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Red coral (*Corallium rubrum*) populations and coralligenous characterization within "Regno di Nettuno MPA" (Tyrrhenian Sea, Italy)

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Abstract
Red coral is one of the most important species belonging to the coralligenous habitats, being a structuring organism and highly sensitive to human pressure. The presence of red coral populations is historically well documented along the Campania coast (Tyrrhenian Sea), and, due to its high economic value, it has been commercially overharvested since ancient times. Red coral populations along several cliffs on the "Regno di Nettuno" MPA of the Gulf of Naples were investigated using ROV-imaging techniques. Coralligenous habitats were characterized in terms of percent cover and number of morphological groups. Pizzaco site showed the richest and most diverse community. Density of red coral colonies was calculated and compared with morphometric parameters. Results show an inversely correlated trend between colonies density and their size. Finally, fishing pressure was estimated through frequency of lost fishing gears, and S. Angelo site resulted the most stressed one. Anthropic stress plays a key role in the degradation of coralligenous habitats and the dramatic reduction of red coral populations recorded in recent years allows to suspect a more extensive degradation of the entire community. An assessment of the distribution and state of the populations can provide useful information to take measures for a better MPAs management.

Keywords: *Red coral, coralligenous habitats, fishing gear, rov image, mediterranean Sea*

Introduction

The hard bottom benthic biocoenoses are characterized by the presence of communities that create ecosystems particularly rich in terms of biodiversity in the Mediterranean Sea (Ballesteros 2006; Ingrosso et al. 2018). Coralligenous habitats are among the most relevant Mediterranean biocoenoses due to high habitat structural complexity and heterogeneity, which promote a large floral and faunal abundance and diversity (Garrabou et al. 2002; Ballesteros 2006; Ferrigno et al. 2018a).

Indeed, these habitats are considered as important Mediterranean biodiversity hotspots for their three-dimensional shape and the presence of numerous structuring organisms such as coralline algae, sponges, bryozoans, gorgonians and the precious-red coral *Corallium rubrum* (L., 1758) (Ballesteros 2006). These groups act as ecosystem engineers, creating heterogeneity and hosting a high alpha diversity (Cerrano et al. 2010). Moreover, being organisms particularly sensitive to environmental changes, they may represent a reliable indicator of environmental quality (Cerrano et al. 2000; Cupido et al. 2008; Garrabou et al. 2009; Piazzi et al. 2012; Bramanti et al. 2013; Ferrigno et al. 2017; Rendina et al. 2019). In particular, *C. rubrum* is a long-lived slow-growing coral occurring in the Mediterranean bottoms between 20 and 200 m depth (Zibrowius et al. 1984), and can constitute *facies* with very high densities up to about 120–150 m of depth (Rossi et al. 2008).

Red coral is one of the most important species within the coralligenous communities (Sará 1973; Giannini et al. 2003; Casas-Güell et al. 2016). Due

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to its high economic value, it has been commercially overharvested since ancient times (Tescione 1973), and is currently exploited all over the Mediterranean Sea (Abbiati et al. 1992; Santangelo et al. 1993; Santangelo & Abbiati 2001; Tsounis et al. 2007).

The presence of red coral populations is historically well documented along the Campania coast (Southern Tyrrhenian Sea), since they have been commercially exploited for a long time, mainly for use in jewellery. The first information on some coral harvesting areas in the Gulf of Naples was provided in 1785 by Cavolini (1785) and Costa (1871), reporting the presence of red coral between Capri and Punta Campanella. In 1909, Lo Bianco (1909) indicated numerous coral banks at 150–200 m depth, at Naples, Capri, and Torre del Greco. In 1918, Mazzarelli and Mazzarelli provided a detailed map with 23 sites exploited by fishermen in the Gulf of Naples, while a recent study on the health and the exploitation status of red coral populations within the Gulf of Naples was carried out by Bavestrello et al. (2014).

In Italy, the strict legislation regulating the red coral harvesting led to an increase of the illegal fishing (Caddy 1993), and the long history of commercial exploitation of this species, combined with its sensitivity to environmental stresses and its slow growth rate (Cattaneo-Vietti & Bavestrello 2010; Tsounis et al. 2010) have led to a dramatic decrease of red coral populations (Santangelo et al. 2007; Bruckner 2009, 2014; Bussoletti et al. 2010; Cattaneo-Vietti et al. 2016). Furthermore, it has to be considered that coralligenous bioconstructions, where red coral thrives, are currently threatened by various impacts, i.e., bottom fishing (Bo et al. 2014), excessive sedimentation (Balata et al. 2005), and underwater tourism (Piazzi et al. 2012). Specifically, fishing can cause mechanical damages mainly to large erect organisms and to those with a calcareous skeleton, particularly corals and gorgonians, or create a secondary substrate on which sediments settle and epibiontic organisms can grow (Bo et al. 2014; Ferrigno et al. 2018a). Moreover, coralligenous assemblages will be more and more affected by climate change in the near future (both ocean warming and acidification), and several mortality events of gorgonians triggered by thermal anomalies have already been reported (Cerrano et al. 2000; Cupido et al. 2008).

The vulnerability and importance of these habitats has been recently recognized by the European Community and the monitoring of coralligenous biocoenoses is considered a useful tool for the identification of anthropic impacts, for the preparation of possible forms of mitigation from habitat degradation, and for the regulation of human activities (Ferrigno et al. 2018a). Due to their high biodiversity, coralligenous assemblages are protected as habitats of particular scientific and ecological interest, with *C. rubrum* included in Annex V of the Habitats Directive (92/43/EEC; SPA/BIO Protocol, Barcelona Convention; Berne Convention), and represent useful indicators for monitoring the ecological status of coastal waters, according to the European Water Framework Directive (WFD, 60/2000/CE). Moreover, they have been recently included among the habitats of special interest within the Marine Strategy Framework Directive (MSFD), aiming at achieving the "Good Environmental Status" (GES) (European Parliament, Council of the European Union 2008; European Commission 2010).

Despite their high economic and ecological value, information available on coralligenous habitats is still scattered, and the management of red coral populations is an international issue far to be fully agreed. Therefore, the aim of this work is to evaluate the state of some red coral populations in "Regno di Nettuno" Marine Protected Area (MPA) within the Gulf of Naples (Tyrrhenian Sea, Italy), along with a characterization of coralligenous habitats at the same sites, providing additional valuable information useful for the implementation of a "red coral resource" management plan in the Mediterranean Sea.

Materials and Methods

Study area

The investigated sites, chosen to assess the ecological status of red coral populations within the coralligenous habitats, are located in the "Regno di Nettuno" MPA, NW side of the Gulf of Naples between 37 and 96 m depth (Figure 1). Three sites with coralligenous assemblages on cliff were considered; in particular, the sites are located in two islands with a rocky substratum of volcanic origin: cape S. Angelo (Ischia Island) at a depth between 87 m and 96 m, cape Solchiaro and cape Pizzaco (Procida Island), the former at a depth ranging from 48 m to 73 m and the latter from 37 m to 79 m. The survey sites were selected on the basis of cartographic and bibliographic information (Russo 1992, 2000), the empirical knowledge of fishermen, and in relation to the results of some recent video surveys aimed mainly at assessing the presence and the state of preservation of some ancient-red coral colonies present in the Gulf of Naples (Bavestrello et al. 2014).

The investigations were carried out in 2017 through the use of a ROV (Remotely Operated Vehicle) "Perseo" by Ageotec equipped with an HD video camera (DVS-3000 high definition), a camera with USBL underwater positioning system

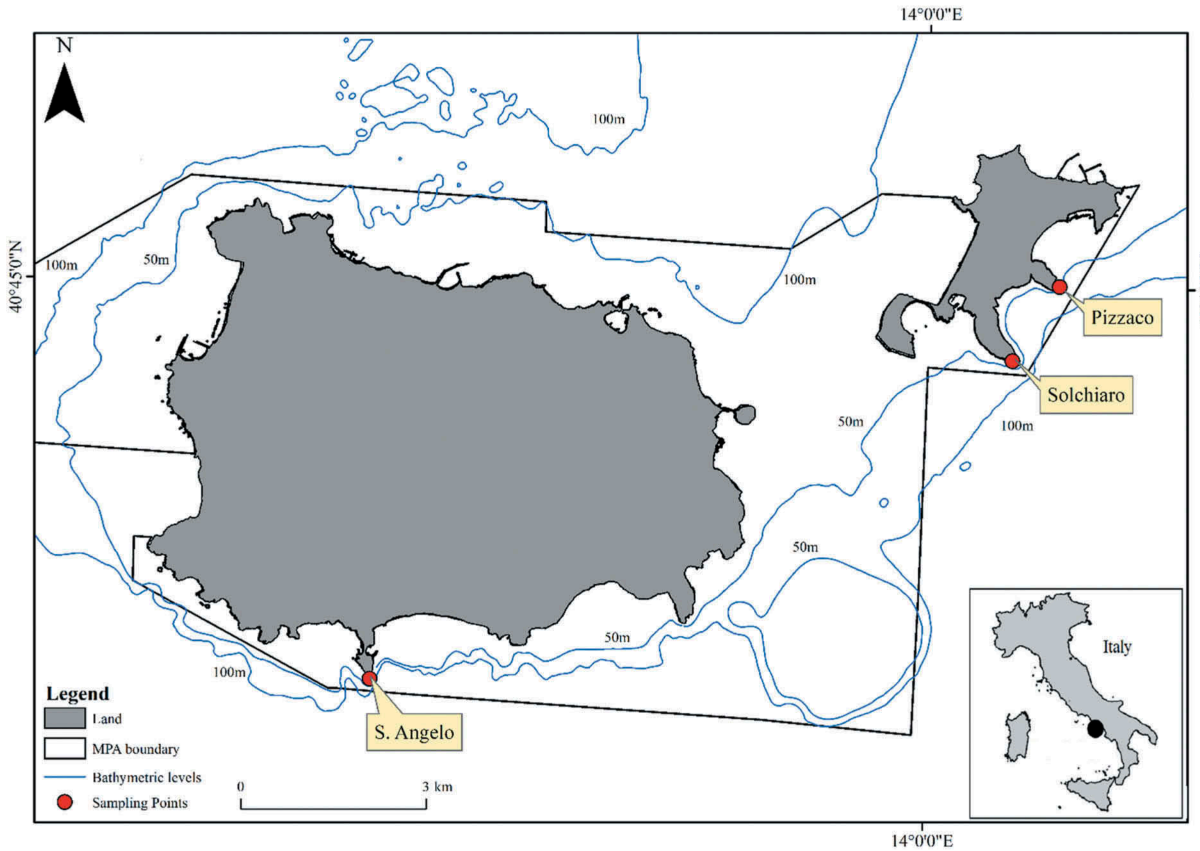

Figure 1. Study area with the sampling sites.

(Ultra Short Base Line System) to determine the geographical location and the depth of the ROV, two spotlights and two laser pointers spaced 14.5 cm for the measurement of the frame area and the organisms size; in particular, a total of three exploration routes were carried out, with a length of about 200 m each.

Data management

The ROV videos were analysed using the VisualSoft® software, which renders HD videos with the overlay of the navigation data.

The characterization of coralligenous habitats was obtained considering the following parameters: (i) the total coralligenous percent cover and (ii) the abundance of the different morphological groups (MGs, groups of species belonging to the same coralligenous taxon and showing similar morphology, *sensu* Ferrigno et al. 2017). For the evaluation of red coral colonies state, the following parameters were considered: (i) the depth range, (ii) the density, and (iii) the morphometric parameters. Both for the habitat characterization and red coral colonies state, 15 random images per site were analysed using ImageJ® and Seascape® software.

In particular, the total coralligenous percent cover was calculated as sum of all MGs plus "other coralligenous" (the coralligenous bioconstructions where taxa are not recognizable); while the MGs abundance, that are used as proxies of species (Ferrigno et al. 2017; Appolloni et al. 2020), was calculated as percent cover of each MG. Non-sessile fauna and other MGs accounting for less than 1% were not considered in the calculation of abundances. Generally, the percent covers were calculated using ImageJ® and Seascape® software and considering an image area of about 0.2 m^2 obtained with the fixed distance between the two ROV laser beams.

The depth range of red coral colonies represents the bathymetric interval where the colonies were found in each site; the density was calculated as number of colonies per m^2; finally, the morphometric parameters (height and width of the colonies in cm) were calculated having as reference the two laser pointers of the ROV.

The pressure of fishing activities on coralligenous habitats was assessed as frequency of fishing gear,

Table I. Explored sites with geographic location and depth ranges; number of extrapolated and analysed frames; red coral colonies depth range and frequency; fishing gear frequency.

Site	Lat	Long	Total frame (n.)	Site depth (m)	Red coral depth (m)	Frame with red coral (%)	Frame with fishing gear (%)
S. Angelo	40°41.370 N	13°53.630 E	164	69-96	87-96	28.05	45.12
Solchiaro	40°44.272 N	14°01.080 E	174	48-73	50-60	87.93	7.47
Pizzaco	40°44.982 N	14°01.556 E	132	37-79	38-63	37.12	12.12

calculated as percentage of frames with coralligenous bioconstructions presenting fishing gear. The frequency of fishing gear was calculated using 470 images, about 150 per site, obtained by video defragmentation each 10 sec with the DVDVideoSoft® software. The main fishing gears impacting on the coralligenous bioconstructions were divided into three categories: "longlines", "nets" (such as trawl nets, gill nets or trammel nets) and "other gears" (pots, ropes, moorings, anchors, etc.).

A distance-based permutation multivariate analysis (PERMANOVA (Anderson 2001a)), based on Bray-Curtis similarities, was carried out on coral densities, previously log(x + 1) transformed. Another multivariate PERMANOVA analyses, based on Euclidean distances (Terlizzi et al. 2007) were also performed on normalized morphological parameters (width and height values) of the red coral colonies. In all statistical analyses the experimental design involved one-factor Site (fixed, three levels) with n = 15, corresponding to analysed images. Each term was tested by 4999 random permutations (Anderson 2001b; Anderson & Braak 2003) and post hoc pair-wise comparisons were conducted.

Multivariate patterns on densities and on morphological parameters were visualized through canonical analysis of principal coordinates [CAP (Anderson & Willis 2003)]. Finally, densities and the number of fishing gear detected in each image were related to morphometric parameters through distance-based linear modelling [DistLM (Anderson 2004)], using Step-wise as section procedure and adjusted R^2 as selection criterion. Relations between morphometric parameters and environmental variables were visualized through distance-based redundancy analysis (dbRDA) (Legendre & Anderson 1999).

Results

The ROV route in the S. Angelo site extends from 69 m to 96 m depth and red coral colonies were found from 87 m to 96 m depth, being present in 28.05% of the 164 extracted frames; at Solchiaro site, route extends from 48 m to 73 m depth, and red coral colonies were found from 50 m to 60 m depth, with a rather high frame frequency of 87.93% of the 174 selected frames; finally, in the Pizzaco site 132 frames were extrapolated, with a bathymetric range of 37–79 m, and red coral colonies were present between 38 m and 63 m depth in 37.12% of the frames (Table I).

The average value of the total coralligenous cover percent (Figure 2) is 53% at S. Angelo site, 65% at Solchiaro site, and 78% at Pizzaco site. The remaining cover percent named "other" is represented by sediment or other substrata devoid of coralligenous.

S. Angelo site was characterized by five main MGs (Figure 2) and was dominated by fan corals, with 58% of total, and encrusting sponges, with 32%; 6 MGs were present at Solchiaro site with encrusting sponges and erect sponges representing, respectively, 54% and 22% of total cover; finally, at Pizzaco site 7 main MGs (dominated by encrusting sponges for 47%, madrepores for 23%, and bryozoans for 15%) were recorded.

The density of *C. rubrum* colonies (Table II and Figure 3) at S. Angelo site was between 3 and 12 colonies m^{-2} (average of 7.71 ± 3.44 colonies m^{-2}), at Solchiaro site was between 10 and 20 colonies m^{-2} (average of 15.14 ± 4.00 colonies m^{-2}), and finally, at Pizzaco site, the density was between 29 and 184 colonies m^{-2} (average of 96.17 ± 61.77 colonies m^{-2}).

The morphometric parameters of *C. rubrum* colonies (Table II and Figure 3) were at S. Angelo site between 8 cm and 11 cm in height (average of 9.56 ± 1.12 cm) and between 5 cm and 20 cm in width (average of 10.89 ± 5.34 cm); at Solchiaro site the colonies had dimensions between 10 cm and 18 cm in height (average of 12.78 ± 3.13 cm) and between 11 cm and 15 cm of width (average of 12.96 ± 1.48 cm); finally, at Pizzaco site the colonies dimensions were between 4 cm and 7 cm in height (average of 5.53 ± 1.07 cm) and between 4 cm and 7 cm in width (average of 5.30 ± 1.17 cm).

The frequency of frames in which fishing gears are present is 45.12% in S. Angelo, where the nets were the most abundant ones (47% of the total), followed by longlines (32%) and others gears (21%); 7.47% in Solchiaro the frames with gears were 7.47%, with longlines most abundant (86%), followed by nets (9%) and other gears (5%); finally, in Pizzaco 12.12% of frames

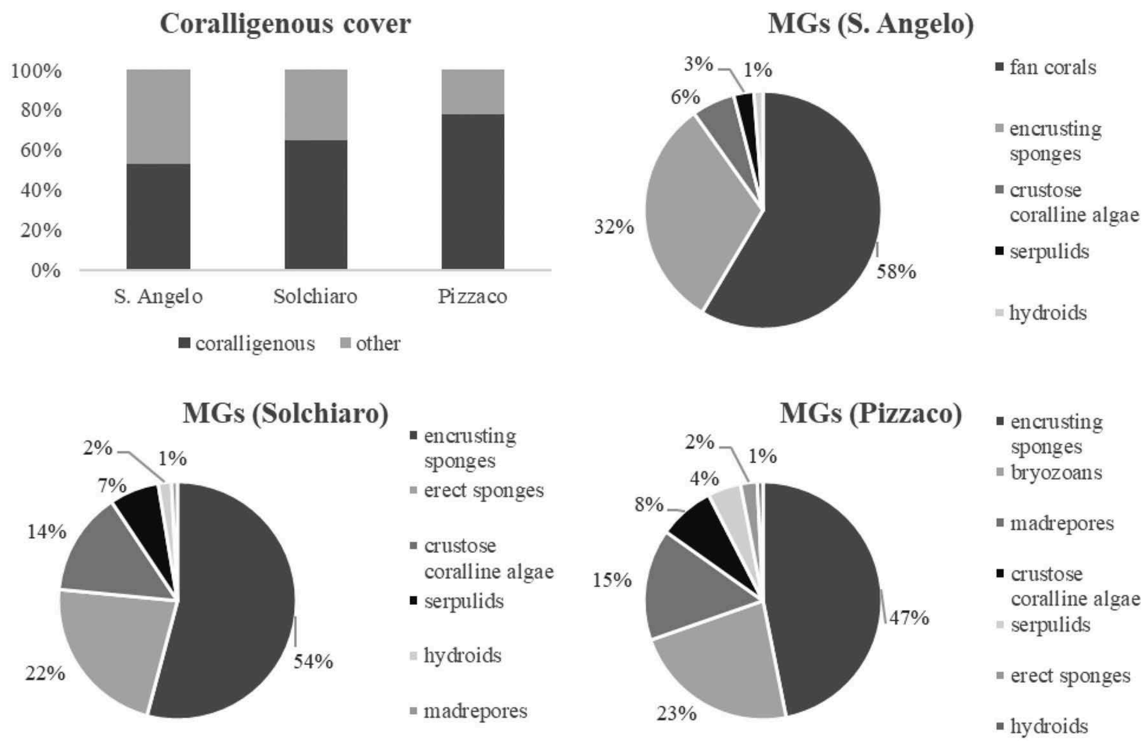

Figure 2. Total coralligenous cover (%) and MGs for each site.

Table II. Density and morphometric parameters (width and height) of red coral colonies.

Site	Red coral density (n. m^{-2})	Width (cm)	Height (cm)
S. Angelo	7.71 ± 3.44	10.89 ± 5.34	9.56 ± 1.12
Solchiaro	15.14 ± 4.00	12.96 ± 1.48	12.78 ± 3.13
Pizzaco	96.17 ± 61.77	5.30 ± 1.17	5.53 ± 1.07

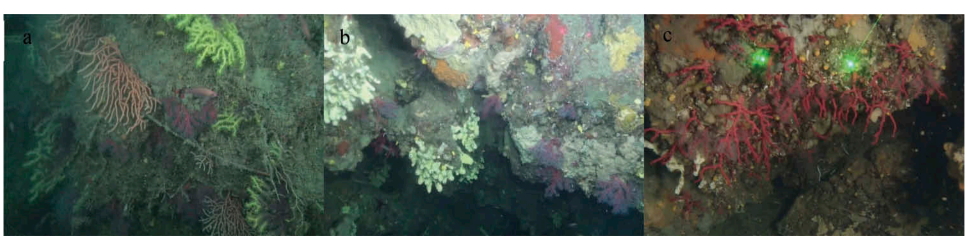

Figure 3. Representative images of the three sites S. Angelo (a), Solchiaro (b), and Pizzaco (c).

had fishing gears, with nets (42%), other gears (40%) and longlines (18%) (Table I and Figure 4).

Densities significantly differ among sites (p = 0.0064), as also confirmed by pair-wise test (Table III), where all sites differ from each other. Width and height values also show significant differences among sites (p = 0.003), as confirmed by pair-wise comparison (Table IV).

In Figure 5 results of CAP analysis are shown. In particular, densities are strongly clustered along a depth gradient (Figure 5(a)), including Pizzaco as the shallowest site and S. Angelo as the deepest site; however, this gradient is not so clear when using width and height values that result to mainly affect, respectively, S. Angelo and Solchiaro site (Figure 5(b)). Pizzaco site, resulting mainly polarized on the negative side of CAP2 axis, does not show any particular orientation on width and height variables. Finally, from distLM analysis, densities significantly affect width and height

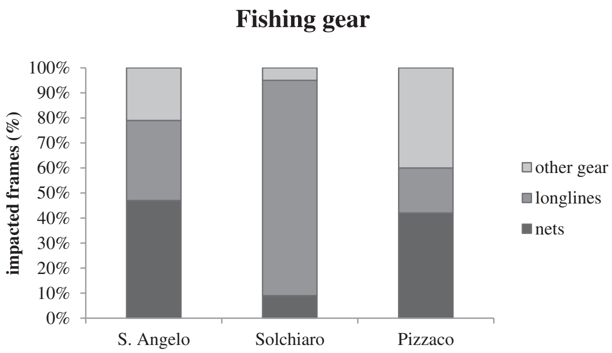

Figure 4. Percentage of different types of fishing gear at each site.

Table III. Pair-wise comparison among sites for differences in red coral densities.

Groups	t	*p*
S. Angelo, Solchiaro	1.6993	0.2036
S. Angelo, Pizzaco	3.7246	0.0954
Solchiaro, Pizzaco	3.2699	0.0928

Table IV. Pair-wise comparison among sites for differences in red coral width and height values.

Groups	t	*p*
S. Angelo, Solchiaro	2.5562	0.0028
S. Angelo, Pizzaco	5.0561	0.0002
Solchiaro, Pizzaco	10.073	0.0002

parameters ($R^2 = 0.33$; $p = 0.0002$), differently to fishing gear. In particular, dbRDA plot shows that densities are inversely correlated with morphometric parameters, explaining about 35% of total variation (Figure 6).

Discussion

The three studied coralligenous assemblages show different values of richness and abundance of MGs. In particular, S. Angelo site displays the lowest values of total coralligenous cover (53%) and MGs number (5), while Pizzaco site the highest values (78% of coralligenous cover and 7 MGs).

These results, as shown by statistical analyses, are consistent with the densities of the red coral colonies at the different sites; indeed, at S. Angelo *C. rubrum* density reaches the lowest value (7.71 ± 3.44 colonies m^{-2}), while at Pizzaco the highest one (96.17 ± 61.77 colonies m^{-2}). However, a similar tendency was not detectable from morphometric parameters, even though the three sites result significantly different from each other for height and width. On the contrary, S. Angelo site showed the highest values of fishing gear presence (45.12% of frames), resulting the most impacted site for the high number of fishing gear and the low values of coralligenous cover, MGs, and red coral density.

Fishing pressure in the study area may be the reason for these results; indeed, it is well known in the scientific literature that this type of human activity can dramatically reduce coverage, diversity and abundance of habitat-forming species and associated organisms (Blanchard et al. 2004; Althaus et al. 2009; Maynou & Cartes 2012; Ferrigno et al. 2016). Furthermore, it may lead to modifications in community structure and functioning, shifting species composition towards opportunistic assemblages with dominance of rapid growth-rate species (Schiaparelli et al. 2001; Clark & Koslow 2007; Daskalov et al. 2007). This type of anthropic pressure, unfortunately very common in many areas of the Tyrrhenian Sea, has a negative impact on benthic communities, crushing the arborescent colonies, increasing the sedimentation rate and inducing diseases due to mechanical friction (Bo et al. 2014; Ferrigno et al. 2018a), leading to the loss of wealth, diversity and density of communities (Smith 2000; Althaus et al. 2009; Clark et al. 2016).

Mostly trawl fishing is responsible for the increase in turbidity and sedimentation rates (Althaus et al. 2009), which often prevents the growth of sessile organisms (Berelson 2002; Balata et al. 2007), with an overall damage on hard bottom bioconstructions, such as the coralligenous (Ferrigno et al. 2018b). In particular, high sedimentation rate may negatively affect settlement, recruitment, growth and survival of individual or change in food interactions of species (Airoldi 2003). It may also generate change in community composition, structure and dynamics, leading to drastic alterations of communities with loss of richness, diversity, and density (De Madron et al. 2005; Clark & Koslow 2007; Althaus et al. 2009).

In the study area, the densities of red coral colonies are inversely correlated with morphometric parameters. Thus, a decrease in the colonies size was observed with the increasing density, and this occurs with particular reference at the Pizzaco site; on the contrary, at S. Angelo site an opposite trend can be observed. Furthermore, from statistical analyses, the densities resulted strongly clustered along a depth gradient, including Pizzaco as the shallowest site and S. Angelo as the deepest site.

Although Pizzaco site showed the highest number of red coral colonies among the sites, their size is the smallest one recorded here (about 5 × 5 cm), therefore, of little or no commercial interest. This reduced

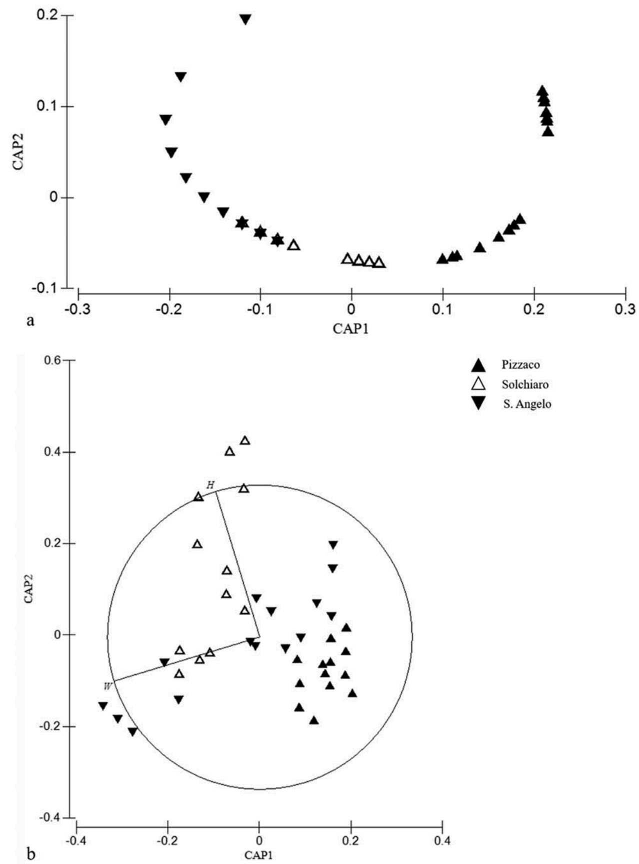

Figure 5. CAP analysis: (a) on red coral densities values and (b) on width and height values: straight lines are vectors of variables whose orientation and length are proportional to the most correlated sites. Circle represents 95% confidence interval.

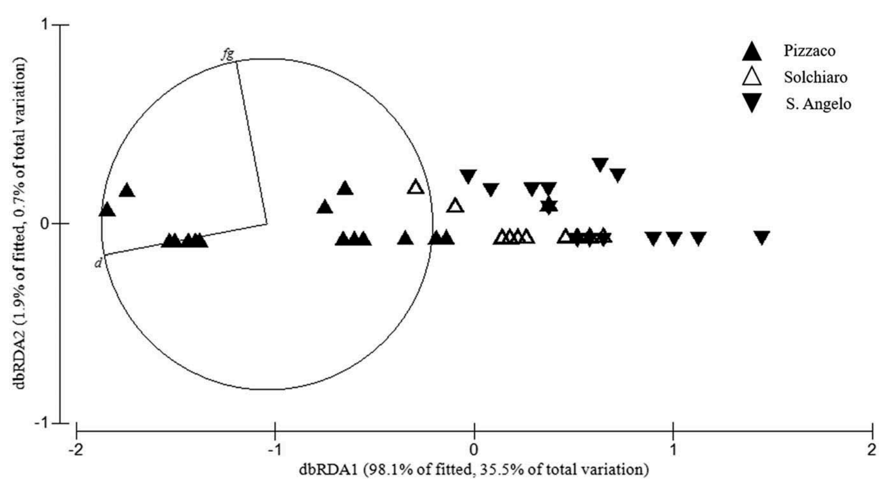

Figure 6. The dbRDA (distance-based redundancy analysis) ordination for width and height values vs. the significant environmental variables: density and fishing gear. Vector overlays represent multiple partial correlations of the explanatory variables with the dbRDA axes.

commercial interest for a size too small to be commercialized may, therefore, be the reason for the higher density of the colonies in Pizzaco site. On the contrary, S. Angelo site showed the presence of larger red coral colonies (about 11 × 10 cm), but with the lowest density. This result may be due to the deeper bathymetric range where colonies were recorded (87–96 m depth), that can make collection of coral by scuba divers more difficult.

Overall, from the observation of the results obtained, it can be affirmed that S. Angelo is the site with the deepest, the less frequent and the less dense *C. rubrum* colonies and with the greater presence of fishing gear (45%). In Solchiaro, instead, there are few fishing tools (7%) and the colonies are very frequent; finally, in Pizzaco the colonies are present in a wider bathymetric range and can be found even at rather shallow depths, with a high density of the colonies, which have a smaller size, and a medium-low presence of fishing gear (12%).

These data are partially comparable to those obtained by Bavestrello et al. (2014), carried out during ROV surveys in 2010 and 2012, at the same sites. Indeed, at S. Angelo site, there are no relevant difference concerning the bathymetric range, the density and the frequency of fishing gear, while an opposite situation was observed between Pizzaco and Solchiaro concerning the red coral density, but not the other parameters.

From the present work, it emerges that the analysed sites have specific coralligenous groups which vary in richness and abundance, probably due to particular environmental characteristics, and differ from each other also in fishing pressure. In S. Angelo, in particular, but also in Pizzaco, fishing activity has been widely practiced, as evidenced by a large number of lost nets trapped in coralligenous bioconstructions. Due to the high biodiversity of these sites, fishing is still quite popular, as demonstrated by the high number of lost longlines found, in particular in Solchiaro. The presence of different morphological groups and, in general, high coralligenous cover, characterize all sites. These host a rich and diversified assemblage of taxa, dominated by large erect suspending organisms, such as the gorgonians *Eunicella cavolinii* and *Paramuricea clavata* and the red coral *Corallium rubrum*, species characteristic of highly hydrodynamic environments (Bo et al. 2009) with moderate eutrophication levels (Ballesteros 2006).

Along the coasts of Campania, various events of mass mortality of benthic organisms, in particular gorgonians and corals, have been recorded in some years mostly during the summer period (Gambi et al. 2010; Bavestrello et al. 2014). The density of some species characteristic of coralligenous habitats, such as *Eunicella cavolinii*, *Paramuricea clavata* and *Corallium rubrum*, has been drastically reduced (Sbrescia et al. 2008). The highest mortality rates were recorded around 30–40 m depth during summer and this is mainly correlated with the increase of the temperatures of the surface waters of the Mediterranean (Cinelli et al. 2009). Strong vertical changes in temperature can also be due to the internal waves propagation along the coast, that causes a thermocline displacement, which may in turn influence the entire water column reaching layers deeper than 30–40 m (de Ruggiero et al. 2018).

In addition, anthropic stress has played a key role in the degradation of these habitats since the areas have been exploited by fishing activities for centuries (Colombo 1887; Russo et al. 2004). The dramatic reduction of red coral populations recorded in recent years allows to suspect a more extensive degradation of the entire deep community (Bavestrello et al. 2014). This phenomenon is truly alarming, considering that the Gulf of Naples has long been among the most studied sites for biodiversity in the whole Mediterranean Sea.

In areas under marked fishing pressure, a detailed assessment of the distribution and status of the communities can provide useful environmental information, allowing to take measures for a better management of MPAs pointing at different levels of protection (Appolloni et al. 2018; Donnarumma et al. 2018; Buonocore et al. 2019). Therefore, more sustainable fishing techniques, more restrictive protection measures and long-term monitoring programs are urgently needed in order to improve the management of the most fragile and valuable ecosystems.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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