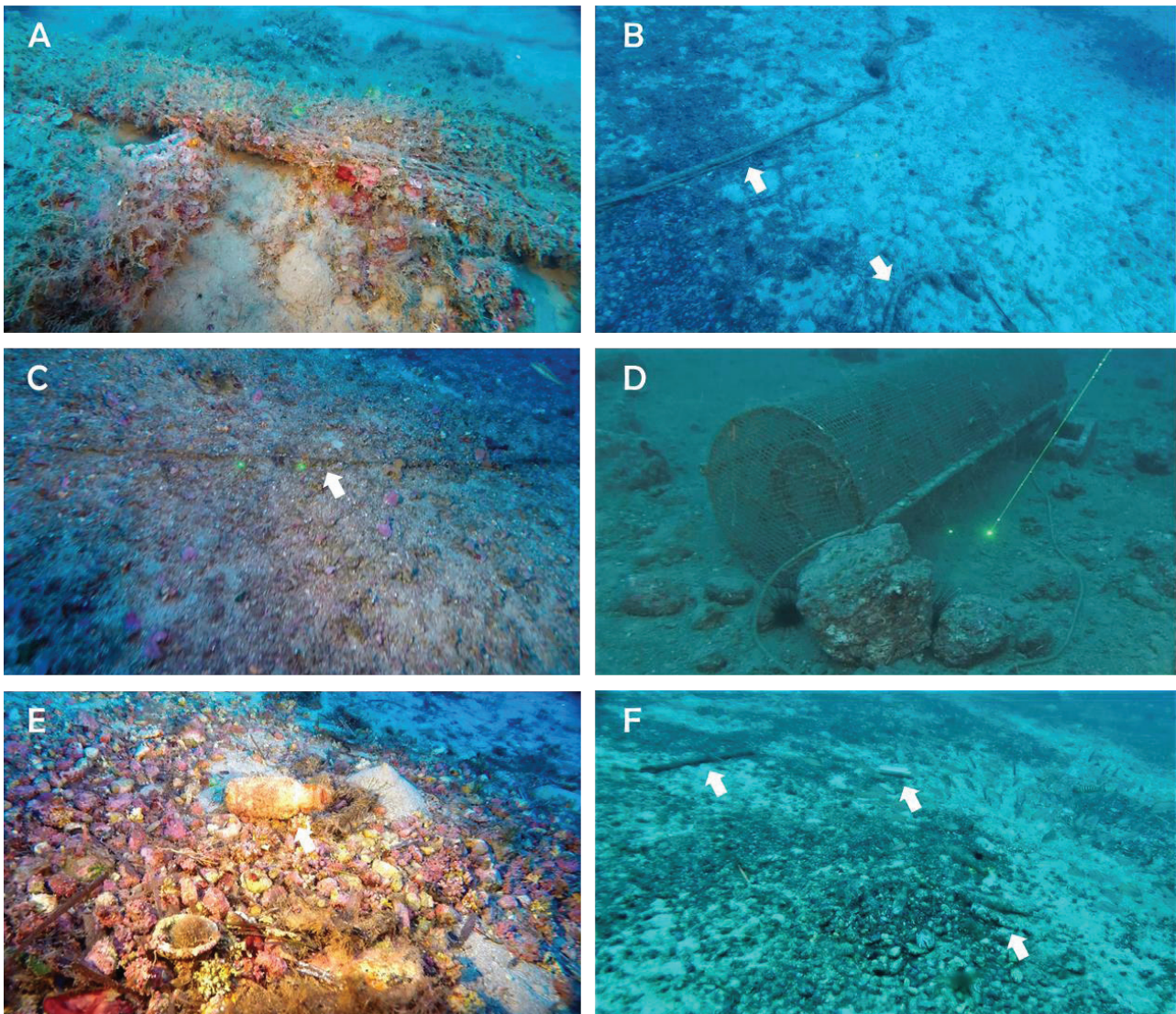
Fig. 3. ROV images of lost gears and litter on the studied rhodolith beds. (A) Derelict net covered in various epibionts such as red algae Corallinaceae and Peyssonneliaceae. (B) Lost rope (arrows). (C) Epibionted longline (arrow). (D) Abandoned fish trap. (E) Encrusted glass bottle. (F) Various plastic, glass, and metal objects (arrows)

As for the relation rhodolith cover *vs* items (Fig. 4A), a negative correlation was detected [Linear Regression, $p = 0.030$], with the rhodolith cover values decreasing with increasing items abundance.

No correlation [Linear Regression, $p = 0.341$] was observed between live/dead rhodolith ratio and items (Fig. 4B).
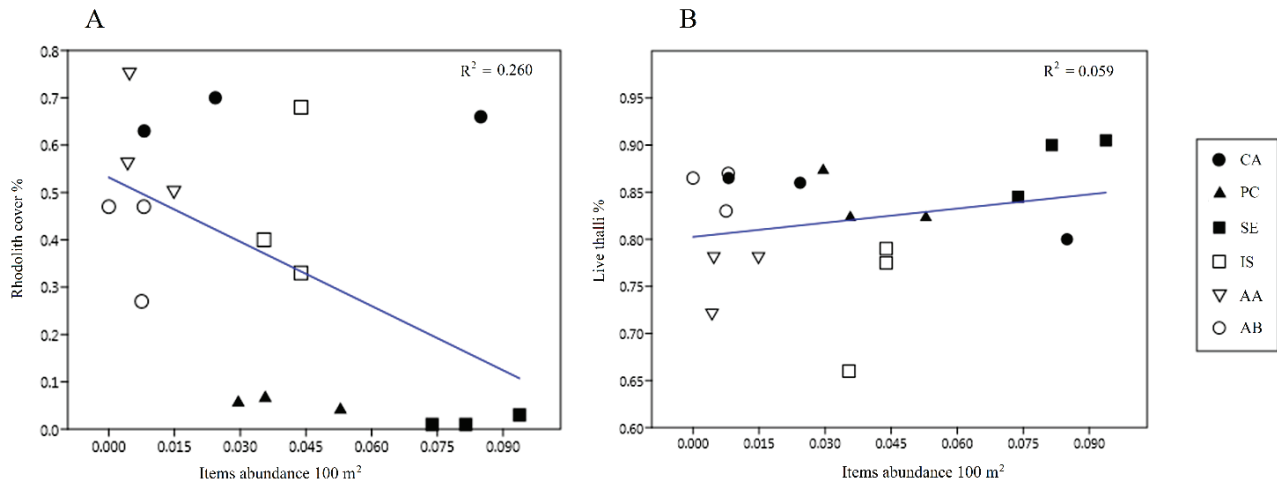
Fig. 4. Linear regression (**A**) between rhodolith cover and items abundance, and (**B**) between live/dead rhodolith ratio (expressed as percentage of live thalli on the total rhodolith cover) and items abundance. CA, Capri; PC, Punta Campanella; SE, Secchitiello; IS, Ischia; AA, Acciaroli A; AB, Acciaroli B. Equal symbols represent the three video-transects analysed for each site

4. Discussion

Despite the effects of fishing gears and litter on deep marine communities and habitats are still poorly known (Vieira et al., 2015), in the last decade, ROV surveys have provided strong evidences of fishing pressure and impact in the Mediterranean Sea (Bo et al., 2014; Ferrigno et al., 2018). This method is particularly useful also to obtain quantitative data on impacts of marine litter on deep-sea benthic communities (Angiolillo et al., 2015; Clark et al., 2016).

Litter (especially plastic materials) is considered among the predominant sources of marine pollution. It is an ecological and social concern, and a growing issue worldwide (Bauer et al., 2008; Löhr et al., 2017). It represents an important and persistent risk for marine ecosystems due to its non-biodegradability and its potential to be ingested by or to entangle organisms (Bo et al., 2014; Angiolillo et al., 2015; Ferrigno et al., 2017; Renzi et al., 2018, 2020). The impact of litter on RBs is poorly known. Additionally, RBs can be highly affected by bottom fisheries, both directly, by mechanical damages (i.e. dredging, fishing gears, bottom trawling; De Grave, 1999; Hall-Spencer and Moore, 2000), and indirectly, by smothering effects and degradation of water quality, representing a severe pressure for these habitats (Hall-Spencer et al., 2006; Sanz-Lázaro et al., 2011).

Our results suggested an important presence of lost fishing gears and litter in all the sites of the Gulf of Naples (i.e. Secchitiello, Punta Campanella, Capri, and Ischia) confirming the high fishing pressure in the area, as reported in previous studies (Russo et al., 2004; Sbrescia et al., 2008; Appolloni et al., 2018; Ferrigno et al., 2018).

The lower abundance of fishing gears and litter recorded in Cilento (i.e. Acciaroli A and B) is likely related to the low human population density characterizing this zone of the Campania region, representing a minor potential source of fishing gears and litter in comparison with the more populated coasts of the Gulf of Naples. This result is in line with several studies supporting the hypothesis that the occurrence of high densities of fishing gears and litter, in proximity to coastal urban areas, is correlated to the size of the nearby human population (Hess et al., 1999; Mordecai et al., 2011; Angiolillo et al., 2015). In Cilento RBs we found only two fishing items and no litter, therefore, these items are related to fishing activities and not to land-based activities.

Our findings indicated that Secchitiello, a small shoal of the Gulf of Naples, located offshore in the channel between the Sorrento Peninsula and Capri island, with a bathymetric range of 70-78 m, was the site characterized by the highest abundance (0.122 ± 0.010 items per 100 m^2) and richness (7/8) of items (both of fishing gears and litter). Fishing gears (i.e. nets, longlines, ropes, and other fishing litter) represents the 62% of the total items. This result is possibly related to the well known high abundance of fine fishes, making it attractive for local recreational and professional fisherman, as a consequence of the peculiar hydrological conditions and of the high biodiversity of the bottom communities (Ferrigno et al., 2017, 2018; Appolloni et al., 2020).

Some studies report plastic objects as the most diffused marine litter on the sea bottom (Galil et al., 1995; Galgani et al., 2000; Law et al., 2010; Miyake et al., 2011). Conversely, our work showed that the occurrence of abandoned items principally concerns fishing gears, particularly lost

longlines, which were widespread in all the studied RBs. This finding is in line with several studies highlighting that fishing gears may be predominant in areas characterized by intense fishing activities (Chiappone et al, 2004, 2005; Watters et al., 2010; Mordecai et al., 2011; Bo et al., 2014; Angiolillo et al., 2015; Ferrigno et al., 2017). Hence, the investigated RBs seem to be particularly threatened by recreational and professional fishing pressure. It has to be considered that a nylon line can take up to six hundred years to decompose (Bianchi et al., 2004). Consequently, fishing gears, which are made of synthetic fibres, appear to be among the most dangerous items for marine wildlife, since they can cause entanglement and can also break down overtime into small fragments that can be ingested by organisms (Laist, 1987). Accordingly, the wide distribution of this type of gears represents a severe source of perturbation for benthic Mediterranean habitats, especially for the fragile RBs.

Despite fishing gears and litter are harmful to marine flora and fauna, these anthropogenic products can also provide artificial substratum for sessile organisms (Watters et al., 2010; Miyake et al., 2011). In this study, the majority of items was colonized by encrusting algae and invertebrates, while only few items, possibly recently abandoned or lost, did not show appreciable signs of sessile organism's colonization (Donohue et al., 2001; Saldanha et al., 2003).

Coherently to what before discussed, our analysis showed a negative correlation between abundance of items and rhodolith cover, with higher rhodolith cover in concurrence with a lower abundance and richness of fishing gears and litter items.

In conclusion, this work gives a further contribute toward a better understanding of the still poorly known distribution and effects of lost fishing gears and marine litter on RBs, a highly vulnerable habitat. These preliminary results highlight the importance of future monitoring programs, in order to provide management and conservation tools useful to develop protection measures and sustainable fishing, which are urgently necessary to preserve a fragile and poorly known marine ecosystem.

Acknowledgements

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