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Abstract

Vulnerable Marine Ecosystems (VMEs) are characterized by prominent biological features susceptible to anthropogenic disturbances. Following international guidelines, the identification and protection of VMEs require a detailed documentation regarding both the community structure and the fishing footprint in the area. This combined information is lacking for the majority of the Mediterranean mesophotic rocky reefs that are known to host valuable animal forests. A deep coralligenous site exploited by artisanal fishermen in the NW Mediterranean Sea, is here used as a model to assess the vulnerability of animal forests and evaluate the sustainability of demersal fishing practices. The Remotely Operated Vehicle (ROV) footage is used to document the biodiversity and health status of the megabenthic communities, while bycatch data are employed to quantify the entanglement risk, discard rates of fragile species and threats to sea floor integrity. A multidisciplinary approach is proposed for the assessment of the vulnerability criteria of an EU Special Area of Conservation, leading to specific conservation measures, including the delineation of fishing restriction zones.

Keywords	VMEs; animal forest; ROV-Imaging; trammel net discard; fishing impact
Taxonomy	Marine Protection, Fishery Management, Conservation, Coastal Zone Management

Corresponding Author	Francesco Enrichetti
Corresponding Author's Institution	Università degli Studi di Genova
Order of Authors	Francesco Enrichetti, Simone Bava, giorgio bavestrello, Federico Betti, Luca Lanteri, Marzia Bo
Suggested reviewers	Giovanni Chimienti, David Vinolas Diaz, Chryssi Mytilineou, Marin Pilar

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Highlights

- A multidisciplinary vulnerability assessment of a Mediterranean deep coralligenous site is carried out.
- ROV-Imaging is used to characterize the benthic biocoenoses and their health status, while discard analysis is used to quantify the impact of the main artisanal fishing *métier*.
- High risk of entanglement leads to loss of structuring species and sea floor integrity.
- A valuable approach for the identification of Vulnerable Marine Ecosystems (VMEs) over Mediterranean mesophotic rocky reefs is here proposed, with implementation of specific conservation measures.

Artisanal fishing impact on deep coralligenous animal forests: a Mediterranean case study of marine vulnerability

Enrichetti F.*✉, Bava S.**, Bavestrello G.*, Betti F.*, Lanteri L.*, Bo M.*

*Dipartimento di Scienze della Terra, dell'Ambiente e della Vita, Università degli Studi di Genova, Corso Europa, 26 - Genova - Italy

**Area Marina Protetta Isola di Bergeggi, Comune di Bergeggi, Via De Mari, 28/D - Savona – Italy

✉Corresponding Author:

Francesco Enrichetti

fraenrichetti@gmail.com

Phone: +39 010 3538019

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Enrichetti F.*✉, Bava S.**, Bavestrello G.*, Betti F.*, Lanteri L.*, Bo M.*

*Dipartimento di Scienze della Terra, dell'Ambiente e della Vita, Università degli Studi di Genova, Corso Europa, 26 - Genova - Italy

**Area Marina Protetta Isola di Bergeggi, Comune di Bergeggi, Via De Mari, 28/D - Savona – Italy

✉Corresponding Author:

Francesco Enrichetti

fraenrichetti@gmail.com

Phone: +39 010 3538019

Abstract

Vulnerable Marine Ecosystems (VMEs) are characterized by prominent biological features susceptible to anthropogenic disturbances. Following international guidelines, the identification and protection of VMEs require a detailed documentation regarding both the community structure and the fishing footprint in the area. This combined information is lacking for the majority of the Mediterranean mesophotic rocky reefs that are known to host valuable animal forests.

A deep coralligenous site exploited by artisanal fishermen in the NW Mediterranean Sea, is here used as a model to assess the vulnerability of animal forests and evaluate the sustainability of demersal fishing practices. The Remotely Operated Vehicle (ROV) footage is used to document the biodiversity and health status of the megabenthic communities, while bycatch data are employed to quantify the entanglement risk, discard rates of fragile species and threats to sea floor integrity.

A multidisciplinary approach is proposed for the assessment of the vulnerability criteria of an EU Special Area of Conservation, leading to specific conservation measures, including the delineation of fishing restriction zones.

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1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) "Deep-sea Fisheries Guidelines" volume describes Vulnerable Marine Ecosystems (VMEs) as areas that may be vulnerable to impact from human activities, especially fishing. Within this context, the term "vulnerable" reflects the fact that they are both easily disturbed and slow or unable to recover (FAO, 2009). VMEs are often overlapped with Essential Fish Habitats (EFHs), identified as fundamental for critical life history stages of exploited fish species (*e.g.* nursery and spawning areas), and Sensitive Habitats (SH), internationally recognized as fragile, ecologically important habitats, which support relevant assemblages of commercial and non-commercial species. More specifically, these vulnerable ecosystems indicate the presence of habitats in which animal forests *sensu latu* (aggregations and bioconstructions) play an important role (Aguilar et al., 2017). Sponges and cnidarians (hydroids, scleractinians, gorgonians, antipatharians) are the most contemplated species in these environments, thanks to their wide distribution and arborescent morphology, leading towards three-dimensional habitats capable of modifying the near-bottom conditions (Buhl-Mortensen et al., 2010; Guizien and Ghisalberti, 2017) and acting as important refuges (Bo et al., 2009, 2015; Cathalot et al., 2015; Cerrano et al., 2015; Maldonado et al., 2017; Rossi et al., 2017).

In recent times, many National and Regional Fisheries Management Organizations (RFMO), as well as non-government organizations, have developed processes to identify VMEs and adopt management measures to protect them from bottom fishing activities including identification of indicator species, fishery monitoring protocols, employment of onboard observers, collection of information regarding bycatch rates, and closure of specific areas (Thompson et al., 2016; OCEANA 2016; Aguilar et al., 2017).

In the Mediterranean Sea, the General Fisheries Commission for the Mediterranean (GFCM) has adopted Fishing Restriction Areas (FRAs) as a multi-purpose spatial-management tool to restrict fishing activities hence protect deep-sea SHs and EFHs (GFCM, 2006, 2009, 2016; Thompson et al., 2016). Furthermore, GFCM has prohibited the use of towed dredges and trawl nets at depths greater than 1000 m (GFCM, 2005), an area that covers more than 60% of the Mediterranean Sea, whether it is not reachable by any present fleet. Despite these limitations, no protection is still in place for the animal forests occurring along the continental platform and upper slope (Gori et al., 2017; Chimienti et al., 2018) where the majority of the Mediterranean artisanal and recreational fishing fleet operates. This is even more relevant as the network of marine protected areas, as well as the coastal trawling prohibition (GFCM, 2012), cover only shallow littoral areas leaving coastal offshore habitats completely unprotected.

The FAO international guidelines for the management of deep-sea fisheries (FAO, 2009) laid out a combination of five characteristics for the classification of marine ecosystems as vulnerable, namely uniqueness, functional significance, fragility, low resilience of dominant species and structural complexity (OCEANA 2016). The identification of these features requires a significant documentation regarding the structure and functioning of the community, the extent of the mechanical disturbance as well as the fishing effort, this latter picturing the amount and type of resources devoted to obtain a certain fishing yield in a specific site (Pascoe and Robinson, 1996; Ruttan, 2003; Del Valle et al., 2003; McCluskey and Lewison, 2008).

ROV-Imaging related tools have already been adopted to characterize benthic communities and quantify fishing disturbance, expressed as density of marine litter and percentage of damaged organisms (Bo et al., 2014; Angiolillo et al., 2015; Díaz et al., 2015). These parameters give a well-defined picture of the health status of these ecosystems, but they do not depict the potential damage on the seafloor of a single fishing event, or the environmental sustainability of a certain *métier* (González-Álvarez et al., 2016) (aka the fishing efficiency calculated considering the commercial yield and the discard rate). This latter aspect can be investigated through the study of fishing benthic discard, but has been relatively overlooked, especially for Mediterranean artisanal fisheries (Hawkins and Roberts, 2004; Mangi and Roberts, 2006; Gökçe and Metin, 2007; Batista et al., 2009).

A multidisciplinary approach targeting the characterization of a deep coralligenous Mediterranean site, is here used as a reference for the assessment of the vulnerability criteria required by FAO for VMEs designation over mesophotic rocky reefs, with implementation of conservation measures regarding EU deep marine tutelary sites.

2. Materials and Methods

2.1 Study area

This study is focused on a deep coralligenous site known as "Maledetti Shoal", located in the western Ligurian Sea (Fig. 1a). The Maledetti Shoal lies in close proximity to the large harbour areas of Vado Ligure (about 4 km south) and Savona (about 9 km south-west). It is a 1 km-long, almost vertical wall, parallel to the coastline and located 1.2 km off the coast, extending from Spotorno to the southern boundary of the Marine Protected Area (MPA) "Isola di Bergeggi". The cliff is not continuous for the presence of two large mudslides, occupying the central part of the shoal, whereas the western and eastern extremities gradually terminate in a highly silted slope (Fig. 1b, c). The vertical profile of the shoal is not even, and it consists of three regions: i) a flat, heavily silted rocky plateau at around 54-60 m depth, ii) a vertical rocky cliff extending down to 75-80 m depth, and iii) large collapsed rocky boulders interspersed with sandy patches down to 130 m depth (Fig. 1b, c). This site is known to host dense forests of the red gorgonian *Paramuricea clavata* (Risso, 1826) as well as the largest Ligurian deep population of the precious red coral *Corallium rubrum* (Linnaeus, 1758) (Parravicini et al., 2007; Cattaneo-Vietti et al., 2016; MIPAAF, 2013; Betti, 2017), whether no specific quantifications were made so far.

2.2 Tutelary regime

The Maledetti Shoal is included within the Special Area of Conservation "Fondali Noli - Bergeggi" (SAC, IT1323271) of the Natura 2000 Network (Fig. 1a). It is an area of 380 hectares, including four Habitat types (following the Directive 92/43/CE): sand banks (1110), *Posidonia oceanica* (Linnaeus) Delile, 1813, meadows (1120), marine caves (8330), and coralligenous cliffs (1170), the latter covering about 46 ha.

The body responsible for the site management is the municipality of Bergeggi through the MPA "Isola di Bergeggi". With special reference to Habitat 1170b (deep coralligenous cliffs), the site is considered important at regional level due to its relative topographic uniqueness and was given high priority of conservation. The protection measures proposed for this area aim at enhancing the environmental status of the ecosystems suffering the effects of three main anthropic pressures, namely dredging, anchoring and fishing. Potential impacts related to dredging and anchoring operations concern destruction and sedimentation of habitat, as well as removal of arborescent species, whether these effects are known only at very local scale. Potential impacts related to fishing gears operated on or nearby Habitat 1170b mainly concern the loss or abandoning of gears. Despite this latter phenomenon is diffusely reported, there are no quantitative information on this pressure or correlation with the conservation of the habitat, hence, differently from dredging and anchoring, no regional legislation is active on this purpose.

No Management Plan still exists for this SAC whether some Conservation Measures (*sensu* Directive 92/43/EEC) have been delineated by the Liguria Region (DGR 1459/2014).

2.3 Fishing pressure

The SAC "Fondali Noli – Bergeggi" lies in close proximity to the harbours of Noli and Vado Ligure (Fig. 1a). These two harbours include the majority of the professional fishing fleet operating in the area comprised between Vado Ligure and Capo Noli, accounting for 29 vessels following the official register (http://ec.europa.eu/fisheries/fleet/index.cfm). Ten fishermen interviewed during this study report that, nowadays, the real number of artisanal vessels operating in the area does not exceed 20 vessels, and that this number has been gradually decreasing since the 1980s.

Four artisanal fishermen declared to fish on the Maledetti Shoal. This site is considered easily accessible (2 and 3 NM from the harbour of Noli and Vado Ligure, respectively). Here, the traditional trammel net called "*aragostara*" represents the main *métier*, targeting the spiny lobster *Palinurus elephas* (Fabricius, 1787) and the European lobster *Homarus gammarus* (Linnaeus, 1758). Gillnets are employed on the flat muddy plateau at the base of the vertical wall, down to 100 m depth. Fishermen declared to frequent the site no more than 10-30 times per year, mainly during summertime, when sea conditions are optimal. Indeed, due to the complex topography of the shoal and the strong bottom currents, fishermen consider difficult to operate on this fishing ground. The name “Maledetti”, which means “damned” in Italian, refers to the easiness to entangle on the sea bottom with the net and to the high likelihood to break it or lose it. Interviewed fishermen declared to strongly entangle on the bottom 2-5 times per years (up to 20) and at least three fishermen reported losing the gear.

In addition to artisanal boats, several recreational fishermen frequent the site, using trolling lines, vertical lines (“*bolentino*”) and longlines, but no quantitative data are available on this fleet. Professional trawlers, accounting for four vessels from the harbour of Savona and one from the harbour of Finale Ligure, are known to avoid the Maledetti Shoal.

2.4 ROV exploration and ROV-Imaging

Data were recorded on board of the R/V *Astrea* (ISPRA, Rome) in August 2015 and September 2016. A high-resolution Multibeam Echo Sounder (MBES, Kongsberg EM2040) has been employed in order to obtain the topography of the site. The resulting multibeam map has been used to localize the geographical position of the cliff and other relevant seabed features. These areas have been subsequently investigated by means of a ROV Pollux III, equipped with a digital camera (Nikon D80), a strobe (Nikon SB 400), a high definition video camera (Sony HDR-HC7), and a 3-jaw grabber. An underwater acoustic positioning system (Ultra Short Baseline Linquest Trackling 1500 MA), a depth sensor, a compass and two parallel laser beams providing an 8-cm scale for the measurements, were also present.

A total of six 200 m-long video transects (R1-R6) have been carried out, accounting for approximately two hours of analysed video, corresponding to 600 m^2 of explored sea bed and including both vertical cliffs and bottom boulders (Fig. 1c; Tab. 1). During video recording, ROV moved close to the sea bottom at a constant speed of 0.2 m s^{-1}. Laser beams were always included in the frame, providing a scale to define a fixed visual field within transects (0.5 m) for a total investigated area, per transect, of 100 m^2. Based on time, percentage of hard bottom and vertical slope was calculated for each transect. The frequent presence of trammel nets' signals during sampling operations prevented the exploration of the central portion of the shoal, both in 2015 and 2016 (Fig. 1c). Qualitative observations for this area were obtained from previous surveys conducted in 2012 by Centro Carabinieri Subacquei (Genova) by means of a Pluto ROV.

The Coralligenous Habitat Monitoring working protocol of the Italian Marine Strategy Framework Directive (MSFD) was applied to assess the structure and the environmental status of the benthic communities thriving on the Maledetti Shoal (MATTM-ISPRA, 2016). The working protocol adopts a landscape-based approach centred on remotely collected data gathered from standard video-transects and high-resolution photographs and focused on the megabenthic organisms, especially structuring species. The recorded videos were edited by means of Final Cut Pro software. Five parameters have been extrapolated from the analysis: i) megabenthic species richness, ii) basal bio-cover, referring to the mean percentage of hard bottoms covered by organisms of the basal and intermediate layer, iii) abundance (n° individuals m^{-2}) and size (cm) of the structuring species (SS), iv) health status of SS anthozoans, considering the percentage of structuring anthozoans showing signs of necrosis and epibiosys or directly entangled with lost fishing gears, v) abundance and typology of marine litter encountered over 100 m^2.

These parameters have been elaborated with the Mesophotic Assemblages Environmental Status (MAES) Index (Cánovas-Molina et al., 2016b) in order to give a picture of the environmental status of the studied areas.

2.5 Discard analysis

A scientific observer was employed to evaluate the average fishing impact of the "*aragostara*" in the site through the analysis of the discard. Five fishing sets (tn1-5) were carried out on the Maledetti Shoal in summer 2016 and 2017 (Fig. 1c; Tab. 2). Data were collected on board of a local fisherman boat, in fiberglass, total length corresponding to 8.55 m, gross tonnage 10 tons and power 115 hp. The boat was equipped with a plotter and a net hauler. The employed trammel net was a polyamide (nylon) monofilament, with an inner mesh size of 10 cm. Soak time varied between 2 and 4 days. The total fishing set was composed by an aligned series of panels of trammel net (from 4 to 10) each one 100 m long and 1 m high. The final length of the fishing set varied from 400 to 1000 m (Tab. 2).

In order to quantify the species composition and abundance of the benthic discard of the "*aragostara*", all the catches gathered during the hauling were identified, weighted, and divided into one or more of the following categories: target catches (*P. elephas* and *H. gammarus*), additional catches (the retained catch of non-target, but still commercial species), commercial discard (potentially marketable organisms returned to the sea because low priced, undersized, bitten, rotten or damaged, both invertebrates and fish), and non-commercial discard (non-marketable benthic organisms, both invertebrates and fish). For every organism of the non-commercial discard, the status upon arrival was detected on board distinguishing between entire or broken specimens. Dead specimens, occurring as skeleton remains, were considered overall as biogenic detritus. Species have been identified at the highest possible taxonomic level and all individuals were photographed and measured. Species difficult to identify on board were taken to the laboratory for detailed taxonomic analysis.

Considering that fishing sets may show variations in the length of the net, mean data of abundance and/or weight of main categories as well as single species or other Operative Taxonomic Units (OTUs) have been normalized to a standard 200 m-length, generally representing the length of a single panel of trammel net.

In order to evaluate the efficiency of the *métier* in the study site and its potential impact, percentage rates of collection of discards were calculated in terms of diversity, abundance and biomass. Commercial targets were also priced following the local fish market prices, in order to estimate the average economic yield of a fishing operation in this site. In addition, the amount of substratum (rocks and coralligenous framework) collected by the gear in each fishing operation was weighted in order to depict the effect of the trammel net on the sea floor integrity. For the same purpose, the number of entanglements on the sea bottom, as well as the number of gear loss events were annotated. Similarly, the marine litter collected by the net was quantified and described. Whenever useful, mean values were given as normalized for 200 m of trammel net.

2.6 Statistical analyses

A one-way ANOVA was carried out to test for differences among the species composition of the megabenthic assemblages of the six transects considering the entire ROV density dataset [transformed sqrt(x) data, Bray-Curtis similarity measure, density data distributed homogenously with n = 100 for each transect]. A similar approach was used to test for differences in species composition of the fishing sets considering the entire dataset [transformed sqrt(x) abundance data normalized for a 200 m-long net, Bray-Curtis similarity measure, data distributed homogenously with n = 100 for each fishing set, excluding dead catches].

Finally, to find out whether there was a significant difference in abundance, mean height, percentage of impacted colonies of the structuring species (PC, *Paramuricea clavata* (Risso, 1826), CR, *Corallium rubrum* (Linnaeus, 1758), EC, *Eunicella cavolini* (Koch, 1887), EV, *Eunicella verrucosa* (Pallas, 1766)) between the six transects, Kruskal-Wallis tests were performed on individual datasets.

Analyses were performed using PAST for MAC version 3.07 (Hammer et al., 2001).

3. Results

3.1 Biocoenotic characterization of the shoal

The results of the video analysis are summarized in Table 3. Biodiversity of the Maledetti Shoal is high, with 100 hard bottom megabenthic OTUs (corresponding to 33621 records) reported for the entire area (SM1). Overall, the species composition well represents a deep coralligenous community. Sponges include 54% of the identified OTUs, followed by cnidarians and echinoderms (13% each), bryozoans and crustaceans (6% each), and annelids (5%) (Fig. 2a). Despite being the most diverse, sponges represent only the 21% of the observed individuals (Fig. 2b), with *Axinella* spp. (up to 11 individuals m^{-2}) (Fig. 3a), *Aplysina cavernicola* (Vacelet, 1959) (up to 5 individuals m^{-2}) (Fig. 3b, c), and *Petrosia (Petrosia) ficiformis* (Poiret, 1789) (up to 5 individuals m^{-2}) (Fig. 3c) being the most abundant. The most represented taxon in terms of abundance is that of cnidarians accounting for 72% of the counted specimens (Fig. 2b). Among them, *P. clavata* (Fig.

3d) and *C. rubrum* (Fig. 3c, e) reach high densities, but the most abundant species of the shoal is the yellow scleractinian *Leptopsammia pruvoti* Lacaze-Duthiers, 1897 with densities up to 64 individuals m^{-2} (Fig. 3c, e, f). Other relatively abundant organisms are mainly bryozoans and echinoderms (3% and 2%, respectively) (Figs. 2b, 3b, i). The ascidian *Halocynthia papillosa* (Linnaeus, 1767) forms only localized aggregations (Fig. 3j).

The analysis of variance revealed no significant difference among the megabenthic communities of the six investigated transect areas supporting a homogeneity of the assemblages (SM2).

Eight structuring species are present in the study area (Tab. 3; Fig. 3c-h) including gorgonians, sponges and bryozoans. The red gorgonian *P. clavata* is significantly the most abundant structuring anthozoan (4.3 ± 1.7 colonies m^{-2}) together with *C. rubrum* (2.2 ± 0.1 colonies m^{-2}) (Kruskal-Wallis, $p<0.001$, $H=14.73$, [PC=CR>EC=EV]) (Fig. 4a). *E. cavolini* (0.2 ± 0.1 colonies m^{-2}; Fig. 3f), *E. verrucosa* (0.1 ± 0.1 colonies m^{-2}; Fig. 3g) and *Leptogorgia sarmentosa* (Esper, 1789) (with only one colony) are also reported. Massive keratose sponges, represented by *Sarcotragus foetidus* Schmidt, 1862 (0.1 ± 0.03 individuals m^{-2}) and *Spongia (Spongia) lamella* (Schulze, 1879) (Fig. 3h) are found together with the arborescent bryozoan *Pentapora fascialis* (Pallas, 1766).

Structuring anthozoans showed a distinct zonation on the shoal (Fig. 5). *P. clavata* and *C. rubrum* reach maximum density values on the vertical wall (up to 7.9 ± 1.4 colonies m^{-2} and 3.9 ± 1.4 colonies m^{-2}, respectively). *C. rubrum* forms dense patches in the small crevices or overhangs of the cliff often in association with *L. pruvoti* and several encrusting or prostrate sponges (Fig. 3c, e, f). *E. verrucosa* forms dense forests on the high silted plateau just above the cliff (Figs. 3g), whereas the collapsed rocks at the cliff base hosts sparse aggregations of *E. cavolini*, sometimes mixed with other gorgonians (Figs. 3f).

The mean heights observed for the four gorgonian species are reported in Fig. 4b supporting *P. clavata* and *E. verrucosa* as the significantly tallest structuring anthozoans in the area (17.2 ± 3.1 cm and 15.9 ± 5.2 cm, respectively) (Kruskal-Wallis, $p<0.001$, $H=11.43$, [PC=EV>EC>CR]). The size-frequency distributions of *P. clavata* reveals an asymmetric trend with a peak in the second size class (height 10-20 cm) (Fig. 4c). Colonies taller than 30 cm account for less than 20% of the total population. The size-frequency distribution of *C. rubrum* reveals a similar trend, with the second class (height 5-10 cm) being the most represented (Fig. 4d).

The soft bottoms near the shoal host aggregations of the structuring hydrozoan *Lytocarpia myriophyllum* (Linnaeus, 1758) (with density up to 0.7 colonies m^{-2}). Other megabenthic organisms observed on the muddy bottoms close to the shoal included *Cerianthus membranaceus* (Gmelin, 1791), *Veretillum cynomorium* (Pallas, 1766), *Acromegalomma* sp., *Myxicola infundibulum* (Montagu, 1808), *Sabella pavonina* Savigny, 1822 and *Parastichopus regalis* (Cuvier, 1817). The fish fauna of the Maledetti Shoal, observed by ROV, included eight species, *Scyliorhinus stellaris* (Linnaeus, 1758), *Conger conger* (Linnaeus, 1758), *Phycis phycis* (Linnaeus, 1766), *Lappanella fasciata* (Cocco, 1833), *Scorpaena* spp., *Serranus cabrilla* (Linnaeus, 1758), an unidentified goby (Gobiidae), and schools of *Anthias anthias* (Linnaeus, 1758).

3.2 Health status of the benthic community

About 40% of the structuring anthozoans observed on the Maledetti Shoal shows signs of impact, corresponding to epibiotic/necrotic portions of the colonies and/or entanglement in fishing gears, with maximum values up to 54% for transect R1, located in the western sector of the vertical wall (Tab. 3, Fig. 6a-c, SM3). *P. clavata*, *E. cavolini* and *E. verrucosa* show the highest percentage of damaged colonies (from 38% to about 54%), whereas *C. rubrum* the lowest (about 12%) (Fig. 4e) (Kruskal-Wallis, $p<0.05$, $H=8.32$, [PC=EC=EV>CR]). Similarly, the three flexible gorgonians are significantly more often epibionted/necrotic (from 13% to 26% of the colonies) than *C. rubrum* (Tab. 3, Fig. 4f) (Kruskal-Wallis, $p<0.05$, $H=9.41$, [PC=EC=EV>CR]). Entanglement is the most common type of impact, involving on average the 30% of the structuring anthozoans (Tab. 3, Fig. 4g) (Kruskal-Wallis, p=ns, $H=5.61$, [PC=EC=EV=CR]).

The marine litter analysis shows a mean density of 0.5 ± 0.1 items m^{-2} for the entire study area (Tab. 3). Marine litter composition analysis shows a strong predominance of fishing material (98%) (Figs. 2c, 6c-i), with lines (65%) and artisanal nets (26%) being the most common. Only few objects are ascribable to the category urban litter, including mainly plastic items.

The application of the MAES Index (Cánovas-Molina et al., 2016b) shows an overall moderate Environmental Status (average score 12 ± 0.3) for the Maledetti shoal (Tab. 3).

3.3 Trammel net catches

Results of the fishing-monitoring program (Fig. 7a) are summarized in Tab. 4 and SM4. All the catches of the five fishing sets (685 records) were identified and split into four categories, namely target (2 species, 13 catches), additional (10 species, 21 catches), commercial discard (16 species, three of which present also in the marketable species, 65 catches), and non-commercial discard (79 OTUs; 586 living catches, 417 dead catches) (Tab. 4, SM4).

The analysis of variance reveals no significant difference between the species composition of the five fishing sets (SM2), which well represent the average content of the fishing catches in the study area.

The daily revenue, estimated per fishing operation, includes two target crustacean species, with *P. elephas* being more frequent than *H. gammarus* (SM4; Fig. 7b, c) and ten additional commercial species, with *Zeus faber* Linnaeus, 1758 and *Scorpaena* spp. being the most frequently collected, together with few other high-quality species such as groupers and seabreams (SM4). On the other hand, commercial discard catches comprehend 16 species of fishes (mainly *S. cabrilla*, *Helicolenus dactylopterus* (Delarche, 1809), and *Pagellus acarne* (Risso, 1827)), and one species of cephalopod *Todarodes sagittatus* (Lamarck, 1798) (SM4). Of the 79 OTUs reported in the non-commercial discard, 51 were always found alive, 8 were always found dead, and 20 were found in both conditions (SM4). Cnidarians, bryozoans, echinoderms and macroalgae are predominant in terms of abundance (SM4, Fig. 2d), while cnidarians, sponges and crustaceans prevail in terms of diversity (SM4). 31 taxa found in the living benthic discard were also detected by ROV investigation. In total, of all the recorded species, 13 are included in international conventions of protection (SM1, SM4).

Collection rates for the most abundant species as well as the most representative morphological-taxonomic groups of the shoals' biocoenoses were considered (Fig. 8a, b). Seaweeds, for instance, represent an important portion of the benthic discard, with brown algae being among the most abundant (3.2 ± 2.1 normalized catches) (Figs. 7d, 8a). Among sponges, only seven of the eleven collected OTUs are considered erect or massive, hence more catchable, whether, overall, this group remains poorly represented (2.0 ± 0.2 normalized catches) (Fig. 8b). *Axinella* spp. are among the most abundantly collected sponges with 1.4 ± 0.2 normalized catches (Figs. 7e, 8a).

Flexible gorgonians are the second-most collected group (6.2 ± 1.9 normalized catches) (Figs. 7f-i, 8b). About 30% of the collected specimens was necrotic or covered by epibiotic organisms (e.g. *Alcyonium coralloides* (Pallas, 1766)) (Fig. 7f). Of the remaining catches, 16% were entire colonies and 84% were fragments (Fig. 7g, h inserts). Among the collected gorgonians, *E. verrucosa* is the most abundant, with 3.7 ± 2.1 normalized catches (colonies/fragments) (Fig. 7h), followed by *P. clavata* (1.7 ± 0.7) (Fig. 7g, 8a). Only one colony of *E. cavolini* was collected (Fig. 7i). Mean height of entire collected living colonies is 18.8 ± 3.8 cm for *E. verrucosa*, and 19.5 ± 4.5 cm for *P. clavata*.

Hard-skeleton cnidarians are represented by living specimens of five scleractinians (Fig. 7m, n) and by red coral (Fig. 7j), with normalized catches of 1.5 ± 0.4 *Caryophyllia* spp. and 0.8 ± 0.6 *C. rubrum* (SM4, Fig. 8a-b). The mean height of the nine collected living colonies was 5.2 cm ± 0.2. Overall, about 92% of the collected *C. rubrum* colonies was represented by dead fragments (Fig. 7j).

The category of soft-body cnidarians includes six OTUs, corresponding to three soft corals, one anemone growing on hermit crabs' shells and two zoanthids, most of whom indirectly collected as they generally have an epibiotic habitus (5.0 ± 2.0 normalized catches) (Fig. 8b). *A. coralloides* and *Calliactis parasitica* (Couch, 1842) are among the most frequently collected taxa (SM4, Figs. 7f, j, 8a).

Calcareous bryozoans, mainly represented by colony fragments, play a major role among non-commercial living discard catches, showing high average collection rates (6.7 ± 2.7 normalized catches) (Figs. 7o-s, 8a-b). *Turbicellepora* sp. is among the most abundant (2.2 ± 0.5), followed by *Smittina cervicornis* (Pallas, 1766) (2.0 ± 1.4), *Frondipora* *verrucosa* (Lamouroux, 1821) (1.1 ± 0.4), and *Pentapora fascialis* (Pallas, 1766) (0.8 ± 0.5) (Fig. 8a). Similarly to red coral, bryozoans are frequently collected dead (in the case of *Turbicellepora* sp., about 20% of the total catches, Fig. 7o, p).

Holothurians are copiously collected by trammel net (6.1 ± 2.7 normalized catches) (Fig. 8b), with the soft-bottom species *Parastichopus regalis* (Cuvier, 1817) among the most abundant catches (3.0 ± 1.1) (SM4; Figs. 7t, 8a). Crustaceans and sea stars are other two moderately collected groups, while sabellid polychaetes, bivalves, gastropods and sea urchins are scarcely represented with less than 1.0 normalized catches (SM4; Fig. 8b).

Damaged benthic invertebrate catches represented here 30.4% of the overall living catches.

3.4 Fishing sustainability

The efficiency and relative impact of the considered *métier* on this particular shoal can be evaluated considering three quantitative parameters (Fig. 9, Tab. 4).

In terms of diversity, commercial species represent on average 10% of the total catch, while the discard rate is 90% of the taxa (76% attributed to living benthic OTUs and 13% to commercial taxa) (Fig. 9a). Similarly, in terms of abundance, the discard rate is on average 94% of the total individuals (82% attributed to benthic invertebrates and 13% to commercial losses) (Fig. 9b).

In terms of biomass, on average, one operation in this site brings on-board 16 ± 2.8 kg of material (6.3 ± 1.3 kg normalized for 200 m of net). Commercial catches account for 19% of the total average weight (3.3 ± 1.1 kg) and discard for the 18% (1.1 ± 0.5 kg and 1.5 ± 0.3 kg, respectively for commercial and benthic discard) (Fig. 9c). A part from the catches, fishing operations on the Maledetti Shoal were not always easy and clear. The net strongly entangled to the seabed 16 times while in place or during hauling, determining the breakage of the gear in three cases (Tab. 4). As a result, substratum (mainly represented by cobbles, pebbles and coralligenous framework) (Fig. 7u) and biogenic detritus largely contribute to the total weight (on average 63%, 10 ± 1.7 kg) (Tab. 4). Detritus is mainly composed of dead bryozoan fragments, 41% (Fig. 7s), dead red coral branches, 28% (Fig. 7j), dead corallites, 20%, gorgonin skeletons, 6%, (Fig. 7f), shells, 5%, and coralline algae, 1%. From an economic point of view, the average revenue is 198 ± 65 €/haul (ranging from virtually nothing up to 400 €) (Tab. 4).

Anthropic waste was consistently collected during the operations (1.9 ± 0.5 normalized items). Marine litter shows a predominance of artisanal and recreational fishing related material (67%), with lines and ropes being prevalent (89%). Recreational hooks and a cephalopod-fishing device represented the remaining fishing material. The urban litter included plastic bags and other plastic material, gloves and fabric.

4. Discussion

The Maledetti Shoal well represents a typical Mediterranean *roche du large* ecosystem (*sensu* Pérès and Picard, 1964) in which structuring species thrive on deep continental hard grounds not directly connected to the littoral ones. The gorgonian forests found here, therefore, do not represent the direct bathymetric continuum of the coastal ones, but a separate ecosystem (Bo et al., 2012, 2015; Gori et al., 2017). Nonetheless, the studies shoal shows exceptional features within the Ligurian underwater panorama. The site lies in close proximity to the Noli Canyon, source of upwelling deep waters, and to the MPA Isola di Bergeggi, an area under tutelary regime. In addition, the topographic features of the shoal comprehend multiple inclinations gradients (plateau, cliff, boulders), allowing the development, environment-driven, of several typologies of animal forests (Fig. 5), thus enhancing the biodiversity levels. The presence of a deep vertical cliff with crevices, in particular, explains the presence of a large population of red coral. No such environment is present elsewhere in Liguria, hence this classifies as the most important Ligurian twilight population of red coral (MIPAAF, 2013; Cattaneo-Vietti et al., 2016). Shallow-water populations of gorgonians are known from this area and nearby sites (Parravicini et al., 2007; Betti, 2017) as well as from the Portofino area in the eastern Ligurian Riviera (Bavestrello et al., 1999; Cerrano et al., 2000). Similarly, information is available on the distribution of shallow-water coralligenous assemblages along the Ligurian coast (Cánovas-Molina et al., 2016a), but, with few exceptions (Cerrano et al., 2010), a large knowledge gap exists below 40 m depth. In this regard, this study represents the first fine characterization of a deep circalittoral site in this region.

Biocoenotic characterization of the area coupled with a quantification of fishing impact were used as proxies to delineate the vulnerability of the ecosystem. Fishing impact has been declined under different forms, mainly related to the health status of the community and the damages inflicted by the gear to the benthic habitat. The ROV approach proved to be highly valuable in defining the community structure and the extent of the impact, even if it does not clearly distinguish between past and present damages. The bycatch investigation proved to be an optimal tool in defining the catchability of the species as well as the punctual efficiency and revenue of a certain *métier*.

Trammel nets are among the most common artisanal gears in the Mediterranean Sea (Cautadella and Spagnolo, 2010) and are known to be potentially highly impacting (Erzini et al., 1997; Gonçalves et al., 2007; Batista et al., 2009) depending on a wide array of parameters including their technical characteristics, the topography and hydrology of the area, as well as the experience of the fishermen and the weather. Based on the analysis of the catches, this gear proved to have high discard rates both in terms of diversity and individuals (especially regarding benthic invertebrates), about 9 and 12 times higher, respectively, than the collection rate of marketable catches. The discard weight rate of this gear in this site is comparable to that of marketable species, suggesting a high loss at all levels. This datum necessarily needs to take into consideration also the large amount of collected substratum, including coralligenous substrate (currently under EU's Habitats Directive - 1170 Reefs, Bern Convention and European Red List of Marine Habitats) (up to 16 kg per fishing set) (Tab. 4). The removal of large pieces of substratum is an evident modification of the seafloor integrity, one of the most relevant descriptors of the EU Marine Strategy Framework. The occurrence of biogenic detritus (as well as typically soft-bottom species), on the other hand, is attributable to the dragging of the net over the detritic bottom at the base of the cliff. Such detritus may result from the natural mortality of organisms rolling down the wall (Bavestrello et al., 1991), however, the high abundance of lost gears on the wall suggests that it is mainly the result of previous mechanical impacts.

Structuring gorgonian species are highly aggregating (here up to 16 colonies per m^2) and are among the most conspicuous elements of deep coralligenous coral forests, leading to high catch rates. In this study, gorgonians have been collected in 80% of the studied fishing sets, a percentage higher than what obtained by longlines from Mediterranean and Macaronesian areas, reporting gorgonians in 15% to 70% of the landings, respectively (Sampaio et al., 2012; Mytilineou et al., 2014). The catch frequency of gorgonian species in the trammel net is up to a maximum of 12 living colonies/fragments per 200 m of trammel net (tn4). The normalized collection rate of the two most relevant species, *P.*

clavata and *E. verrucosa*, respectively 1.7 colonies/fragments and 3.7 colonies/fragments, does not reflect their bottom density, being the abundance of the red gorgonian one order of magnitude higher. This could be explained by the habitus of *E. verrucosa*, thriving in the most exposed locations of the shoal (the plateau above the cliff), and to settle on pebbles surrounded by biogenic detritus, thus being more susceptible to be captured by the net. On the other hand, *E. cavolini*, almost never collected, lies deeper on the shoal, among the rocks, less exposed to the fishing gears. It is also plausible that the collection of *P. clavata* is now limited by the fact that the most exposed colonies have been eradicated and the remaining ones are covered by lost gears or are limited to sheltered crevices. A similar situation is evidenced also for red coral: denser patches (250-300 colonies m^{-2}) of taller colonies (10 cm) are found in the cavities and overhangs (MIPAAF, 2013; Cattaneo-Vietti et al., 2016).

The catchability of the species is dependent on the shape, size and exposure of the colonies (Mytilineou *et al.*, 2014; Bo et al., 2014; Kaiser et al., 2018), but is also mediated by the response of each species to the mechanical stress, mainly related to the resistance offered by the skeleton: flexible gorgonin skeletons or thin calcified bryozoans are more often partially broke-down in fragments, while thick calcareous red coral colonies are more often pulled off entirely (as observed in the biogenic detritus).

Trammel net is selective neither on the targets nor on the discard as demonstrated by the wide array of collected species. Collection of benthos interests not only sessile arborescent species, but also organisms thriving in the forest understory, both sessile (sponges, bryozoans) and vagile (echinoderms and crustaceans, many of whom attracted by the rotting material hanging on the net). The potential impact of this gear is evident not only when in place, but also during hauling as demonstrated by the high percentage of damaged specimens. Survival rate of organisms is generally poor. Despite some species could survive if returned to the sea (including some gorgonians, such as *E. verrucosa*, settled on cobbles), the trammel net is often hauled quickly in order to avoid entanglements and then cleaned in the harbour; in these cases, the catches are either not returned in their original location or dry out, including the more resistant ones.

Various evidences suggest a long-term exploitation of the shoal. The prolonged disturbance is supported by the collection of epibionted and necrotic specimens, reflecting the epibionts overgrowth observed in the forest assemblage (up to 30% of the colonies), and by the size structure of the gorgonian population, showing a peak in the small-medium class. Additionally, there is an exceptionally high density of lost fishing gears (about 45 items observed every 200 m of seabed explored), many of which heavily encrusted by algae, cnidarians and bryozoans, suggesting a long permanence on the sea floor. Such density of lost gears has never been reported before in similar studies (Bavestrello et al., 2014; Bo et al., 2014; Angiolillo et al., 2015; Yıldız and Karakulak, 2016; Cattaneo-Vietti et al., 2017).

A higher exploitation of the shoal in the past may explain the exceptional accumulation of gears on the bottom. Anyway, the loosing of gears is still going on nowadays, as demonstrated by the presence of abandoned fishing nets almost new, not covered by epibionts. The current esteem of the artisanal effort (at least four fishermen each spending 10-30 fishing day per years), suggests that recreational fishing is highly underestimated in this area. This latter activity certainly plays a major role, as demonstrated by the large number of lines on the bottom and the collected devices. Based on the entanglement events and the breakages occurred during the surveys, the loss risk frequency in this site is very high, around 60%. This couples with high entanglement percentages of structuring species (ranging from 17% to 52%). In any case, in some areas of the wall, the gears coverage is so dense that new nets tend to entangle not on rock or organisms but on lost material. This high risk can be explained by the tendency of fishermen to set nets or lines in close proximity to the wall or on the boulders at the wall's base, where the majority of the burrows are. Moreover, the daylong permanence of gears set in place, enhances the chance for current to move it towards the cliff, hence getting entangled during hauling. Considering the gasoline expenses, the risk of losing the net, the time spent in cleaning the gear from discard and litter, and the average revenue estimated (around € 200 per day), this activity would seem unprofitable.

5. Conclusions

The multidisciplinary approach employed here allows to fulfil the international guidelines defining the criteria to assess VMEs in the context of mesophotic Mediterranean rocky shoals.

GFCM suggested five main ecological parameters supporting the definition of a vulnerable area (FAO 2009), and the Maledetti Shoal fits well in all of them: i) *Uniqueness or rarity*: the biological and topographic features of the Maledetti Shoal are unique in the Ligurian underwater panorama, including a deep coralligenous community dominated by a gorgonian forest of about 350000 colonies and the largest mesophotic red coral population, ii) *Functional significance*: the area represents an important site of breading and nursery for several commercial and non-commercial species, including chondrichthyes, iii) *Fragility*: highlighted by the catchability of the structuring species and the modification of the sea floor integrity, iv) *Peculiar life-history traits*: reflected in the occurrence of slow-growing canopy-forming species as well as deep coralligenous bioconstruction, v) *Structural complexity*: supported by a large variety of environments, the site hosts a complex three-dimensional forest enhancing high biodiversity levels.

Scientific and socio-economic evidence regarding the fishing fleet and the related activities are fundamental to define or implement specific conservation measures for EU Special Areas of Conservation.

In the specific case of the Maledetti Shoal, based on the frequentation levels and the fishermen community involved, on the typology of the fishing activity, on the risk of gears loss, on the accessibility of the area, on the characteristics of the biocoenoses, and on the present environmental status of the gorgonian canopy, the following actions are suggested as complement to the existing measures: i) fulfilment of an environmental recovery program, through the systematic cleaning of the shoal by means of technical divers and ROV and successive disposal of the recovered gears, ii) definition of educative programs directed to the fishermen community (professional and recreational) delineating the importance and fragility of the shoal and nearby rocky areas, iii) definition of a Fishing Restriction Zone (Fig. 10) including a large area of about 53 ha of the Maledetti Shoal, iv) definition of fishing guidelines, including restricted permissions for professional and recreational fishermen, log books, maximal length of nets and longlines, obligation to return immediately living benthic discard within the collection area.

Supplementary material

SM1. Hard-bottom invertebrate OTUs list resulting from the ROV video transects analysis. Aside numbers refer to the total number of individuals observed in the video footages. ° indicates species included in international conventions of protection (Barcelona, Berna, Bonn, Habitat Directive, Red List).

SM2. Results of the one-way ANOVA tests carried out on the ROV and fishing discard datasets, respectively.

SM3. ROV video sequence showing the impact of fishing activities on the Maledetti Shoal. The distance between laser beams is 8 cm.

SM4. Catches list, in taxonomic order, resulting from the fishing monitoring. Aside numbers refer to the total number of individuals collected. * indicates species of the benthic discard only collected as dead, or ** both living and dead. Bold values indicate those species found also in the ROV benthic characterization. ° indicates species included in international conventions of protection (Barcelona, Berna, Bonn, Habitat Directive, Red List).

Declaration of interest

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Figure legends

Figure 1. Map of the study area. a) Geographic localization of the Maledetti Shoal in relation to the main cities of the area, the Marine Protected Area "Isola di Bergeggi" (light orange), the Special Area of Conservation "Fondali Noli-Bergeggi" (SAC, dotted yellow), and the main features of the sea bed topography. Insert: localization of the Ligurian Sea and the study area within the western Mediterranean basin. b) Three-dimensional elaboration of the Maledetti Shoal. The vertical wall, the rocks at the cliff base, and the muddy landslides in-between are visible. c) Multibeam map showing the position of the six ROV transects (R1-R6, white) and the five fishing sets (tn1-tn5, blue).

Figure 2. Benthic community structure, marine litter and fishing benthic discard. a) Percentage composition of megabenthic OTUs in the video footage. b) Percentage number of individuals per taxonomic category. c) Percentage composition of the marine litter on the sea bottom. d) Percentage composition of the benthic discard (as number of organisms).

Figure 3. Biodiversity and major communities of the Maledetti Shoal. The shallower portion of the vertical wall hosts several sponge aggregations, including a) *Axinella* spp. (*A*) covered with *Parazoanthus axinellae* (*Pa)*, b) *Aplysina cavernicola* (*Ac*) and *Hexadella racovitzai* (*Hr*). A specimen of *Holothuria (Panningothurua) forskali* (*Hf*) is

also present. c) The sponge community associated with the red coral facies includes *Petrosia ficiformis* (*Pf*), *Haliclona poecillastroides* (*Hpo*) and *A. cavernicola*. d) *Paramuricea clavata* (*Pc*) forest acting as a refuge for *Phycis phycis* (*Pp*) and *Scorpaena* sp. (*S*). e) *Corallium rubrum* (*Cr*) forest pending from the roof of a crevice, together with several sponges and the yellow scleractinian *Leptopsammia pruvoti* (*Lp*). f) The deepest portion of a rock at the base of the cliff shows a complete cover of sponges, *L. pruvoti* and *Eunicella cavolini* (*Ec*). g) *Eunicella verrucosa* (*Ev*) aggregation on the high silted plateau at the top of the shoal. h) Keratose massive sponges: *Sarcotragus foetidus* (*Sf*) and *Spongia lamella* (*Sl*). i) Calcareous bryozoans: *Smittina cervicornis* (*Sc*) and *Reteporella* spp. (*R*) j) Dense assemblage of the ascidian *Halocynthia papillosa* (*Hpa*). Scale bar: 10 cm.

Figure 4. Structuring species on the Maledetti Shoal: a) mean density, b) mean height, c) size distribution of *Paramuricea clavata* and d) *Corallium rubrum*, e) mean percentage of impacted structuring anthozoan colonies, f) mean percentage of structuring anthozoan colonies showing epibiosys or necrosis, g) mean percentage of entangled structuring anthozoan colonies.

Figure 5. Schematic representation of the benthic zonation on the Maledetti Shoal.

Figure 6. Fishing activities impacts on the Maledetti Shoal. a) *Paralcyonium coralloides* (*Pco*) overgrowth on a colony of *Paramuricea clavata*, b) Signs of epibionts overgrowth and necrosis on *Eunicella cavolini* colonies, c) lines entangling colonies of *Corallium rubrum*. d) Highly encrusted lost trammel net on the vertical cliff, e) freshly entangled

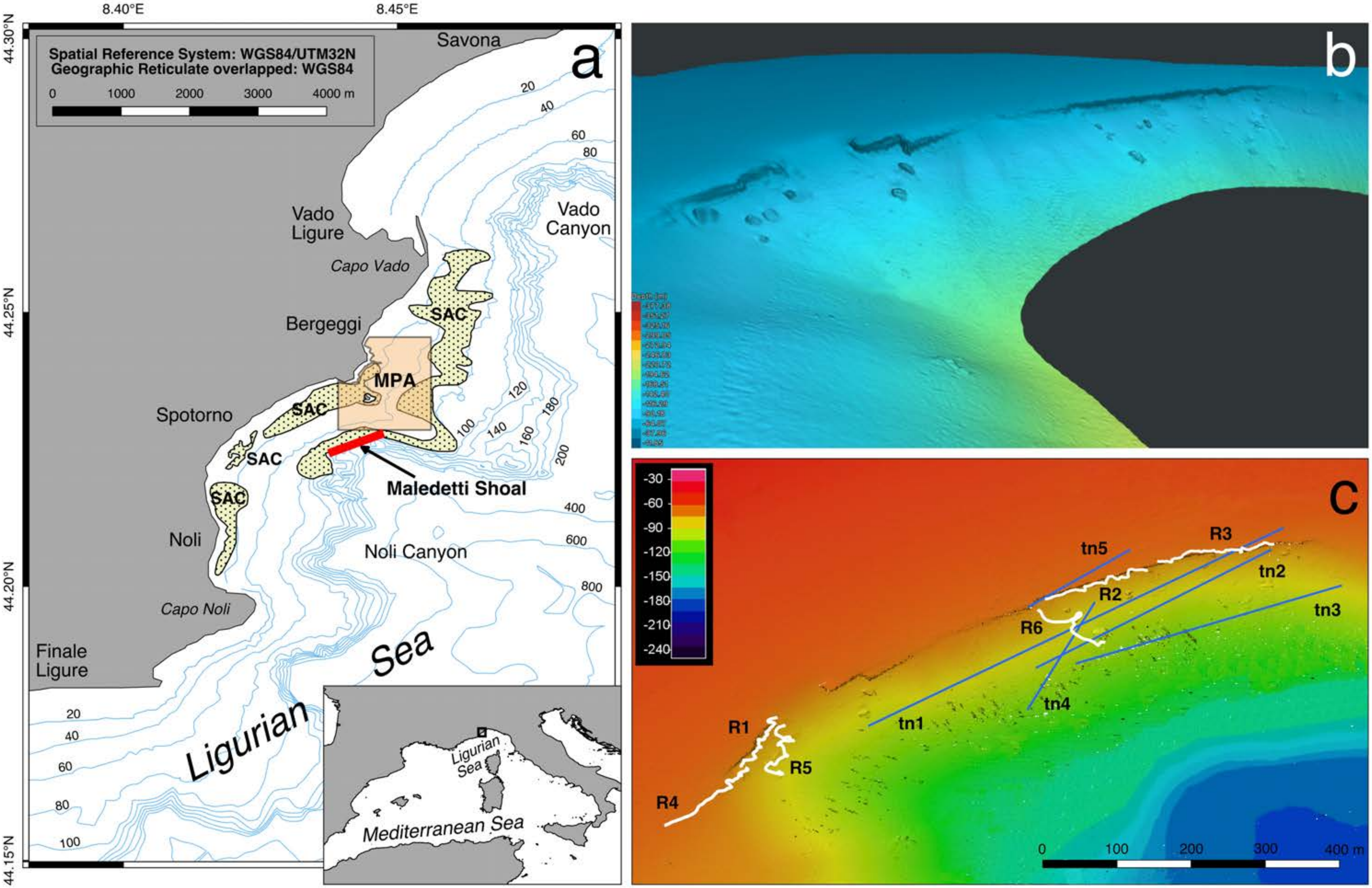
clean trammel net enveloping *P. clavata* colonies, f-g) numerous ropes and nets fragment entangled on the cliff and gorgonians, h) remains of a fishing pot, i) lost anchor and dead gorgonians. Scale bar: 10 cm.

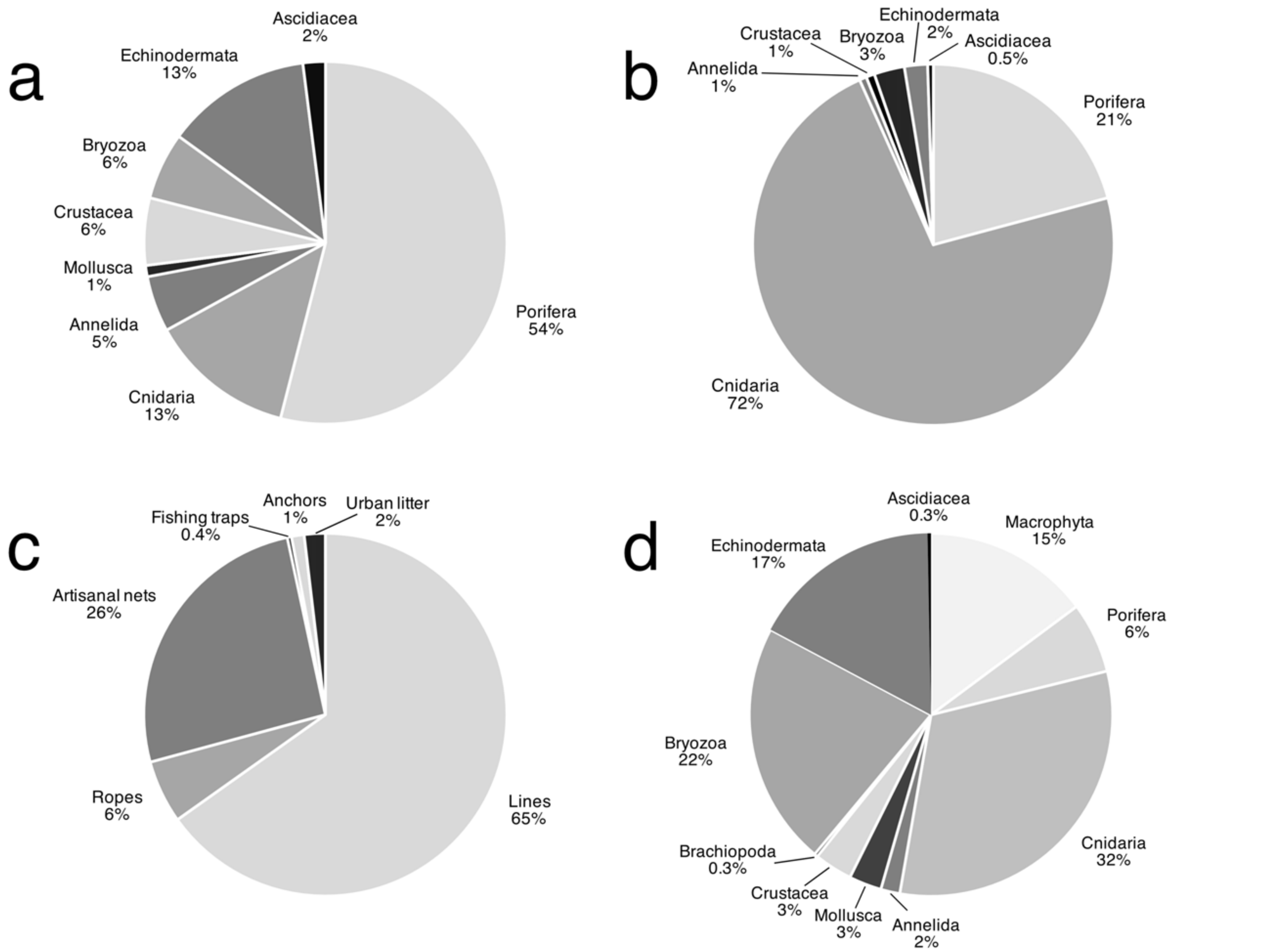
Figure 7. Discard of the trammel net from Maledetti Shoal. a) Hauling of the net. The target species *Palinurus elephas* (b) and *Homarus gammarus* (c). d-u) Non-commercial discard. d) Algae. e) *Axinella* spp. with *Parazoanthus axinellae*. f) Dead gorgonian with *Alcyonium coralloides* overgrowth. g) Colony and fragments (insert) of *Paramuricea clavata*. h) Entire colony of *Eunicella verrucosa* just picked by the net (inserts: *E. verrucosa* fragments). i) Colony of *E. cavolini*. j) Dead and living colonies of red coral. k) *Alcyonium palmatum* colonies. l) *Calliactis parasitica* over a hermit crab. m-n) The scleractinians *Caryophyllia* sp. (m) and *Monomyces pygmaea* (n). o-r) Calcareous bryozoans. Dead (o) and living (p) colonies of *Turbicellepora* sp., *Frondipora verrucosa* (q), *Pentapora fascialis* (r). s) mix biogenic detritus with bryozoan fragments and shells. t) Several specimens of *Parastichopus regalis*. q) Substratum collected in one haul. Scale bar: m, n = 1 cm; d, h (inserts), i, k, l, o, p, q, r = 2 cm; e, f, g, g (insert), j, s = 5 cm; b, c, h, t, u = 10 cm.

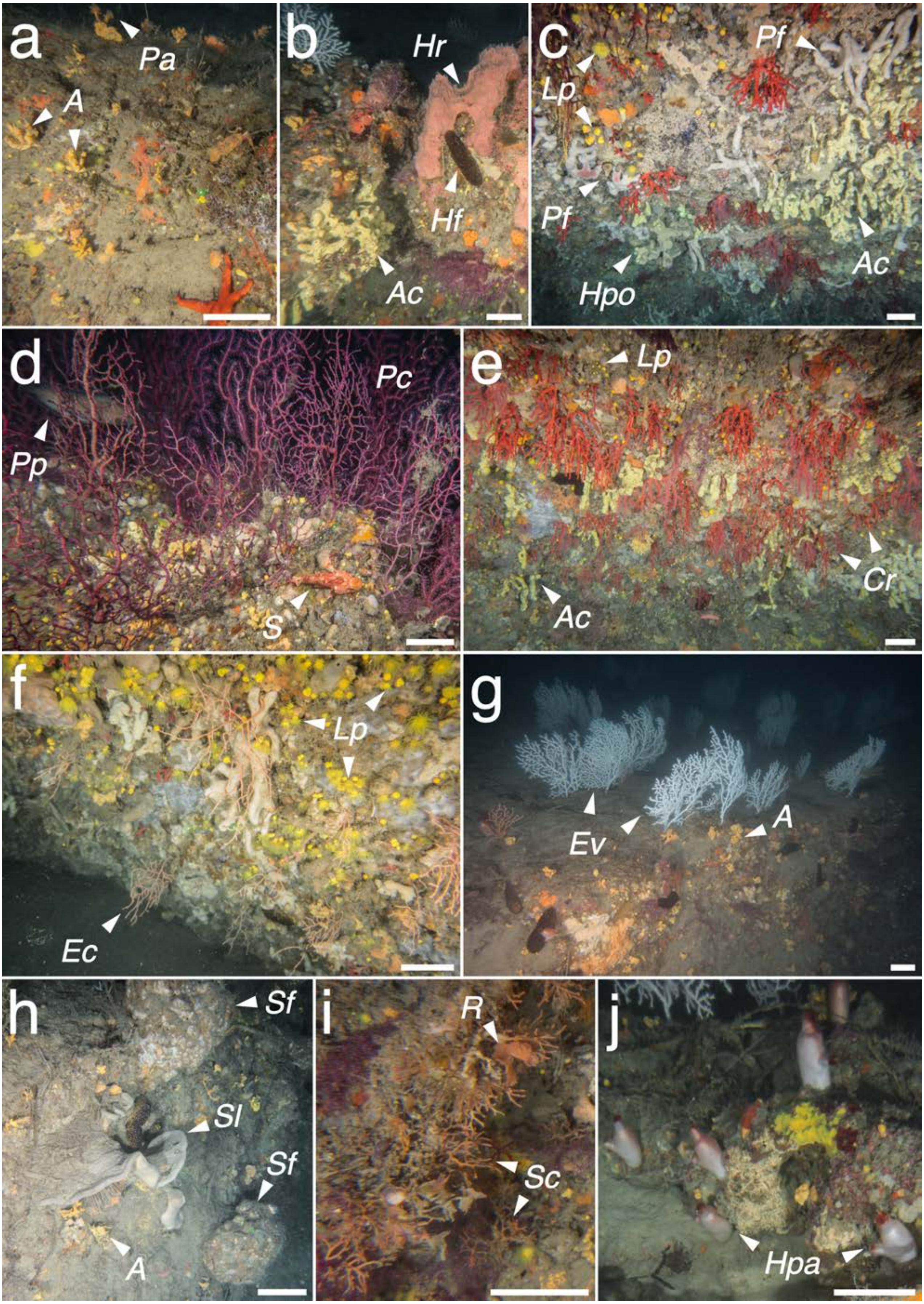
Figure 8. a) Average collection rate (normalized over 200m of net) of the 20 most abundant benthic OTUs of the discard, b) average collection rate (normalized over 200m of net) of the 13 most representative morphological-taxonomic groups of the benthic discard.

Figure 9. Fishing catch characteristics. Percentage composition of the trammel net catch expressed as n° of species (a), n° of individuals (b) and as weight (kg) (c) for the five analysed fishing sets.

Figure 10. Proposal for a Fishing Restriction Zone over the Maledetti Shoal.


8.40°E
8.45°E
44.30°N
44.25°N
44.20°N
44.15°N
Spatial Reference System: WGS84/UTM32N
Geographic Reticulate overlapped: WGS84
0
1000
2000
3000
4000 m
a
Savona
Vado Ligure
Capo Vado
Vado Canyon
Bergeggi
SAC
MPA
Spotorno
SAC
SAC
SAC
Maledetti Shoal
Noli
Noli Canyon
Capo Noli
Finale Ligure
Ligurian Sea
Ligurian Sea
Mediterranean Sea
20
40
60
80
100
120
140
160
180
200
400
600
800
b
c
-30
-60
-90
-120
-150
-180
-210
-240
tn1
tn2
tn3
tn4
tn5
R1
R2
R3
R4
R5
R6
0
100
200
300
400 m


a
Ascidiacea
2%
Echinodermata
13%
Bryozoa
6%
Crustacea
6%
Mollusca
1%
Annelida
5%
Cnidaria
13%
Porifera
54%
b
Crustacea
1%
Bryozoa
3%
Echinodermata
2%
Ascidiacea
0.5%
Annelida
1%
Porifera
21%
Cnidaria
72%
c
Fishing traps
0.4%
Anchors
1%
Urban litter
2%
Artisanal nets
26%
Ropes
6%
Lines
65%
d
Ascidiacea
0.3%
Macrophyta
15%
Echinodermata
17%
Porifera
6%
Bryozoa
22%
Brachiopoda
0.3%
Crustacea
3%
Mollusca
3%
Annelida
2%
Cnidaria
32%


a
Pa
A
b
Hr
Hf
Ac
c
Pf
Lp
Pf
Hpo
Ac
d
Pc
Pp
S
e
Lp
Cr
Ac
f
Lp
Ec
g
Ev
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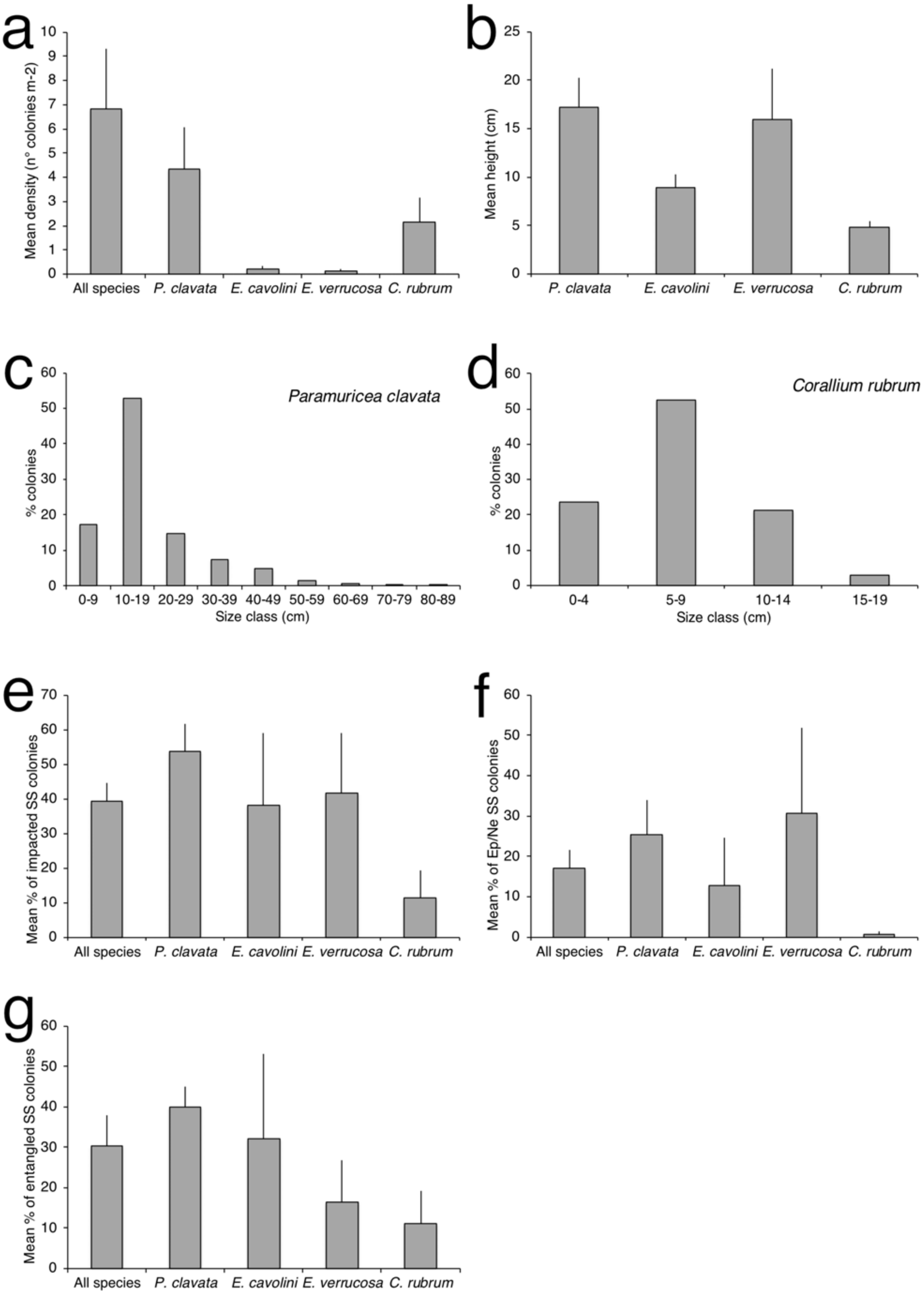
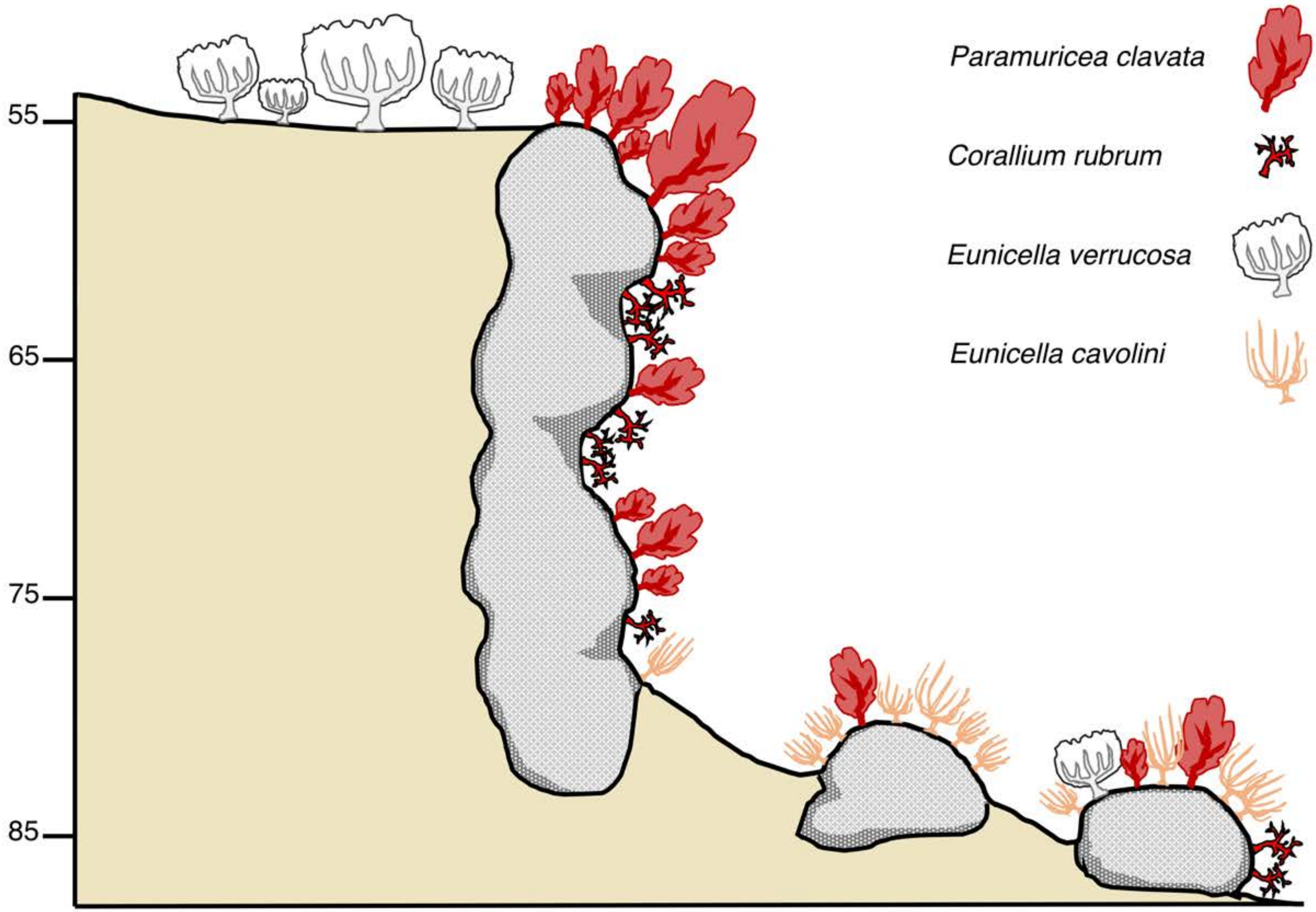
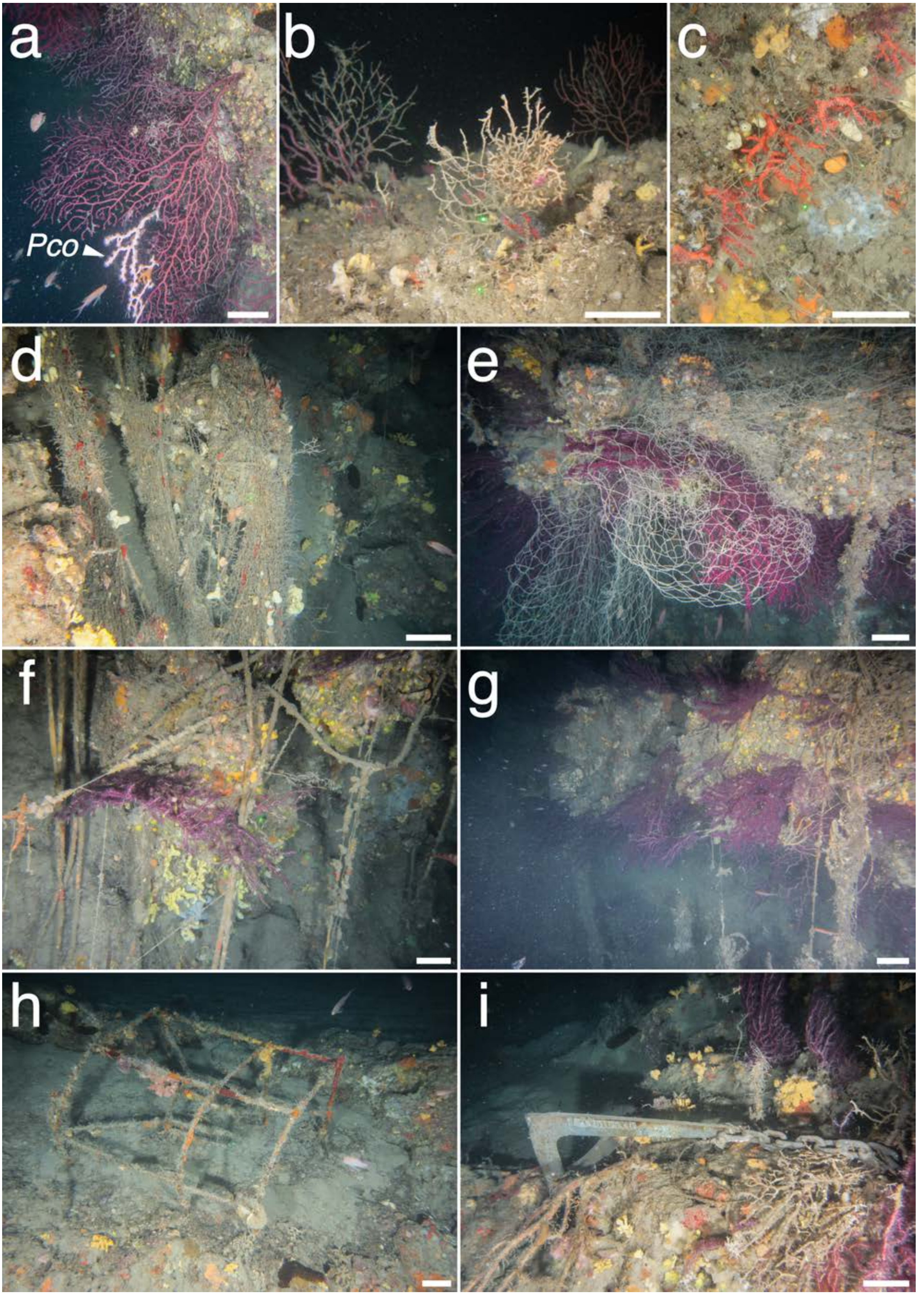
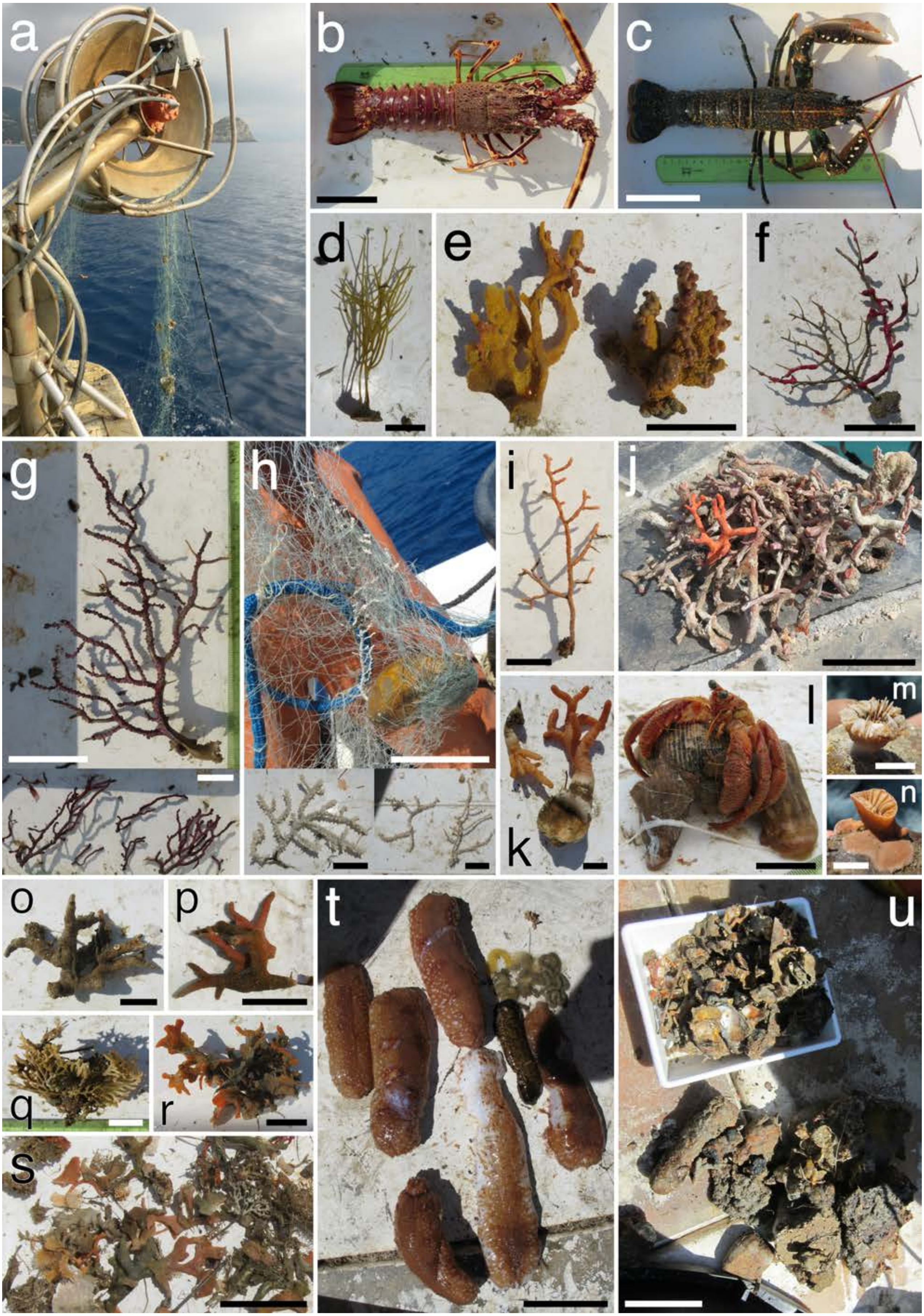
h
Sf
Sl
Sf
A
i
R
Sc
j
Hpa


a
Mean density (n° colonies m-2)
All species
P. clavata
E. cavolini
E. verrucosa
C. rubrum
b
Mean height (cm)
c
Paramuricea clavata
% colonies
Size class (cm)
0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
d
Corallium rubrum
0-4
5-9
10-14
15-19
e
Mean % of impacted SS colonies
f
Mean % of Ep/Ne SS colonies
g
Mean % of entangled SS colonies



55
65
75
85
Paramuricea clavata
Corallium rubrum
Eunicella verrucosa
Eunicella cavolini


a
b
c
Pco
d
e
f
g
h
i


a
b
c
d
e
f
g
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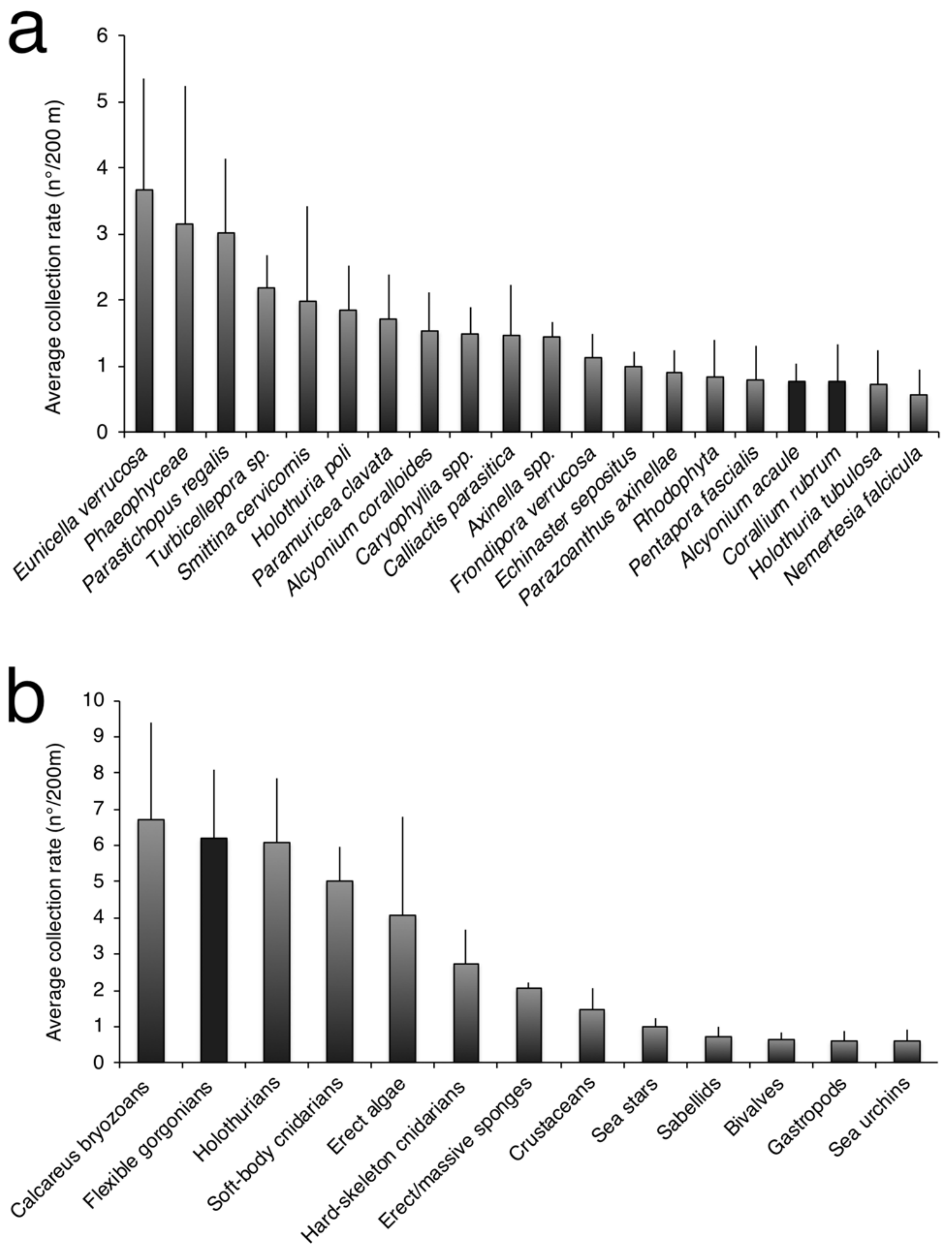
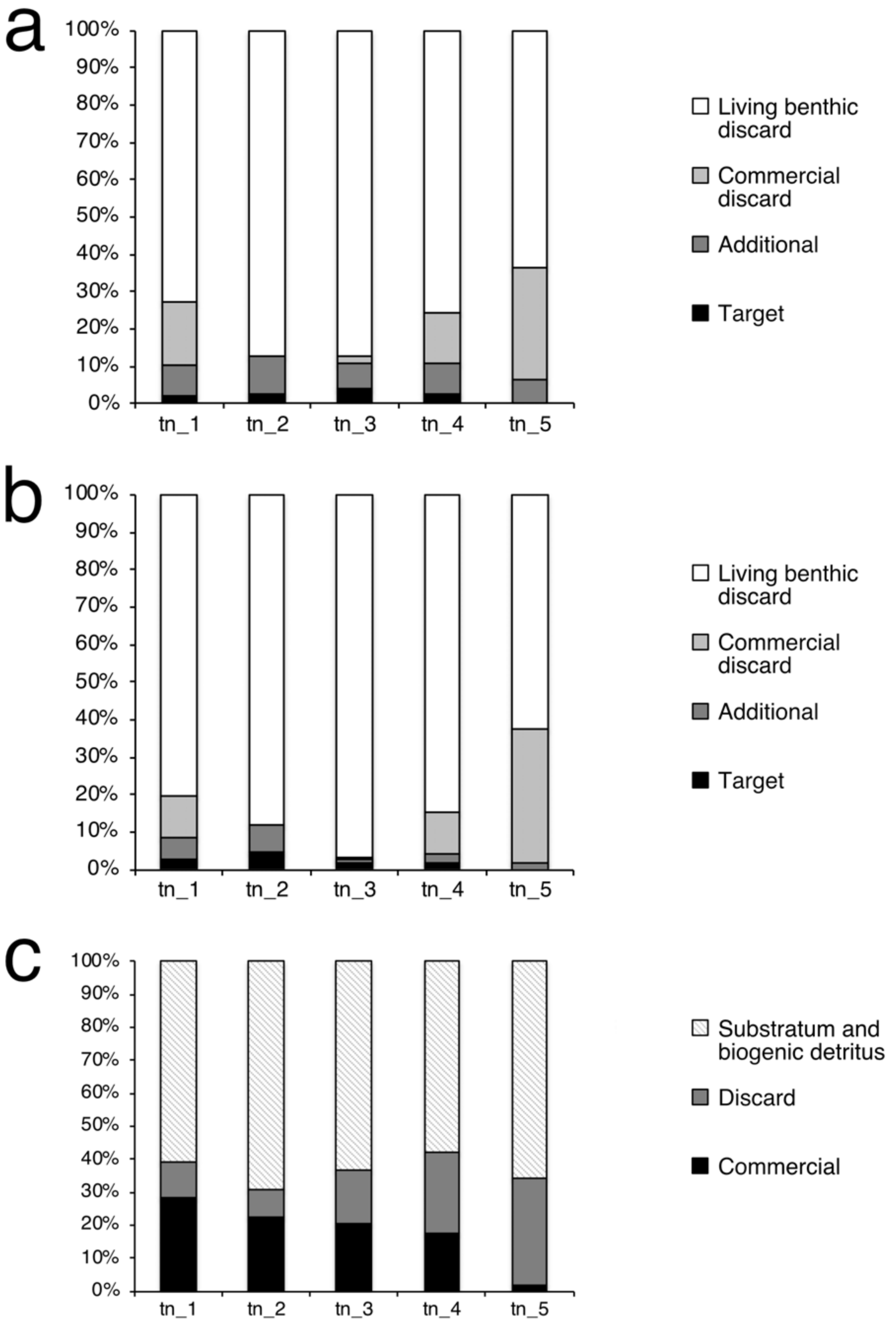
i
j
k
l
m
n
o
p
q
r
s
t
u


a
Average collection rate (n°/200 m)
0
1
2
3
4
5
6
Eunicella verrucosa
Phaeophyceae
Parastichopus regalis
Turbicellepora sp.
Smittina cervicornis
Holothuria poli
Paramuricea clavata
Alcyonium coralloides
Caryophyllia spp.
Calliactis parasitica
Axinella spp.
Frondipora verrucosa
Echinaster sepositus
Parazoanthus axinellae
Rhodophyta
Pentapora fascialis
Alcyonium acaule
Corallium rubrum
Holothuria tubulosa
Nemertesia falcicula
b
Average collection rate (n°/200m)
0
1
2
3
4
5
6
7
8
9
10
Calcareus bryozoans
Flexible gorgonians
Holothurians
Soft-body cnidarians
Erect algae
Hard-skeleton cnidarians
Erect/massive sponges
Crustaceans
Sea stars
Sabellids
Bivalves
Gastropods
Sea urchins


a
b
c
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
tn_1
tn_2
tn_3
tn_4
tn_5
Living benthic discard
Commercial discard
Additional
Target
Substratum and biogenic detritus
Discard
Commercial

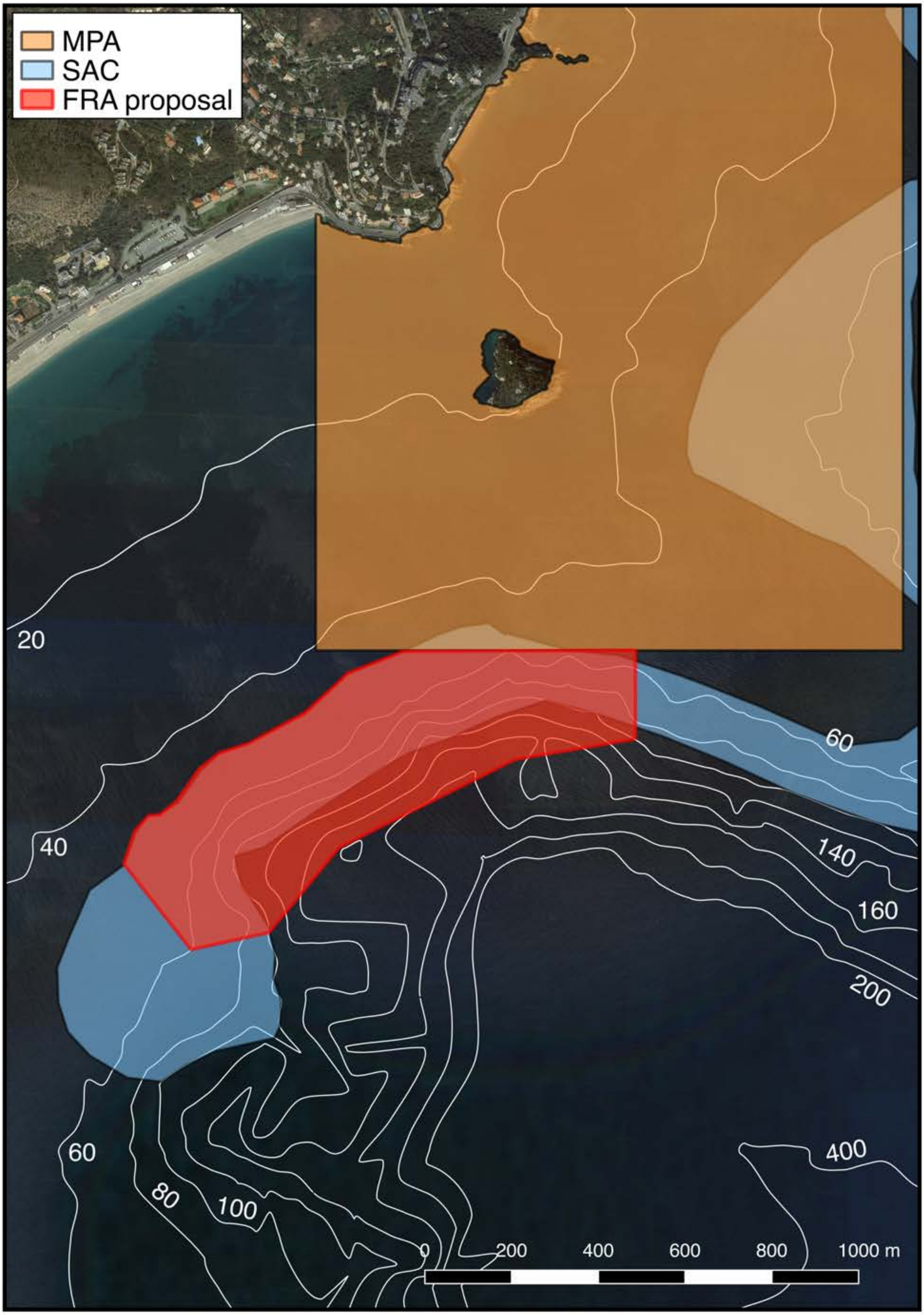

MPA
SAC
FRA proposal
20
40
60
60
80
100
140
160
200
400
0
200
400
600
800
1000 m

Table 1. ROV video transects (R) general information.

ID Code	Date	LAT start (°N)	LONG start (°E)	LAT end (°N)	LONG end (°E)	Depth range (m)	Edited video duration (min:sec)	% Hard bottom	% Vertical slope
R1	10.08.15	44.2242216	8.4368384	44.2250363	8.4374341	54-67	19:45	95	43
R2	04.09.16	44.2275283	8.4436285	44.2270358	8.4419893	53-65	23:34	100	94
R3	04.09.16	44.2279609	8.4458152	44.2276694	8.4438833	53-63	23:03	98	89
R4	10.08.15	44.2232218	8.4355699	44.2241786	8.4369322	52-70	15:05	59	12
R5	10.08.15	44.2248987	8.4375622	44.2241211	8.4374819	68-87	13:23	99	42
R6	04.09.16	44.2268384	8.4418616	44.2263079	8.4429599	52-112	13:39	51	48

Table 2. Fishing operations general information (tn = trammel net).

ID Code	Hauling Date	LAT start (°N)	LONG start (°E)	LAT end (°N)	LONG end (°E)	Depth start (m)	Depth end (m)	Soak time (days)	Fishing set total length (m)
tn1	12.07.16	44.22823	8.44598	44.22490	8.43900	55	107	3	500
tn2	03.08.16	44.22786	8.44577	44.22588	8.44183	61	97	3	500
tn3	22.07.17	44.22726	8.44696	44.22595	8.44250	79	98	4	1000
tn4	12.08.17	44.22697	8.44280	44.22518	8.44168	65	89	3	400
tn5	25.08.17	44.22786	8.44339	44.22691	8.44170	48	52	2	400

3

Table 3. Results of the ROV video transects analysis. Within each transect, the dominant structuring species is *Paramuricea clavata*, with the exception of the transect R5, for which it is *Corallium rubrum* (*). Average values are reported with standard errors (± SE). SS = structuring species; Ep/Ne = epibiosis and necrosis; na= not applicable. MAES index ranges: 15-18, Good; 10-14, Moderate; ≤ 9, Bad (Cánovas-Molina et al., 2016).

ID Code	N° of OTU	N° of individuals	Basal cover (%)	N° of SS	TOT density SS (org. m^{-2})	Mean height dominant SS (cm ± SE)	% Impacted SS anthozoans	% Ep/Ne SS anthozoans	% Entangled SS anthozoans	Litter density (items m^{-2})	MAES index value
R1	40	8264	78	6	7.26	21.7 (± 0.9)	53.8	11.1	51.7	0.54	13
R2	53	9771	91	8	13.28	11.1 (± 0.2)	27.8	13.2	23.8	0.81	12
R3	73	9723	92	5	15.48	19.7 (± 0.4)	33.0	16.5	28.1	0.88	13
R4	50	1759	72	6	1.88	22.5 (± 2.2)	40.8	9.7	39.8	0.12	12
R5	46	2739	74	6	2.15	*4.5 (± 0.5)	35.6	28.8	17.1	0.20	12
R6	38	1365	70	5	1.59	10.2 (± 1.2)	44.7	23.7	21.1	0.12	11
Avg.	50 (± 5.2)	5604 (± 1657)	79.5 (± 3.9)	6.0 (± 0.4)	6.94 (± 2.52)	na	39.3 (± 3.8)	17.2 (± 3.1)	30.3 (± 5.3)	0.45 (± 0.1)	12 (± 0.3)

Table 4. Summary table of the catches expressed as n° of individuals (in brackets n° of species) and other parameters of the fishing sets. Mean values are reported normalized for 200 m of trammel net (tn) with the exception of *. Mean values are reported with standard errors (± SE).

ID code	Target	Additional	Commercial discard	Living benthic discard	Amount commercial (kg)	Amount discard (kg)	Revenue per fishing day (Euro)	Entang. events/ set	Gear breaking events/set	Biogenic detritus (kg)	Substratum collected (kg)	Marine litter (n° items)
tn1	3 (1)	7 (4)	13 (8)	95 (35)	7.2	2.9	392	3	1	0.4	15	2
tn2	4 (1)	6 (4)	0 (0)	75 (34)	3.7	1.5	265	5	1	0.4	11	4
tn3	4 (2)	3 (3)	1 (1)	245 (41)	2.9	2.3	193	2	0	0.9	8	12
tn4	2 (1)	3 (3)	14 (5)	106 (28)	2.8	3.8	139	1	0	0.1	9	7
tn5	0 (0)	2 (2)	37 (9)	65 (19)	0.1	2.5	3	5	1	0.1	5	2
Mean norm. value	0.9 (± 0.3)	1.7 (± 0.4)	6.2 (± 3.4)	40.5 (± 4.5)	1.3 (± 0.5)	1.1 (± 0.3)	198 (± 65) *	na	na	0.1 (± 0.03)	3.8 (± 0.8)	1.9 (± 0.5)

SM1. Hard-bottom invertebrate OTUs list resulting from the ROV video transects analysis. Aside numbers refer to the total number of individuals observed in the video footages. ° indicates species included in international conventions of protection (Barcelona, Berna, Bonn, Habitat Directive, Red List).

Porifera		*Spongia (Spongia) lamella* (Schulze, 1879) °	7
Acanthella acuta Schmidt, 1862	1	**Cnidaria**	
Agelas oroides (Schmidt, 1864)	272	*Alcyonium acaule* Marion, 1878	1
Aplysina cavernicola (Vacelet, 1959) °	1039	*Alcyonium coralloides* (Pallas, 1766)	153
Axinella spp.	3612	*Caryophyllia* sp.	5
Calyx nicaensis (Risso, 1826)	4	*Corallium rubrum* (Linnaeus, 1758) °	1252
Chondrosia reniformis Nardo, 1847	43	*Eunicella cavolini* (Koch, 1887)	107
Clathrina sp.	4	*Eunicella verrucosa* (Pallas, 1766)	47
Corticium sp.	1	*Leptogorgia sarmentosa* (Esper, 1789)	1
Dysidea sp.	1	*Leptopsammia pruvoti* Lacaze-Duthiers, 1897	20047
Haliclona poecillastroides (Vacelet, 1969)	136	*Paramuricea clavata* (Risso, 1826)	2470
Haliclona sp. 1	42	*Parazoanthus axinellae* (Schmidt, 1862)	252
Haliclona sp. 2	3	*Savalia savaglia* (Bertoloni, 1819) °	1
Haliclona sp. 3	1	Scleractinia sp. 1	27
Haliclona sp. 4	4	Scleractinia sp. 2	11
Hexadella racovitzai Topsent, 1896	125	**Anellida**	
Ircinia variabilis (Schmidt, 1862)	5	*Apomatus/Protula* complex	2
Keratosa sp. 1	25	*Bonellia viridis* Rolando, 1822	8
Keratosa sp. 2	4	*Filograna/Salmacina* complex	142
Keratosa sp. 3	25	*Sabella spallanzanii* (Gmelin, 1791)	5
Keratosa sp. 4	1	Serpulidae	58
Keratosa sp. 5	14	**Mollusca**	
Keratosa sp. 6	1	*Peltodoris atromaculata* Bergh, 1880	1
Keratosa sp. 7	1	**Crustacea**	
Keratosa sp. 8	2	*Galathea* sp.	1
Keratosa sp. 9	2	*Lysmata seticaudata* (Risso, 1816)	5
Oscarella sp.	170	*Munida rugosa* (Fabricius, 1775)	2
Petrosia ficiformis (Poiret, 1789)	646	Paguroidea	1
Pleraplysilla spinifera (Schulze, 1879)	1	*Palinurus elephas* (Fabricius, 1787) °	4
Porifera sp. 1	2	*Plesionika narval* (Fabricius, 1787)	239
Porifera sp. 2	8	**Bryozoa**	
Porifera sp. 3	44	*Adeonella calveti* (Canu & Bassler, 1930)	17
Porifera sp. 4	154	*Frondipora verrucosa* (Lamouroux, 1821)	13
Porifera sp. 5	10	*Pentapora fascialis* (Pallas, 1766)	5
Porifera sp. 6	11	*Reteporella* spp.	127
Porifera sp. 7	2	*Smittina cervicornis* (Pallas, 1766)	622
Porifera sp. 8	2	*Turbicellepora* sp.	131
Porifera sp. 9	1	**Echinodermata**	
Porifera sp.10	7	Asteroidea	6
Porifera sp. 11	4	*Astrospartus mediterraneus* (Risso, 1826)	1
Porifera sp. 12	136	*Centrostephanus longispinus* (Philippi, 1845) °	10
Porifera sp. 13	1	*Chaetaster longipes* (Bruzelius, 1805)	4
Porifera sp. 14	3	Cidaridae	24
Porifera sp. 15	18	*Echinaster (Echinaster) sepositus* (Retzius, 1783)	30
Porifera sp. 16	11	*Echinus melo* Lamarck, 1816	2
Porifera sp. 17	3	*Hacelia attenuata* Gray, 1840	17
Porifera sp. 18	1	*Holothuria (Panning.) forskali* Delle Chiaje, 1823	68
Porifera sp. 19	2	*Holothuria (Roweothuria) poli* Delle Chiaje, 1824	50
Porifera sp. 20	12	*Holothuria* sp.	421
Porifera sp. 21	327	*Holothuria (Holothuria) tubulosa* Gmelin, 1791	62
Porifera sp. 22	5	Ophiuroidea	1
Porifera sp. 23	1	**Ascidiacea**	
Porifera sp. 24	3	*Ciona* sp.	2
Sarcotragus foetidus Schmidt, 1862 °	49	*Halocynthia papillosa* (Linnaeus, 1767)	168

SM2. Results of the one-way ANOVA tests carried out on the ROV and fishing discard datasets, respectively.

ROV transects dataset	SS	df	MS	F	p(same)
Between groups	5.21169	5	1.04234	1.95	ns
Within groups	317.487	594	0.53449		
Total	322.699	599			

Fishing discard dataset	SS	df	MS	F	p(same)
Between groups	1.12819	4	0.282046	0.83	ns
Within groups	168.447	495	0.340298		
Total	169.576	499			

SM4. Catches list, in taxonomic order, resulting from the fishing monitoring. Aside numbers refer to the total number of individuals collected. * indicates species of the benthic discard only collected as dead, or ** both living and dead. Bold values indicate those species found also in the ROV benthic characterization. ° indicates species included in international conventions of protection (Barcelona, Berna, Bonn, Habitat Directive, Red List).

Target catches	
Homarus gammarus (Linnaeus, 1758) °	4
***Palinurus elephas* (Fabricius, 1787) °**	**9**
Additional catches	
Epinephelus marginatus (Lowe, 1834) °	1
Lophius budegassa Spinola, 1807	1
Pagellus acarne (Risso, 1827)	2
Phycis phycis (Linnaeus, 1766)	2
Scomber scombrus Linnaeus, 1758	1
Scorpaena elongata Cadenat, 1943	1
Scorpaena porcus Linnaeus, 1758	1
Scorpaena scrofa Linnaeus, 1758	2
Scorpaena sp.	4
Zeus faber Linnaeus, 1758	6
Commercial discard catches	
Boops boops (Linnaeus, 1758)	1
Citharus linguatula (Linnaeus, 1758)	1
Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	1
Engraulis encrasicolus (Linnaeus, 1758)	26
Helicolenus dactylopterus (Delaroche, 1809)	5
Merluccius merluccius (Linnaeus, 1758)	3
Mullus surmuletus Linnaeus, 1758	2
Pagellus acarne (Risso, 1827)	7
Phycis phycis (Linnaeus, 1766)	4
Scomber colias Gmelin, 1789	1
Scorpaena notata Rafinesque, 1810	1
Scyliorhinus canicula (Linnaeus, 1758)	2
Serranus cabrilla (Linnaeus, 1758)	7
Synapturichthys kleinii (Risso, 1827)	1
Todarodes sagittatus (Lamarck, 1798)	1
Trachinus draco Linnaeus, 1758	1
Zeus faber Linnaeus, 1758	1
Non-commercial discard catches	
Phaeophyceae Kjellman, 1891	**67**
Rhodophyta Wettstein, 1901	**23****
Chlorophyta Pascher, 1914	**2**
***Aplysina cavernicola* (Vacelet, 1959) °**	**2**
Axinella polypoides Schmidt, 1862°	1
***Axinella* spp.**	**19**
Bubaris sp.	3
***Dysidea* sp.**	**2**
***Haliclona* sp.**	**3**
Hymedesmia sp.	2
***Pleraplysilla spinifera* (Schulze, 1879)**	**1**
Scalarispongia scalaris (Schmidt, 1862)	6**
Suberites sp.	1
Sycon sp.	1
Actiniaria	1
***Alcyonium acaule* Marion, 1878**	**11**
***Alcyonium coralloides* (Pallas, 1766)**	**19**
Alcyonium palmatum Pallas, 1766	2
Calliactis parasitica (Couch, 1842)	17
***Caryophyllia* sp.**	**89****
Cladocora caespitosa (Linnaeus, 1767) °	3**
***Corallium rubrum* (Linnaeus, 1758) °**	**116****
Dendrophyllia cornigera (Lamarck, 1816) °	5*
Epizoanthus sp.	2
Eudendrium sp.	7**
***Eunicella cavolini* (Koch, 1887)**	**1**
***Eunicella verrucosa* (Pallas, 1766)**	**67****
***Leptopsammia pruvoti* Lacaze-Duthiers, 1897**	**3**
Hoplangia durotrix Gosse, 1860	4*
Monomyces pygmaea (Risso, 1826)	4**
Nemertesia falcicula Ramil & Vervoort, 1992	8
Nemertesia sp.	5
Paracyathus pulchellus (Philippi, 1842)	1
***Paramuricea clavata* (Risso, 1826)**	**20**
***Parazoanthus axinellae* (Schmidt, 1862)**	**12**
Phyllangia americana mouchezii M-E and H, 1849	1*
***Apomatus/Protula* complex**	**2**
***Filograna/Salmacina* complex**	**6****
Pontogenia chrysocoma (Baird, 1865)	1
Sabellidae	2
Aporrhais pespelecani Linnaeus, 1758	4*
Bolinus brandaris (Linnaeus, 1758)	9**
Galeodea echinophora (Linnaeus, 1758)	1
Neopycnodonte cochlear (Poli, 1795)	17**
Pecten jacobaeus Linnaeus, 1758	3*
Pteria hirundo (Linnaeus, 1758)	3
Trivia multilirata (G. B. Sowerby II, 1870)	1
Tethys fimbria Linnaeus, 1758	1*
Calappa granulata (Linnaeus, 1758)	6**
Dardanus arrosor (Herbst, 1796)	6
Dromia personata (Linnaeus, 1758)	3
Homola barbata (Fabricius, 1793)	1
Maja squinado (Herbst, 1788)°	3
Medorippe lanata (Linnaeus, 1767)	3
Neomaja goltziana (d'Oliveira, 1889)	1
Paguroidea	2
Parapenaeus longirostris (Lucas, 1847)	1*
Spinolambrus macrochelos (Herbst, 1790)	1
Scyllarus arctus (Linnaeus, 1758) °	1
Megerlia truncata (Linnaeus, 1767)	2
***Adeonella calveti* (Canu & Bassler, 1930)**	**4**
Cellaria salicornioides Lamouroux, 1816	1
***Frondipora verrucosa* (Lamouroux, 1821)**	**31****
Myriapora truncata (Pallas, 1766)	2**
***Pentapora fascialis* (Pallas, 1766)**	**24***
***Reteporella* spp.**	**9****
Schizomavella sp.	7**
***Smittina cervicornis* (Pallas, 1766)**	**49****
***Turbicellepora* sp.**	**165****
Antedon mediterranea (Lamarck, 1816)	3
Cidaridae	**8**
***Echinaster (Echinaster) sepositus* (Retzius, 1783)**	**13**
***Holothuria (Panning.) forskali* Delle Chiaje, 1823**	**5**
***Holothuria (Roweothuria) poli* Delle Chiaje, 1824**	**23**
Holothuria (Holothuria) tubulosa Gmelin, 1791	10
Parastichopus regalis (Cuvier, 1817)	38**
Aplidium sp.	1
***Ciona* sp.**	**1**